This book is dedicated to my wife
BETTY

Spun Yarn Technology

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Preface

This book brings together important, but scattered, sources of information relating to spun yarn manufacture so that they form a coherent whole; it is intended to provide a comprehensive review of principles for newcomers to the industry, and a comprehensive reference source for the practising Textile Technologist. References to original sources of information are given at the end of each chapter.

For readers requiring more information, a very detailed review of the literature is given in the author's PhD thesis, part of which formed the basis for this present work. The thesis, entitled 'Spun Yarn Technology', 1979, may be referred to at Bradford University.

No attempt has been made to describe fibre production, although some reference to it is inevitable; readers should refer to appropriate text books where necessary.

Scientific research has revealed the principles underlying the previously existing rule-of-thumb methods, but the work has been carried out in isolated sections of the industry, such as cotton in Lancashire, wool in Yorkshire, jute in Scotland, etc., as well as in other countries, where different units of measurement were in use.

In recent years the traditional sectional boundaries of the spinning industry have been blurred by the impact of man-made fibres; Research Associations, originally formed to serve separate sections of the industry, have maintained closer liaison or even merged.

The spinning industry has reached the stage where the common features are more easily recognized, and yet sectional differences still exist. The book has been written using metric units and the Tex system for yarn counts, with little reference to other units.

Throughout the book many clear diagrams have been provided to aid the explanations given; however, it must be emphasized that the diagrams are not drawn to scale.

Although continuous filament yarns have been mentioned in passing, the book deliberately has been limited to the subject of spun yarn technology and closely related items.

The author hopes that this book will prove helpful to current students, to many of his past students who are awaiting its publication, and to others.

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Leicester

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INTRODUCTION

Linguistically the word yarn has connections with the Dutch 'garen' and the German 'garn' which both have their origins in the Old Norse (Old Icelandic) garn, meaning gut; this is related outside Teutonic to the Lithuanian 'žárna' meaning intestine. Presumably long thin strips of this material were used to sew together pieces of skin to form garments, footwear, and shelter.

Yarn.

A yarn may be defined as a product of substantial length and relatively small cross-section of fibres and/or filament(s) with or without twist, used for interlacing in processes such as knitting, weaving, or sewing. This definition includes single, folded, and cabled yarns whether they are staple, continuous filament, monofilament, or zero twist, and whether they are made from such materials as paper, metal, film, or glass, for example.

Yarns are the product of a process called spinning; there are two distinctly different meanings of the word: firstly extrusion spinning, and secondly staple fibre spinning.

Continuous Filament Production

Extrusion

In the spinning of both silk and man-made continuous filaments, a fibre-forming substance is forced through the holes of a spinneret beyond which it solidifies in the form of filaments. An alternative arrangement is to force the polymer through a narrow slit to form a film which can then be divided into narrow strips. The production of textiles from film has been confined largely to the production of twine, cordage, carpet-backing, and sacks.

Because man-made fibres are widely used in the production of spun yarns, and continuous filament yarns may be used in conjunction with them, a brief outline of their production and principal properties is given here.

Filament drawing

After extrusion, continuous filaments may be subjected to a drawing process which stretches them. The term 'stretch spinning' applies specifically to a process involving substantial stretch for the production of high-tenacity filaments. Drawing improves the orientation of the molecules in the direction of the filament axis, improving filament strength, but reducing its extension at break. The method used may be either cold or hot drawing. The applications of the word 'drawing' should not be confused with the drawing operations which involve the drafting and doubling of staple fibres prior to spinning.

The product of filament extrusion may be in the form of either yarn or tow.

(1) Continuous Filament Yarn

In this case the spinneret must have the exact number of holes to produce a yarn with the mass per unit length and number of filaments required. Each spinneret must be followed by all the necessary apparatus to process the individual yarn produced, including some method of winding on to a package, and, when required, twist insertion. The small spinneret limits the output per head, and furthermore the yarn take-up system imposes speed limitations and consumes a considerable amount of power. Continuous filament yarns are composed of one or more filaments which run the whole length of the yarn, a filament being defined as a fibre of indefinite length. Monofilament yarns contain only one filament, whereas multifilament yarns contain a number of filaments alongside each other; continuous filament yarns may be of the following types:

(i) *Smooth filament yarns*

In these, the filaments are smooth and straight, lying close to each other, forming a compact thread. They are sometimes referred to as 'flat' filament yarns (which is misleading), or 'producer' filament yarns — a term best avoided in these days of producer-textured yarns.

(ii) *Textured filament yarns*

These yarns may be divided into two main groups:
(a) Bulked filament yarns which have been treated physically or chemically to have a notably greater apparent volume or bulk, sufficiently stable to withstand yarn processing tensions and the normal forces exerted on garments during wear. There are various methods of obtaining the bulk effect.
(b) Stretch filament yarns, made from thermoplastic continuous filaments, which are capable of a pronounced degree of stretch and rapid recovery. This property is conferred on yarn which has been subjected to a combination of deforming, heat setting, and developing treatments. Such yarns may have more bulk in the unstretched form than in the stretched form. Stretch yarns may be subdivided into two major groups: crimped (or non-torque) yarns, and twist (or torque) yarns.

(iii) *Speciality filament yarns*

A variety of speciality yarn may be made, including.
(a) Aerated yarn. The filaments of such a yarn enclose bubbles of a gas.
(b) Bicomponent yarn in which each filament is composed of more than one type of polymer; after wet processing, bulk or stretch properties may develop.
(c) Elastomeric yarns, composed largely of segmented polyurethane filaments which exhibit rapid recovery from extensions up to about 600%
(d) Metallic yarns, which provide a very shiny appearance often exploited for decorative effect. They may be extruded metal strip or continuous filament yarn on which metal is deposited; a clear or coloured protective outer covering is used.

(2) Continuous Filament Tow

This is a large number of filaments collected into a loose strand substantially without twist. It is converted into staple fibre by either cutting or breaking before being passed through yarn manufacturing processes to become a spun staple fibre yarn. For its production each spinneret may have thousands of holes, permitting high rates of production. Because the tow is fairly robust, a relatively simple form of delivery is sufficient either to deliver the tow direct into a polythene lined carton, or alternatively to cut it into staple fibre before packing it under pressure. These forms of delivery consume less power and place less restriction on the speed of delivery, with the result that a given mass of tow or staple fibre is usually much cheaper than an equal mass of the same material in continuous filament yarn form. Staple fibre has a limited maximum fibre length, such as with cotton or wool; the maximum fibre length depends on the particular quality of fibre under consideration.

Spun Yarn Production

Spun yarns are produced by placing a series of individual fibres together to form a continuous assembly of overlapping fibres, usually bound together by twist. 'Staple fibre yarn manufacture' is the collective term which describes the processes involved in this branch of yarn production, with staple fibre spinning being the last process in the production of a single spun yarn. All the natural fibres (including waste silk, but excluding continuous filament silk) occur in staple fibre form, and most man-made fibres also are available in that form.

Drafting

This is frequently employed in the processing of fibre assemblies prior to staple fibre spinning. It consists of passing a continuous assembly of fibres between relatively slowly rotating back rollers, and then between a pair of front rollers running at a higher surface speed (*Figure. 1.1*)
In this way the fibres are caused to slide past each other so that the fibre assembly becomes longer and thinner; in addition, fibre parallelization may be improved. The back and front rollers can be seen in *Plate 10*. It is important to realize that the drafting process does not cause any significant elongation of the individual fibres — it merely re-arranges their relative positions as they pass through the drafting zone between the two sets of rollers. The draft imposed is usually expressed as a ratio:

$$\frac{\text{Input mass per unit length}}{\text{Output mass per unit length}}$$

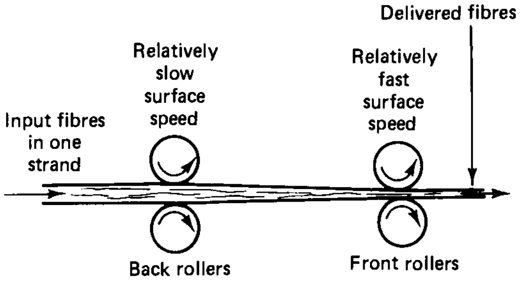

Figure 1.1 A simple drafting zone

Alternatively it may be calculated from:

$$\frac{\text{front roller surface speed}}{\text{Back roller surface speed}} \quad \text{or} \quad \frac{\text{Output length per unit mass}}{\text{Input length per unit mass}}$$

Doubling

Doubling is the feeding of two or more fibre assemblies simultaneously into a drafting zone so that they are combined together and delivered as one fibre assembly, the purpose being to promote regularity and fibre mixing. It should not be confused with the term 'doubling' which is used in Lancashire to mean the folding together of two or more single yarns to form a folded yarn. Doublings are represented in *Figure 1.2*, and can be seen at the back of the drawframe in *Plate 17*.

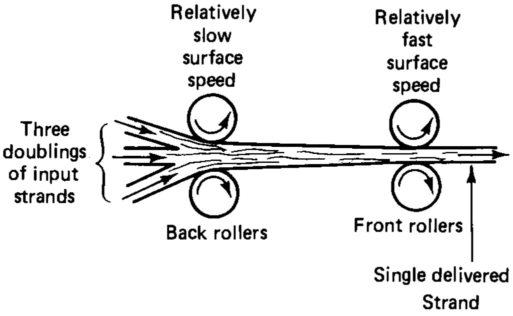

Figure 1.2 A drafting zone fed by three doublings

Spun Yarn Types

There are two main groups of spun yarn types:

(1) Drawn-and-spun yarns

These yarns are produced from fibres which have been subjected to a series of preparatory drafting and doubling operations immediately prior to the spinning process; collectively these operations are called a drawing set.

This group may be sub-divided into two sections:

(i) Carded yarns and combed yarns

These are made from relatively long fibres from which some short fibres may have been removed. Consequently these yarns are relatively smooth, compact, and strong. Carded yarns are produced from fibres which have been carded, whereas combed yarns are produced from fibres which have been combed subsequent to previous preparatory processes (which frequently include carding). Systems in this section are: long staple, which includes worsted and flax; and short staple, which includes carded cotton and combed cotton.

(ii) Prepared yarns

In this case there is no significant removal of short fibres. Yarns of this type include jute and semi-worsted. Wools processed on the long wool 'preparing' system are not included in this group because they are later combed and made into worsted yarns.

(2) Condenser-spun yarns

These yarns are spun direct from threads which have been consolidated by a rubbing action from strips of card web. This method is generally used for relatively short fibres although carpet yarns are often an exception to this rule; a low draft is applied at the spinning process only. The result is that yarns of this type have a disorientated fibre arrangement, conferring bulk, but a lower yarn strength. Yarns of this type include woollen, condenser cotton, and silk noil yarns.

Basic Operations in the Production of Spun Yarns

All staple fibres follow a similar basic routine of conversion to spun yarn although man-made fibres do not require the cleaning which is necessary for natural fibres. The general outline of the processes is as follows:

(1) Preliminary processes

(i) Cleaning

This is necessary with natural fibres in order to remove the impurities present in the raw fibre before further processing can take place. The cleaning process may be chemical, physical, or a combination of the two, depending on the nature of the impurities.

(ii) Opening and disentangling

Opening may be necessary after the cleaning operation, or it may form part of the cleaning operation. In the case of man-made fibres although cleaning is not required, it is often necessary to open the fibres because they have been closely packed in a bale or other container.

(iii) Blending

This may be necessary to ensure uniformity of product by eliminating variations between different sources of fibres or in the case of man-made fibres between different production runs. Product properties and price are other factors which influence blending.

(2) Formation of a continuous strand

This is frequently performed by a carding process, although it may sometimes be performed by some other operation such as long wool preparing or tow to sliver processing in the case of man-made fibres. It enables subsequent processes to take place more conveniently, and is the initial formation of continuity in order to produce a yarn. Continuity is more easily achieved with a relatively thick fibre assembly which at this stage is twistless and is called a sliver. A sliver may be defined as a long continuous assembly of overlapping fibres held together by cohesion without the aid of twist

(3) Reduction of strand thickness

(i) By division

This method is used in the production of condenser spun yarns; the carded web of fibres is divided into narrow strips before being spun into yarn.

(ii) By drawing

This involves the use of a series of operations, collectively called a drawing set, using drafting and doubling to reduce the sliver thickness.

(4) Twist insertion

A conventional spun yarn has twist inserted into it to prevent fibre slippage by increasing the inter-fibre friction.

(5) Ancillary processes

Processes such as folding, winding, warping, and reeling may be necessary to present the yarn in the form required for further processing.

The way in which these basic operations are combined for the production of different yarn types is shown in more detail in the Appendix.

Terminology of Spun Yarns

Until the early twentieth century, natural fibres were the only fibres available in commercial quantities. They had widely differing physical and chemical properties which during the industrial revolution had led to distinctly different methods of processing using specialist machinery, frequently restricted to geographically localized areas, and resulting in yarns with distinctly different characteristics. The more recent availability of staple man-made fibre means that yarns can be produced by the different manufacturing systems from chemically identical fibres of the required dimensions. This development has blurred the traditional boundaries which separated the different systems. Nevertheless there may be differences between yarn properties when chemically identical fibres of different dimensions are processed on different systems, and so it is prudent to use distinctive yarn descriptions which indicate these potential differences.

The hyphenated suffix '-spun' denotes staple man-made fibre either 100% or blended. The respective prefix in the second column of *Table 1.1* indicates the processing system used. For example, a worsted yarn is processed from 100% combed wool, whereas a worsted-spun yarn contains fibre other than wool which has been processed on machinery of the type originally designed for the production of worsted yarn; the man-made fibre may be uncombed.

Yarn Thickness

Yarn thickness is difficult to measure because of the ill-defined yarn surface and inherent compressibility.

It cannot be too greatly emphasised that there is no such thing as spun yarn thickness in the absolute sense; under a transverse load yarn cross-sectional shape deforms to an extent largely determined by the compressive force applied. Many methods have been devised to measure yarn thickness directly, and some methods take into account the differences in yarn thickness which occur when different loads are applied. Such methods, however, although useful

Table 1.1 *Spun yarn descriptive terms*

Yarns spun from 100% natural fibre	*Yarns containing other fibre*
worsted (100% combed wool)	worsted-spun
woollen(1) (100% wool)	woollen-spun(1)
carded or combed cotton	cotton-spun
condenser cotton(1)	condenser-spun(1)
jute	jute-spun
spun silk(2)	silk-spun (or schappe-spun)
linen	flax-spun

(1) 'condenser-spun' may also be used as a collective adjective for any yarn spun direct from consolidated strips of card web. Hence woollen, condenser cotton, and woollen-spun yarns may all be described as condenser-spun. (2) 'spun silk' means yarn produced from 100% waste silk as distinct from nett silk continuous filament yarns. The terms 'spun silk' and 'silk-spun' should not be confused.

for research purposes, are too time-consuming for every day use in industry.

Yarn Count

Instead the accurate determination of the mass of a known length of yarn is universally used in commerce and industry. The data thus obtained may then be expressed in either of two ways:

(1) Mass per unit of length. This is known as the direct method where a higher count number denotes a thicker yarn.
(2) Length per unit of mass. In this, the indirect method, a higher count number denotes a thinner yarn.

It is important to realize that yarn diameter is related to $\sqrt{}$(yarn count), either directly in the case of the direct count systems, or inversely for the indirect count systems. This relationship holds for a range of different yarn counts which have been spun by the same method from the same fibre stock, but as yarn diameter is also influenced by factors such as fibre density, fibre configuration, and yarn twist, it does not follow that all yarns of the same count necessarily have the same diameter. For example, the following thickness and compression indices refer to a series of yarns spun on the worsted system; in each case the finished yarn was 37 tex:

The Thickness Index represents the yarn thickness when compressed between parallel steel plates under a low load of only 1g/cm. A yarn with a bigger Compression Index indicates that the yarn undergoes a greater reduction in thickness for a given increase of measuring load than would a yarn with a lower Compression Index.

Thickness index (μm)	*Compression index*	*Yarn composition*
224	0.220	low-crimp nylon
266	0.193	merino wool
370	0.267	high-crimp nylon
530	0.265	bulked Orlon

At least 29 different yarn counting systems, both direct and indirect have been developed either in different localities of the UK or in other countries. Industrial expansion and improved communications have rendered these older systems obsolescent. It is clearly illogical for knitters or carpet manufacturers, for example, both of whom use a multiplicity of yarn types, to purchase yarns which may be described by different yarn counting systems; there are at least fourteen systems for woollen yarns alone!

The idea of replacing all these systems with one Universal system was discussed for some considerable time; eventually it led to the Tex System being recommended.

The Tex System

At the Southport conference of the Textile Section of the International Organization for Standardization (ISO/TC 38) in 1956, a unanimous vote of delegations from twenty countries supported the resolution that tex should be recommended as the universal system for describing yarn mass per unit length. In 1957 a resolution was passed recommending that all International and National Textile Federations and Associations should do everything possible to bring the Tex System into general use. Subsequent moves towards the adoption of the Tex System have met with resistance in many sections of industry, both in the UK and elsewhere. It is likely that this situation will continue in the UK until complete metrication takes place, when conversions to Imperial Units may be inconvenient.

The Tex System provides a simple means of numbering all filament and fibre assemblies according to a common basis of measurement. For very fine yarns or fibres, and for thick fibre assemblies,

Table 1.2 *Tex system preferred units*

Name	*Symbol for the unit*	*Symbol for the quantity*	*Definition*
millitex	*mtex*	*Tt*	1 mtex = 1 mg/1000 m
decitex	*dtex*	*Tt*	1 dtex = 1 dg/1000 m
tex	*tex*	*Tt*	1 tex = 1 g/1000 m
kilotex	*ktex*	*Tt*	1 ktex = 1 kg/1000 m

*The symbol *Tt* is equivalent to the expression 'mass per unit length expressed in the Tex System; it is intended for use in formulae etcetera where a numerical value is not given.

multiple and sub-multiples are recommended as shown in *Table 1.2.*

Details of various yarn counting systems other than Tex are summarized in *Table 1.3* along with the constants required for converting to and from the Tex System. The Tex System is used throughout this book, using the recommended fold-to-single notation for folded and cabled yarns.

The world 'count' or the symbol *Tt* is used to indicate the quantity 'mass per unit length expressed in the Tex System' for fibres, yarns, and other fibre assemblies; the word tex is only used to indicate the name of the unit.

Yarn twist direction is indicated by the letters S or Z according to the angle of fibre inclination *(Figure 1.3)*. The amount of twist may be determined by standard tests. In this book the quantity of twist is expressed in turns per metre.

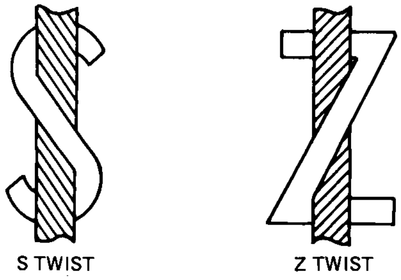

Figure 1.3 Yarn twist: (a) S twist (b) Z twist

General Machine Features

Many machines in yarn manufacturing processes must be set to deliver a pre-determined count of sliver or yarn. Usually this is achieved by using a suitable number of teeth on the gear wheel reserved for this purpose. As the other components in the drive remain unchanged, it is convenient to calculate a gaugepoint (or machine constant). A gaugepoint is a number which represents the constant value relating the change wheel to the item which that change wheel controls, such as draft, or twist. The application of the gaugepoint depends on the position of the change wheel in the machine drive. In the case of draft, for example, the relationship may be gaugepoint/draft = change wheel, or draft/gaugepoint = change wheel, either of these methods may be used on different machines. Instead of change wheel, alternative arrangements may be used such as positively infinitely variable (PIV) drives, hydraulic variators, and variable speed motor drives.

Machine Sequences

During the production of a spun yarn, fibres usually have to pass through a number of sequential operations. This introduces problems of maintaining a balance of production from each stage in processing. Modern factories are designed to have a high productive efficiency; this usually entails a reduction in the range of end-products which may be produced. Flexibility may be eased somewhat at the increased cost of having a suitable 'reservoir' of material in work between each process.

General Comparison of Continuous Filament and Spun Yarns

Continuous filament yarns have the general advantages of fineness, strength, smoothness, uniformity, and resistance to pilling; as a result it is usual to find them used in light-weight fabrics which exploit these advantages.

Spun yarns have a characteristic texture which is often considered desirable. They can contain natural or man-made fibres, and one of the great advantages of spun yarns is their ability to exploit blends of fibres to satisfy requirements such as properties, processing, price, and end-use. Extensive use of colour mixing is possible with staple fibres, and frequently spun yarns can be produced cheaper from staple man-made fibre than can the same count of continuous filament yarn. For a given staple fibre there is a limit to the fineness of yarn which can be spun — known as the fine count limit —

consequently spun yarns are usually of thicker counts than continuous filament yarns.

Exceptions to this general division include some heavy industrial fabrics where high strength is essential, and in situations where increased process efficiency can compensate for the higher cost of filament yarn; a good example of this is in the tufted carpet process where the use of a more expensive textured continuous filament pile yarn may increase the tufting process efficiency to such an extent that the end-product is cheaper than if a relatively cheap spun yarn were used instead.

Fibre Properties

Fibre properties largely determine processing and end-product characteristics, and hence are of paramount importance to a spinner. The intrinsic element of yarn quality is settled when the raw materials and the processing system have been selected. After spinning a yarn, all that the spinner can do is to assess its technical merit as a measure of the degree of success in approaching an ideal yarn — this is his measure of 'quality'.

Primary fibre characteristics include the chemical

Table 1.3

INDIRECT YARN COUNT SYSTEMS

Yarn count system	*Symbol*	*Unit of yarn count*	*Conversion numerator**
Asbestos (American)	Na_A	100 yd/lb	4961
Asbestos (English)	Ne_A	50 yd/lb	9921
Cotton bump	N_B	1 yd/oz	31 000
Cotton (English)	Ne_C	840 yd/lb	590.5
Cotton (Catalonian)	Ne_C	500 canas/1.1 lb cat	565.9
Glass (USA & UK)	N_G	100 yd/lb	4961
Linen (wet or dry spun)	Ne_L	300 yd/lb	1654
Metric	Nm	1 km/kg	1000
Numero en puntos	Np	1320m/lb de Alcoy	358.7
Spun silk	N_s	840 yd/lb	590.5
Typp (American)	Nt	1000 yd/lb	496.1
Worsted	Ne_W	560 yd/lb	885.8
Woollen systems			
Alloa	Nal	11 520 yd/24 lb	1033
American cut	Nac	300 yd/lb	1654
American run	Nar	100 yd/oz	310
Cardado Covilha	Np_W	1 m/5 g	5000
Dewsbury & Batley	Nd	1 yd/oz	31 000
Galashiels	Ng	300 yd/24 oz	2480
Hawick	Nh	300 yd/26 oz	2687
Irish	Ni_w	1 yd/0.25 oz	7751
West of England	Nwe	320 yd/lb	1550
Yorkshire	Ny	256 yd/lb	1938

DIRECT YARN COUNT SYSTEMS

			Multiplying factors	
			Tex to yarn number	*yarn no. to Tex*
Denier	Td	1 g/9000 m	9	0.1111
Hemp, jute & linen (dry)	Tj	1 lb/14 400 yd	0.02903	34.45
Numero en quartos de onza	To	0.24 onza/500 canas	0.0933	10.71
Woollen (Aberdeen)	Ta	1 lb/14 400 yd	0.02903	34.45
Woollen (American grain)	Tg_a	1 grain/20 yd	0.2822	3.543
Woollen (Catalonian)	Tc_w	1g/504 m	0.504	1.984

$$\frac{{}^{*}\text{Conversion numerator}}{\text{Indirect yarn count}} = \text{count (tex units)}$$

$$\frac{\text{Conversion numerator}}{\text{count (tex units)}} = \text{Indirect yarn count}$$

composition and molecular structure, fibre length, cross-sectional shape and area; these largely determine the behaviour of fibres during processing into a yarn.

Secondary characteristics may be defined as the degree of variation of the primary ones. Differences in fibre dimensions and fabric structure may completely alter the comfort of apparel made from a given substance.

Derived characteristics include all the properties which inevitably follow from the primary and secondary characteristics. These include factors such as strength, moisture properties, dye uptake, abrasion resistance, and many others.

Additional characteristics are those which may be superimposed on to the basic fibre; examples are fibre surface properties and crimp.

However, it is possible for a given fibre characteristic to be either derived or additional, depending on the particular circumstances. For example, crimp may be derived in a bicomponent fibre, or additional by using a heat-set process in the case of a suitably homogeneous polymer.

Fibre properties with a direct bearing on processing performance include: fibre fineness and its variation; fibre length and its variation; the ratio of fibre length to fibre fineness; fibre tensile properties such as strength, extensibility, elongation at break, elasticity, and shear strength; bending and torsional rigidity; fibre friction, lubrication, and static electrification; fibre/moisture relations; fibre crimp; fibre cross-sectional shape; and fibre bulk and compressibility.

Fibre inflammability and resistance to microbiological degradation may also be considered.

Other fibre properties are more concerned with end-product characteristics such as lustre, fabric crease recovery, crease retention, fabric handle, and resistance to abrasion and pilling, and these must be borne in mind by the spinner.

The amount of moisture present in an assembly of fibres is usually expressed in terms of 'regain'.

Regain may be defined as the mass of water in the material expressed as a percentage of the oven-dry mass of the same quantity of material:

$$\text{Percentage Regain} = \frac{100(\text{mass of water})}{\text{oven dry mass}}$$

For each type of fibre a certain quantity of moisture added to the oven-dry mass is permitted for commercial purposes: this is known as the official regain.

An important characteristic which is unique to animal fibres is the 'directional frictional effect' (DFE). A fibre withdrawn from other fibres in the direction of root-end first develops less frictional resistance than when it is withdrawn tip-end first. DFE is of considerable importance in fabric finishing, but clearly it must also influence fibre movement in yarn manufacture, although its effect would be difficult to quantify.

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2

OPENING AND CLEANING

Automatic Feeders

Automatic feeders are widely used in opening and cleaning loose fibres in the early stages of yarn manufacture. The main object of a hopper feeder is to provide a constant supply of fibres spread uniformly across the width of the following machine. A widely used method is based on a weighing system which attempts to deliver fibre portions of equal mass at regular time intervals; an alternative arrangement is based on volume instead of mass. The most critical feed conditions are encountered in woollen carding; other processes such as cotton opening, wool scouring, and wool drying are not quite as exacting because there are more opportunities during subsequent stages of processing to correct any irregularities.

The basic arrangement of a traditional woollen carding hopper is shown in *Figure 2.1*. Fibres A are carried on B to maintain pressure against C1, the spikes of which pluck tufts of fibres from A. The reciprocating action of D returns surplus tufts to A before the rest of the fibres retained by C1 are removed by E1 to pass F to G which is mounted on horizontal balance-beam arms with adjustable counter-balance weights. When a sufficient fibre mass has been fed to G a balance-beam switch is actuated to disengage the drive to C1, and to close K. At fixed time intervals G is then opened by a time-actuated cam to permit the fibres to fall on to H; the balance-beam switch then restores the drive to C1 and opens K. The material on H is pushed forward by J to close gaps between successive weighs. A magnet may be fitted over C1 to collect any stray particles of ferrous metal.

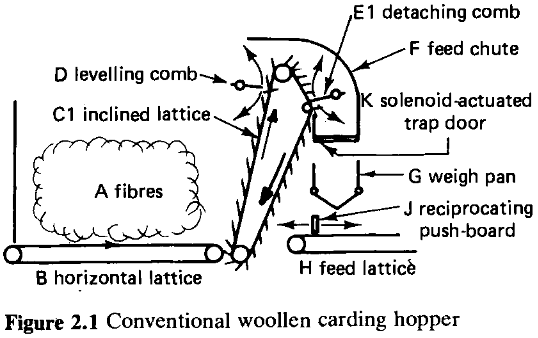

Figure 2.1 Conventional woollen carding hopper

The problem of uniform feeding depends on: a constant uniform supply of fibres to C1; the efficiency of the shutter mechanism of G; the sensitivity of the weighing mechanism which actuates the switch; and the uniformity of fibre distribution on H. The main factors which lead to variation of the weighs delivered by G include changes in the height of material at A, the inertia of G, and the irregular flow of fibres from E1; longer fibre length and increased fibre entanglement are associated with greater weigh variation. Weigh variations can be minimized by having as thin a feed in to the weigh pan as is possible; clearly this may be contrary to production requirements.

An alternative is to have a 'trickle feed' whereby a fast flow of fibres is fed into G until the balance-point is almost reached, after which a reduced flow of fibres is permitted until the necessary fibre mass has been fed into G. In this arrangement E1 is usually replaced by a rotating clearer roller.

To reduce the variations caused by changes in the height of A, a self-emptying hopper may be used. The essential differences for this arrangement are shown in *Figure 2.2*. The horizontal lattice B is replaced by L which, aided by M, carries an even feed of fibres *underneath* L, to be collected by the

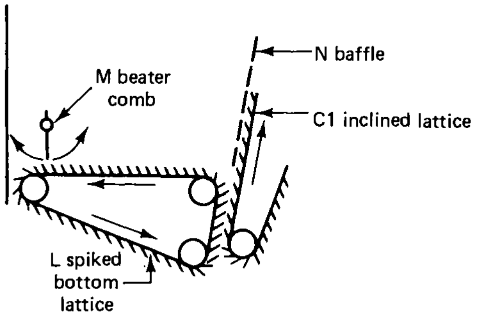

Figure 2.2 Self-emptying hopper lattices

faster moving surface of C1. Direct contact of the mass of fibres with C1 is prevented by N; this method has never been widely used.

A double-hopper may be advantageous in high production carding for thick count production for end-products such as carpets. In this arrangement the first hopper is a large capacity version of that shown in *Figure 2.1*. Movement of C1 is controlled by the time-cam and the balance-beam switch to maintain a constant level of material in the second hopper. The second hopper is a self-emptying V-shape (*Figure 2.3*), the balance-beam switch controls C2 and actuates K. A double-hopper arrangement has been shown to reduce the percentage range of mass of 28 m (approximately) lengths of woollen slubbing from about 25% to 5%; a double-hopper is shown in *Plate 5*.

Further improvements to feed uniformity can be obtained by having the hopper weigh-pan wider than the machine being fed, and set diagonally above H at an angle of about 30° so that at any instant the input across the width of the machine being fed will include material from about five different hopper weighs; this method has not been widely used.

Blending systems may be designed which use a similar weighing principle; this has the advantage of the blend proportions not being influenced by component bulk differences.

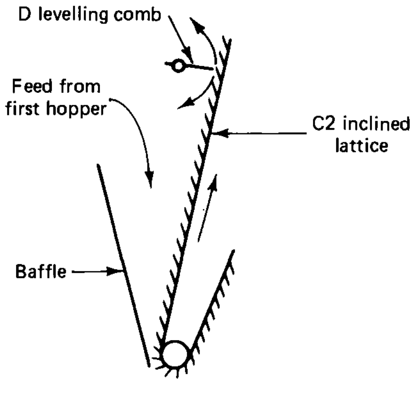

Figure 2.3 Second hopper of double-hopper arrangement

A later development to the weigh-pan type of hopper has been the application of microprocessor control. This permits high-speed filling of the weigh-pan followed by a trickle feed, if required. Any difference between the required weight and the actual weigh is taken into the microprocessor memory, which adjusts the cut-off point of subsequent weighs to maintain a constant running average.

The volumetric continuous feed hopper has been introduced as an alternative to the weighing method of controlling fibre flow into worsted and semi-worsted cards where high production rates make the satisfactory performance of a weigh-pan mechanism difficult to attain. The essential difference is that the weigh-pan arrangement of *Figure 2.1* is replaced by a vertical chute P as shown in (*Figure 2.4*). The movement of B is controlled by a sensor which detects the amount of surplus material returned by D. The action of E2 packs fibres evenly into P up to the required level which is sensed by height detectors controlling the intermittent drive to C1. Adjustment of production is by setting the appropriate distance between: 1. the front and back walls of P, and 2. between C1 and D, and also by selecting the required speeds of Q and C1.

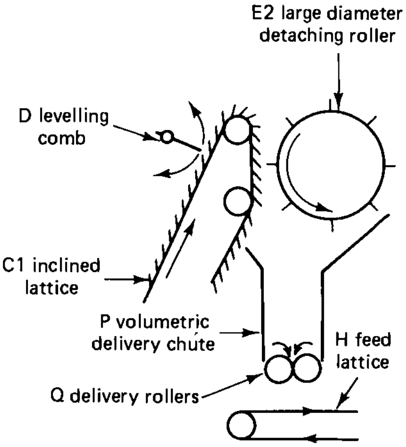

Figure 2.4 Volumetric continuous-feed hopper

The volumetric hopper is claimed to avoid the periodic gaps characteristic of the weighing hopper (hence J is not used), giving more uniform carding performance and hence permitting higher production rates. On the other hand, the hopper may need re-adjusting every time there is a change of fibre, and it is essential to have a uniform degree of fibre opening before carding throughout each batch of material processed.

For cotton processing the volumetric principle may be used in the form of a chute feed in which the supply to the main hopper bin is from a reserve compartment containing a photoelectrically controlled constant height of fibres. A constant height of fibres is also maintained between the front and back panels of the delivery chute which are vibrated to compact the feed. The uniformity of feed into chute-fed cotton cards may not be as good as that from the traditional lap feed, but with the more widespread application of autolevelling this fact is of reduced importance.

Raw wool processing

Raw wool impurities

Raw wool contains a number of impurities which must be removed to facilitate yarn production.

The 'natural' impurities produced by the sheep itself include wool grease, suint (or dried sweat), and the excretion stains caused by dung and urine in the britch area; kemps may be regarded as an impurity in fine wools, but may be a desirable feature in coarse wools.

The 'acquired' impurities picked up by the sheep from its habitat include: minerals such as sand, dust, soil, and lime; vegetable matter such as burrs ie. prickly seed-appendages, seeds, and grass; and animal impurities which include insect parasites and pests.

The 'applied' impurities which are added to the coats of domestic sheep by the farmer include dips to rid the animal of parasites, and brands to indicate identification and ownership.

Removal of impurities from wool

Wool grease is normally removed by emulsion scouring although it can be removed by organic solvents. Suint is water-soluble and is removed in the wool scouring process. Wool grease and suint together may constitute approximately 10% to 50% of the mass of raw wool.

Excretion stained fibres are usually removed and treated separately from the bulk of the wool; such fibres frequently remain stained and weakened and may be used in some woollen blends.

Kemps are thick fibres which have been shed from the follicle and they usually resist dyeing. Kempy areas of the fleece are usually removed manually from fine wools and are treated separately from the bulk of the wool; they are common in carpet wools, for example, and are a desirable feature in coarse tweeds.

Except in some coarse wools and hairs, most of the mineral impurity is attached to the fibres by wool grease and so is released when the grease is removed during scouring.

Normally vegetable impurities tenaciously cling to the fibres and are removed mechanically during carding and, on the worsted system, during combing. Chemical removal of vegetable impurities by carbonizing is commonly used in woollen processing, and occasionally is used in worsted processing.

Vegetable and mineral impurities together may account for from approximately 5% to 25% of the mass of raw wool.

Animal pests are usually killed by chemical treatment during the normal husbandry excercised by the farmer — this is essential for the health of the animals and therefore for the standard of fibre produced; any living insects still present on the wool would perish during scouring.

Branding fluids now consist of lanolin-based emulsions which are emulsified during normal scouring, and the dips used by farmers to maintain the health of animals have their residues removed during scouring.

Wool opening and shaking

Hair fibres and low quality wools such as carpet wools frequently contain a considerable amount of dust and a relatively low percentage of grease. Mechanical beating in a shaking machine which contains revolving spiked rollers will release a lot of the dust prior to scouring. In order to avoid fibre entanglement and subsequent fibre breakage fine wools, particularly those intended for worsted processing, are not usually treated in this way although very dirty, burry, and entangled short merino wools may be an exception to this rule.

Wool scouring

The most widely used scouring method is the emulsion system in which either a combination of soap and alkali, or a synthetic detergent, emulsifies the wool grease.

Scouring should result in the wool being clean, lofty, and open (i.e. not entangled); with the change in appearance which takes place, the wool is increased in value considerably. If scouring is not properly conducted, perfectly good raw material may be ruined by discolouration, entanglement, and weakening. Good scouring is essential so that the fibres may be separated, to assist in processing, and to enable uniform dyeing to take place.

The agents used in conventional emulsion scouring, and their functions are:

Water

This dissolves the suint, provides a basis for the solutions used, provides a transport medium for the wool, and provides a medium through which heat may be applied. In the later stages it rinses the dirt, alkali, and soap (or synthetic detergent) from the wool.

Alkali

This is used because it is cheaper than sopa and it improves the scouring efficiency of sopa; the alkali normally use in woolscouring is sodium carbonate.

Its functions are to act as a buffer to maintain the pH of the scouring solution at about pH 10, to prevent the hydrolysis of soap in the solution, to act as a salt to produce a concentration of soap molecules at the grease/solution interface, to satisfy the affinity of the wool fibre for alkali, and to neutralise some free fatty acids present in wool grease, thereby forming soap.

When used at normal concentrations and temperatures, sodium carbonate does not damage the wool fibres even though an aqueous extract from the scoured wool will have a pH of between 9 and 10.

Soap

Usually hard soap in the form of flakes is boiled up in water to form a stock solution which can then be added to the scouring process as required. The addition of sufficient soap helps to wet-out the wool by reducing the surface tension, emulsifies the grease, and maintains a stable emulsion.

Synthetic detergents

Biodegradable synthetic detergents may be used instead of soap and alkali; by this means it is possible to produce a neutral wool product and a neutral wool-grease by-product (which has enhanced value). This may be of particular advantage when scouring either (a) burry wool in order to avoid yellow staining of the wool from the burrs, or (b) if the wool is to be Vigoureux (melange) printed in order to avoid yellowing of the unprinted sections of the fibres during steaming.

Heat

This aids the formation of the scouring solutions and melts the wool grease ready for emusification. Wool grease melts at about 38 °C and so in a four-bowl scouring set temperatures may range from 50 °C to 60 °C at the first main scouring bowl down to about 40 °C at the rinsing bowl.

Slightly lower temperatures may be used for cross-bred wools, and in the case of lustre wools and hairs such as mohair, the maximum temperature limit is about 40 °C in order to avoid a reduction of the natural lustre of the fibres.

Agitation

This means relative movement between the solution and the fibres, either by propelling the wool through the liquor, or vice-versa. Agitation is important because it provides improved contact between the detergent solution and the grease, and it provides mechanical forces which aid the grease removal. Excessive agitation can increase fibre entanglement, leading to subsequent fibre breakage, but insufficient agitation may leave dirt on the fibres.

Time

This is the 'balancing' agent: more time is needed if other agents are less active, and vice-versa. The average time for which fibres are immersed varies from about 4 to 9 minutes from entering the first solution to leaving the rinsing solution.

There is a wide variation in the details employed in scouring practice and there is no standard solution strength even for wools containing equal amounts of grease. The amounts of the chemical agents required vary according to the detailed constitution of impurities present in the wool being scoured; as an approximate guide Wira recommend 2 kg of soap and 3 kg of sodium carbonate per 100 kg of clean wool.

Wool drying

Wool leaving the squeeze rollers of a scouring set may have a moisture regain of about 65%, the actual regain depending on factors such as roller pressure, roller covering, wool quality, and wool/liquor temperature. It is necessary to reduce this to about 20% regain for subsequent processing or even lower for storage. Too much moisture may cause milldew, spontaneous combustion, or rusting of machinery, and may contribute to excessive nep formation in carding.

Hot air drying is normally used to remove most of the moisture; this may be supplemented by a radio-frequency dryer. A hot air dryer is shown at the far end of the scouring set in *Plate 1*.

The moisture-carrying capacity of air increases with temperature. Theoretically, therefore, a higher temperature should give more rapid drying; nevertheless dryers are normally operated with a temperature of about 82 °C in the middle section, with a higher temperature at the point of entry of the wet wool where the heat loss by evaporation keeps the fibres at a lower temperature.

The speed and efficiency of the drying process is largely dependent on the following factors:

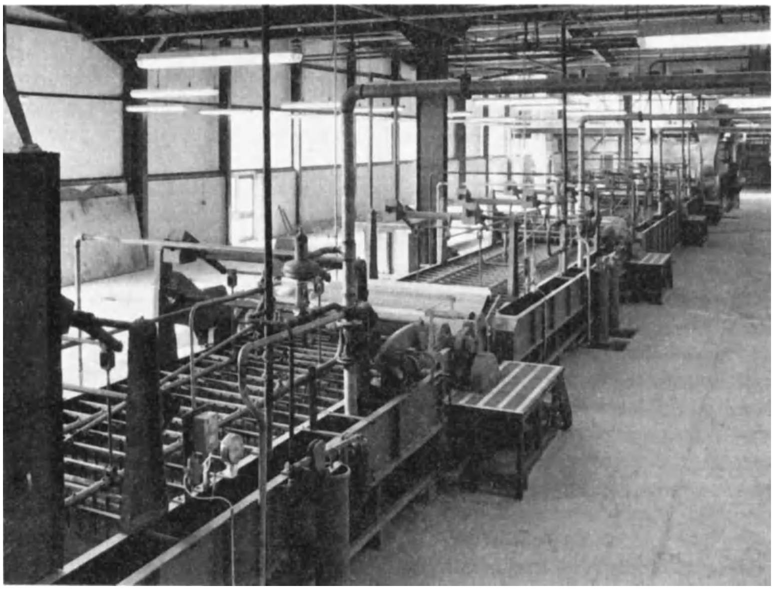

Plate 1. Four-bowl wool scouring set. The fourth bowl delivers the wool fibres to the dryer at the far end of the line. The working width is 1.8 m and the overall width is about 3.35 m. The overall length of the scouring set is about 34 m. In addition there is a hopper feeder (not shown) and the dryer. A greasy input of 1500 kg/h could be sustained with this scouring set. Machines are also available with working widths of 0.9 m and 1.2 m, with production rates pro rata. Courtesy of Petrie & McNaught Ltd

(1) air temperature;
(2) rate of air circulation (m^3/min);
(3) the time for which the wool is exposed to the drying air;
(4) the state of the material to be dried (e.g. wool quality, thickness and even-ness of the fibre layer and its packing density);
(5) the direction of the air currents in relation to the wool.

There are two types of hot air drying machines in current use for wool drying: lattice dryers, and suction-drum dryers.

The thermal efficiency of a dryer may be expressed as 'specific steam consumption' in terms of the ratio kg of steam consumed/kg of water evaporated. Because of heat losses, modern lattice dryers may have a total specific steam consumption less than 2, and suction-drum dryers approach closely to 1.35 which is about equal to the essential heat required for evaporation. Older types of dryers used to have a total specific steam consumption of about 5 or 6.

It is unlikely that further developments in hot air dryers will bring about any great improvement. Fundamental difficulties include the lack of homogeneity, bulk, and poor thermal conductivity of fibrous assemblies which cause thermal gradients, air channelling and slow heating. Although hot air drying is economical for loose fibres, it has the disadvantages of lack of precise control and local regain variations.

On its own, radio-frequency drying is uneconomic for scoured wool, but it can be used to follow a conventional dryer. The principle consists of passing the fibres between two electrodes subjected to a high frequency alternating voltage; this results in heat being generated within the material. A supplementary radio-frequency dryer following a hot air dryer delivers a product with less variation of moisture content and instantaneous control can be exercised. An essential feature is the provision of ventilation to remove steam produced during drying and to prevent condensation of liquid water on the relatively cold electrodes.

In worsted processing it is common practice to add about 0.5% of carding oil to the wool as it leaves the dryer, whereas in woollen processing oil is usually added to the fibres after they have passed through the blending process prior to carding.

Raw cotton processing

Raw cotton impurities

An important difference between cotton processing and wool processing is that the natural wax found on cotton fibres is an aid to processing throughout all stages of cotton yarn manufacture, consequently normally it is not removed until the cotton has been processed into fabric form.

In addition to the wax, raw cotton contains a number of impurities, usually known collectively as 'trash'. These impurities include those produced by the cotton plant itself, and those which originate in its habitat.

It is necessary to remove trash particles mechanically in order to facilitate processing and to obtain a satisfactory end-product appearance.

Types of cotton impurities include the following:

(1) Sand, soil and dust. These are easy to remove because of their density and shape.

(2) Whole seeds. The are smooth and fairly easy to remove even though they are small and light.

(3) Broken seed down to small pieces of seed coat covered with fibre; these may be difficult to remove.

(4) Undeveloped seed and broken fragments. These are tough, leathery, and difficult to remove. They cling to the cotton fibres and survive various mechanical treatments. In carding they may become ground up to form 'fuzzy motes‘.

The largest fuzzy motes consist of whole aborted immature seeds covered with very short lint fibres (i.e. fibres which stopped developing at a very early stage in their growth). Small fuzzy motes originate as either undeveloped or fully grown seeds which are broken in ginning and desintegrate still further in the opening, cleaning, and carding processes.

Another type of mote, known as a bearded mote, consists of a piece of seed-coat with fairly long lint fibres attached.

Both classes of mote become entangled with the cotton and their complete elimination is impossible except by combing.

Fuzzy and bearded motes which carry only a small piece of barely visible seed-coat are frequently termed seed-coat neps.

(5) Small seed fragments caused by faulty ginning or pest attack. These may survive the spinning process and form faults in the cloth; they produce yellow/brown stains if subjected to alkaline solutions.

(6) Leaf fragments, and stalks. These have poor clinging power and their presence in yarn indicates poor cleaning efficiency in the blowroom. Normally up to two-thirds of the trash removed in the blowroom may be of this type.

(7) Short and immature fibres which are unsuitable for processing into carded or combed cotton yarns.

The amount and composition of trash depends on the grade and type of cotton. For example, a short low quality Indian cotton needs considerably more processing than a long staple high grade Egyptian cotton, Even within the nine American cotton grades there is a wide variation of trash contents, ranging from the best, known as Middling Fair which contains about 1.0% of trash, to the worst, known as Good Ordinary which contains about 9.8% of trash, with the middle grade, known as Middling containing about 3.1% of trash.

Removal of impurities from cotton

The removal of dust and trash is largely dependent on the degree of fibre individualisation which can be achieved in processing.

Most of the removal of impurities takes place in the blowroom, the objectives of which are to open, clean, blend and mix the fibres, and in conventional blowrooms to form a lap.

The name blowroom indicates that pneumatic transfer of fibres from one machine to the next is used by providing reduced air pressure near to the destination of the fibres.

Further removal of impurities takes place in carding and (if used) in combing, and there may be some dust removal at the drawframe. Tandem carding has been found to be particularly effective for the removal of fine dust and impurities for open-end spinning.

Blowroom opening and cleaning lines

Cleaning lines consist of from two beating points for synthetics up to about seven beating points for low grade cottons with trash contents exceeding about 3%. To enable more than one grade to be processed on a given cleaning line, some machines may be provided with a by-pass.

The minimum amount of beating to give sufficient opening is desirable; if opening could approach the single fibre state, then the cleaning efficiency of the blowroom would rise from the present 50 to 80% up to 95% with fewer machines.

However, intensive opening may create difficulties such as damaged staple and poor lap formation due to the fluffy state of the fibres. Cotton can be over-worked in the blowroom to the detriment of

Plate 2. Automatic bale opening for cotton. Up to 35 bales in a row may be traversed by the take-off unit to remove from 0.15 to 0.55 kg from each bale on each forward and each return traverse. Different bale heights are sensed and a microprocessor ensures equal run-out of a set of bales. During running, a new set of bales is laid out at the other side of the rail track and when one set of bales is used up, the take-off unit tower rotates 180° to commence on the new set. The continual feeding of uniform quantities of very small fibre tufts ensures good cleaning and blending. A single take-off unit can deliver 200 to 300 kg/h, depending on blend complexity. Courtesy of Rieter A.G.

the ultimate yarn. Sometimes it may be better to have a little lower blowroom cleaning efficiency, and rely on the card for the removal of finer trash in order to obtain a stronger, more uniform, nep-free yarn.

The percentage cleaning efficiency of a machine equals

$$\frac{(\text{mass of trash removed}) \times 100}{\text{mass of trash in the feed cotton}}$$

In any system of cleaning cotton, the waste inevitably includes some good fibre, whilst the delivery includes some trash, and, in considering the cleaning efficiency of a system, it is necessary to take into account not only the amount of trash removed, or the amount of trash left in the delivery, but also the good fibre rejected in the waste.

Machine harvesting has led to an increase in the trash content of baled cotton. This, added to the effect of over-ginning and high density baling, has led to the need for greater blowroom cleaning efficiency; machines have been introduced which provide greater cleaning efficiency than was usual when more cottons were hand picked.

For open-end spinning greater use of high velocity air and filter screens is used to remove as much fine dust and micro-dust as possible.

Accurate feed control is required between each opening section to maintain a balance of production and constant processing conditions. This is done by doors which operate electrical switches when the pressures of cotton exceeds a predetermined amount, and accounts for the use of a few hopper feeders in a cleaning line. Photoelectric cells are also used to indicate the height of cotton in a hopper.

Blowroom methods of cleaning and opening

The actions used in the blowroom include one or more of the following:

Opposing spikes

These are found in bale-breakers, bale-openers, and hopper feeders. They usually give a rough pin action which breaks open large tufts of fibres to form smaller tufts. Closer settings usually give better opening and better mixing, but lower output. A higher speed, but thinner, feed may give good opening and maintain a reasonable production rate.

Beaters

These provide an important action and they are responsible, along with air currents, for removing almost all the impurities removed in the blowroom. It involves a mechanical means of releasing the particles of trash by striking heavy blows on the cotton. While being struck, the cotton may be impaled on spikes, may be held by rollers or a pedal/roller arrangement, may be in a restricted space between the beater and grid bars, or may be under the influence of air currents.

Air currents

Besides a sufficiently powerful fan to provide the air currents, it is also necessary to provide air-tight ducting and machine casings, pre-determined air entry places with the means of controlling the rate of airflow, means of separating the air and trash from the cotton, and a suitable air exit with filters to extract impurities collected by the air.

Separation of the cotton from the air-borne trash

There are three main methods of separating the cotton fibres from the trash particles and the air in which both are being conveyed.

The first involves drawing the air through the holes in a moving perforated surface; the fibres are collected by the screen, but some particles of trash pass through the holes along with the air. A higher speed of the screen gives a thinner film of cotton and therefore better dust separation. Perforated cages, condenser delivery boxes, and the Shirley wheel are types of delivery in which this principle is applied.

The second involves the diversion of the air currents. Well-opened cotton tufts have a high aerodynamic drag coefficient in relation to their mass, whereas trash generally has a low drag coefficient related to its mass. Aerodynamic drag forces will arise when there is a velocity difference between the material and the air current. When a loose tuft of cotton is subjected to a rapid horizontal deceleration, the high mass and virtually zero air-drag force on the trash enables it to be dislodged from the tuft of fibres.

The third method makes use of the different buoyancy of the fibres and trash under the influence of air currents and gravity. The cotton tufts are directed vertically downwards and a stream of air crosses this path horizontally. The near-zero drag force on the trash enables it to continue vertically downwards under the influence of inertia and gravity, whereas the air-drag on the fibres provides horizontal acceleration thereby separating them from the trash.

Blowroom lap formation

In conventional processing the delivery of the last machine in the blowroom, the scutcher, is in the form of a lap. Calender rollers form a compacted sheet of cotton which is then rolled to form a lap wide enough to feed the following carding machine. The total lap may have a mass of 25 to 40 kg, a count of about 400 ktex, and a length of 60 to 100 m. Automatic doffing permits continuous running of the scutcher thereby increasing productive efficiency and reducing count variations caused by stopping and starting.

The lap form of delivery is still used in some factories although since the development of autolevelling there has been a trend towards pneumatic conveyance of fibres to the chute feeds of the carding machines.

Raw Flax Processing

Flax fibres occur in bundles embedded in the layer of pectinous gums which lie between the woody core and the outer bark of the flax plant stem, which achieves a height of up to 1.2 m. Each fibre is composed of a large number of ultimates which have a mean length of 33 mm and a mean diameter of 19 μm; the ultimates are cemented together by the same pectinous gums which permeate the whole fibre layer.

The bulk of the fibre bundles are inter-connected and form a network from root to tip, but the majority of forks are in the form of an upright 'Y' when the plant is standing; for this reason a short section of the root end is processed first in both hackling and scutching, allowing the remaining length to be processed towards the tip, thereby minimising the breakage of the bundles.

About one third of the stem is fibre, and the rest is made up of the woody core and the outer bark. The seeds are usually removed from the head of the plant mechanically before retting.

Retting

Retting consists of a fermentation process which decomposes the pectins which hold the fibre bundles, and it also rots the woody part of the stem so that it will break up and aid its removal. The process is complete when the fibre separates freely from the straw. Insufficient retting yields coarse, strong fibre which is hard to clean whereas excessive retting yields clean but weak fibres; hence it is preferable to err on the side of under-retting rather than over-retting.

Drying

Drying is used to terminate retting before undue damage occurs to the fibre bundles themselves, and to enable the dried straw to be stored for a few weeks if necessary before further processing.

Breaking and scutching

Breaking consists of passing the straw root end first between six to twelve pairs of intermeshing fluted rollers, which do not quite contact each other, in order to crush and break the brittle parts of the straw prior to scutching.

The objective of scutching is to remove the crushed wood and cortex from the fibre bundles with a minimum of fibre breakage. Scutching basically consist of gripping the straw and presenting the root ends to the action of intersecting revolving beaters after which the root end is gripped while the remaining (longer) length is beaten.

After this process the fibres are arranged in strands of about fifteen approximately parallel fibre bundles. Unfortunately some short fibre, known as scutching tow, is removed at this process; after being carded and possibly combed it will be used for spinning into coarse count flax yarns.

Hackling

Hackling is intended to produce the finest and longest fibres possible by disentangling and straightening the fibres; by separating the fibre bundles and splitting each bundle up; by removing the remaining impurities after scutching; and by removing short fibres, known as hackling tow.

The flax is prepared for hackling by dividing the flax into equal-sized 'pieces', each about 70 g, from which the ends have been removed to minimize fibre length variation. The pieces are loaded into a holder with the root end projecting. The fibres are lowered between two sets of pins which move downwards until the full projecting length has been treated. This action is automatically repeated many times with progressively finer and closer pinning until the treatment of the root end has been completed. The pieces are then gripped by the root end while the whole process is repeated by a second section of the machine on the longer remaining length of fibre.

The processes up to and including scutching are always carried out by the fibre producer, whereas hackling may be done by either the fibre producer or the spinner.

The long fibre or 'line' delivered by hackling is processed into the best and finest count flax yarns, whereas the short fibre or tow from hackling and other processs is processed into thicker count tow yarns.

Raw jute processing

Jute fibres occur in concentric layers of bundles around the central woody core of the plant stem which may grow up to about 5 m tall and 18 mm thick. The ultimates of jute are much shorter than those in flax, having a mean length of about 2.3 mm; the mean diameter is similar to that of flax, being about 18 μm.

After harvesting the stems are stripped of leaves etc. and are retted prior to stripping of the fibre bundles from the stem before being dried and baled. At this stage the jute is in the form of a long mesh of interconnected fibres ranging from 1 to 4.5 m long.

In the factory they are subject to flexing and crushing actions with oil or emulsion added, prior to carding which breaks the jute into separate branched 'fibres'.

Jute is restricted to coarse yarns in which appearance is usually of minor importance for use in products such as sacking, carpet backing, and some wallcoverings. Jute has been largely displaced by polyolefins in sacking and tufted carpet backing applications.

Spun Silk Processing

Spun silk is produced from the wastes arising from the production of continuous filament silk yarns. Only about two-thirds of each cocoon can be unwound in a continuous length — the rest, called 'waste silk', is used for spun silk production. Damaged cocoons are another source of waste silk, along with some of the wastes made in other silk processes.

Raw silk fibre is coated with a natural gum, known as 'seracin', the average gum content is about 28%. All or most of the gum is removed at the first process of spun silk yarn production.

The fibres, which vary considerably in length, are opened into a more-or-less parallel arrangement and are fed to the filling machine at which the maximum fibre length is limited by cutting through the lap of material at intervals of about 150 mm.

Later the fibres may be sorted into length groups at a 'dressing' process, followed by carding, gilling, and rectilinear combing; the noil may be used in condenser spinning.

Drawing and spinning of silk used to take place on specially built machinery using pin control, but the practice of processing spun silk on worsted drawing and spinning machinery has now become quite widespread.

The flow charts given in the Appendix indicate how these processes fit into the sequence of operations for different yarn manufacturing systems.

Further Reading

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3

BLENDING AND MIXING

The basic objective of fibre blending is to assemble and combine together the correct proportions of components so that the relative amounts of each kind fed to the succeeding process (e.g. carding) remain constant throughout the whole batch of material.

It is clear, therefore, that the product of a blending process is not an intimate mixture of fibres, but rather a fibre assembly (of slivers, tufts, or bundles) in the required proportions and dimensions to enable the following process to bring about the necessary fibre-to-fibre mixing.

Hence a blend is formed by blending various sorts of qualities in such a way that when subsequent mixing takes place (e.g. in the carding process), an acceptably uniform mixture will ensue; bearing in mind that perfect mixing of fibres is unattainable, and for certain yarn types, perhaps undesirable.

The position occupied by blending in the sequence of operations is indicated in the Appendix.

The more detailed reasons for blending in yarn manufacture include:

(1) The need to produce a constant standard of product from variable raw materials, such as blending lots of different mean fibre fineness in order to produce a blend with the required mean fibre fineness: e.g. blending cottons of different fineness

$$F_b = \frac{100}{\dfrac{P_1}{F_1} + \dfrac{P_2}{F_2} + \quad . \quad . \quad . \quad + \dfrac{P_n}{F_n}} = \frac{100}{\sum \dfrac{P}{F}}$$

where F_b is the fineness of a blend of n components (mtex), P is the percentage by mass of any one component, and F is the fineness of any one component (mtex). (Jennings & Lewis, Text. Res.J.)

(2) To produce yarn at a specified price: to balance performance and luxury against economy.

(3) To meet aesthetic or performance requirements in the end-product, such as fabric stability, abrasion resistance, raised finish, moisture absorption, or increased bulk.

(4) To substitute one type of fibre for another.

(5) To improve processing performance and production rates.

(6) To permit adulteration in order to use up small proportions of faulty or inferior materials such as discoloured or enevenly dyed fibres, waste fibres which, are suitable for reprocessing, overscoured or overdried wools, and some skin wools; other considerations such as yarn count may dictate the extent to which this may be done.

(7) To produce colour and cross-dyeing effects, or novelty effects such as slubs, kemps, and knops.

(8) In addition, during blending the opportunity may be taken to reduce large matted fibre bundles to smaller, relatively lofty fibre bundles, remove some dirt from natural fibres, and then add lubrication to the fibres.

Fabrics made from blends of different fibre types are unlikely to be superior in any one property to fabrics produced from an individual fibre type, but fibre blending does enable fabrics to be produced with combinations of porperties which would be unattainable by using only one fibre type.

Experience with blending has led to a wide recognition of the main benefits which may be conferred by particular fibres; these are neatly summarized in *Table 3.1*.

The comfort factor conferred by the high moisture uptake of wool, cotton, and viscose is well known, although other man-made fibres have been shown to be equally comfortable in suitable structures.

Table 3.1 ***Benefits conferred by fibres in blends*** *(from Smithies, J., J Text Inst,* **50** *p598 (1959)*

	Polyester	*Acrylic*	*Nylon*	*Viscose*	*Acetate*	*Wool*
surface properties and handle	3	2	3	3	2	1
fullness	3	1	3	3	3	2
crease recovery at 65% R.H.	1	2	3	3	2	1
crease recovery at 90% R.H.	1	3	3	4	3	3
pleat stability at 65% R.H.	1	1	2	3	3	2*
pleat stability wet	1	1	4	4	4	4*
shrinkage resistance	1	1	1	4	1	4^{+}
tearing resistance	1	3	1	3	3	3
abrasion resistance	1	3	1	3	4	2
resistance to static charges	4	3	3	1	3	2
resistance to melting	3	2	2	1	3	1

Since this table was originally compiled, note should be taken of two important developments: $^{+}$Wool shrinkage can now be inhibited by suitable chemical treatment *Permanent press can now be conferred on wool.

1 = excellent. 2 = good, 3 = adequate, 4 = poor.

In order to obtain the benefits of pleat stability more than 50% of fibres conferring this property must be present in the blend. Some man-made fibres may give rise to pilling (e.g. nylon or polyester blends with wool). To avoid this the maximum acceptable fibre count may be used in combination with increased spinning twist compatible with fabric handle requirements; low-pill versions of the fibres are also available.

Basic blending requirements

In order to produce a large quantity of uniform blend of the required component proportions it is necessary to divide the total batch into smaller portions and to weigh the components of each small portion to the required accuracy. It is also necessary for each component to have a known uniform moisture content at the time of weighing and each component mass should allow for the application of its respective official regain allowance.

Blending is best carried out from a maximum number of bales and early in the sequence of processing so that maximum benefit can be obtained from the mixing involved in the subsequent processes. The tangled mass of fibres should be reduced to a small uniform tuft size to improve accuracy of blend proportions; this is particularly important when diverse components are to be blended as otherwise component separation might occur subsequently.

Small proportion components should be premixed with a major blend component representing about 20% of the total blend before being introduced into the main blend. The 'threshold percentage' at which this becomes necessary lies between about 2% to 5% of the total. The actual value depends on factors such as end-use requirements, and the minority component colour in relation to the remainder of the blend. A higher threshold percentage would apply for a two-component blend of contrasting colours than for a blend in which the minority component harmonized with one or more of the majority.

To avoid confusion during blending where an undyed blend is made which may be cross-dyed later, a fugitive tint may be applied to one of the components; this will be removed subsequently.

As an additional aid to blend uniformity, blends which are stored in bales in the chronological order of production should be withdrawn for use in an order which cuts across the chronological order.

Blending Systems

Blending can take place before or after carding. Pre-card blending takes advantage of the opening power of the card and therefore gives the most intimate mixing of fibres, which in turn may improve subsequent drafting. Various blending systems have been developed for different fibres; they may be classified into the following groups according to the principles involved:

(1) stack blending (also known as pile, sandwich, or layer blending),
(2) blending hoppers,
(3) batch blending using bins,
(4) continuous blending, and
(5) sliver blending.

Stack blending

This is the oldest and simplest method which is still used where small total quantities are involved. The total masses of each component required are first weighed and assembled together before being spread out in horizontal layers, each about 150 mm thick, over a large floor area, to build up a deep stack. Oil and other additives may be applied evenly between some of the layers, the necessary total mass of each additive having been determined previously. The stack is manually broken down into vertical 'slices' before being fed to an opening machine.

This method has the advantage of assembling the total batch together at one time and ensures the correct proportions of components, but it is labour-intensive, intermittent, and slow. After opening, a second stack may be made, and the process repeated if necessary.

Blending hoppers

Each of several automatic weighing hoppers delivers a pre-determined mass of the respective blend components simultaneously on to a transverse conveyor which feeds the combined components to a further opening machine. This system has been widely used in both cotton and jute processing, and may form the feed to a continuous opening unit.

Batch blending using bins

The total blend is divided into smaller representative batches of bales from which fibres are fed simultaneously to opening machine no. 1 (*Figure 3.1*) before being conveyed pneumatically to a rotating exit point called a rotary spreader mounted over the first blending bin (1a), which, like the other bins is preferably circular in plan. When bin 1a is full the delivery of opening machine no.1 is diverted to an alternative first bin (1b).

Thin vertical wedge-shaped slices of fibres (like slices from a circular cake) are then removed from the first full bin 1a, and fed pneumatically to a rotary spreader mounted over a second bin (2a), forming horizontal layers.

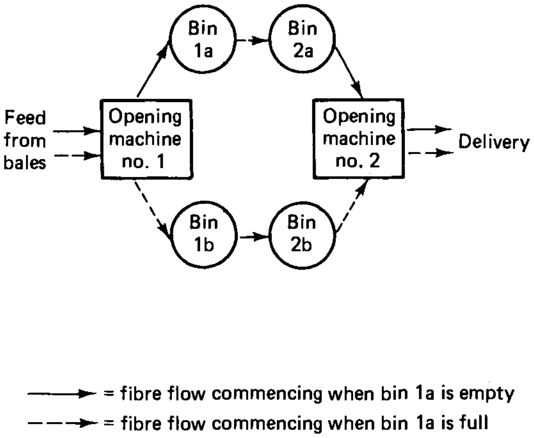

Figure 3.1 Schematic plan view of a batch blending bin system

Fibres removed in vertical slices from the alternative second bin 2b are fed pneumatically to opening machine no.2 at the delivery of which oil or other additive may be applied to the fibres.

As one bin becomes full, and another empty, the roles of the 'a' bins are changed with those of the 'b' bins so that opening can be continuous.

The pneumatic delivery may be either direct to the carding hoppers or alternatively to a sheeting-up process which produces bales of blend for storage.

With this method, which is widely used on the woollen system, the total blend is only assembled together at the input before commencement, and at the delivery after completion. For this reason the maximum number of bales should be used simultaneously for feeding, and maximum mixing of delivered bales should be attained subsequently. An important advantage of this system is that if required, further mixing can be obtained by passing material from bin to bin without the necessity of having to pass it through the opening machine each time.

An automatic blending plant which is based on similar principles is shown in *Figure 3.2*; such a system is less flexible than the system described above, but is useful where long runs of the same blends are possible.

After initial cleaning and opening, the fibre tufts are built up into horizontal layers in a storage bin by the cylone. After the bin has been filled, vertical 'slices' are removed by the bin emptier; the fibres either may be transferred to the second bin, or they may pass directly to the fearnought and oiling unit.

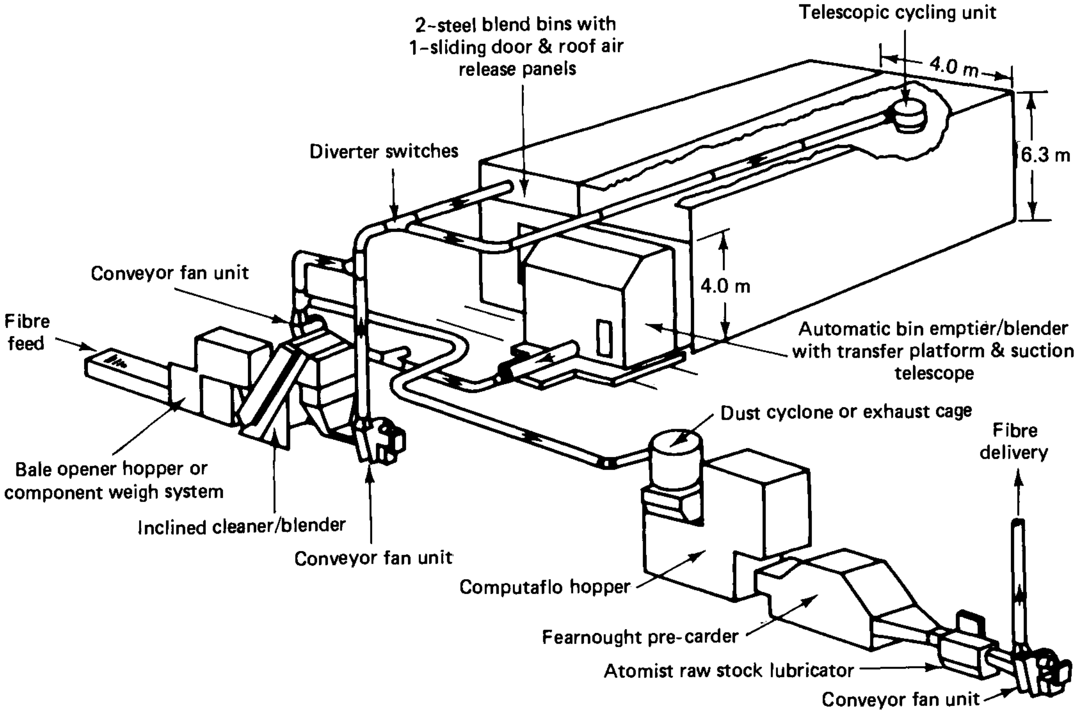

Figure 3.2 Automatic fibre blending for the woollen system. Using a second bin re-mix, this plant produces up to 800 kg/h, and with direct passage using only one bin up to 1500 kg/h. An additional emptier and pair of bins can almost double the production rate of a single fibre feed and fibre delivery line. A two-bin system has a capacity of about 15 tonnes of wool, man-made fibres or blends. Courtesy of Pneumatic Conveyors (Huddersfield) Ltd.

Continuous blending

On the woollen system, blending units of this type are suitable for relatively simple blends available in large quantity. Instead of the material being partially accumulated in a bin, the rotary spreader is used to feed a centrifugal blender which removes loose dust and mixes the fibre tufts together before allowing them to fall down on to a lattice which feeds the hopper of the following opening machine. This action is usually repeated before oil is added to the fibres just prior to delivery.

For the cotton system various systems of continuous blending have been developed recently which are based on a modification of the stack principle, and involve automatic 'bale digesting'. One method is shown in *Plate 2*; alternatively a number of bales or part-bales can be loaded on to the feed lattice of the blending unit which may move the bales backwards and forwards over the 'digesting' units which remove tufts of fibre from the bales either by a rotating beater-type opener, a spiked lattice, or by finger-like projections which perform a plucking action. The tufts are then fed into a large machine which in effect builds up a stack of fibres from which transverse 'slices' of fibre are removed automatically. The large storage capacity of the 'moving stack' ensures that fibres which were fed in at times separated by intervals of up to about 2½ hours will be delivered simultaneously. A similar system may be used for wool on the worsted system.

Sliver blending

This system may be used at, for example, the cotton drawframe or the worsted gill box, by feeding a drafting zone with the necessary number of doublings. This method is preferred for blending fibres which require distinctly different treatment at preceeding processes, such as natural and man-made fibre blends. There is also the advantage that separate component wastes are produced at the earlier processes, instead of mixed waste which is less valuable. Using the simplest form of this system, the blend proportions are limited by the number of doublings, although specially designed multi-head mixing machines using a large total number of doublings can reduce this limitation and improve the mixing by superimposing thin webs of fibre on each other.

In coloured worsted yarn manufacture a slightly more involved method may be used which enables any blend proportion to be processed.

Because sliver blending may not provide the intimacy of mixing which can be obtained by carding, it should be initiated at the earliest possible stage.

When this method also involves a reduction of strand thickness, the evenness of mixing may seem to improve up to a certain operation, after which the evenness apparently deteriorates. This is because a random fibre arrangement *appears* to be more uniform when there is a large number of fibres present than when a thinner sliver or yarn is observed.

Blending tolerances

End-use may influence the selection of processing method and the acceptability of blend appearance and a failure may be said to have occurred when the end-product is judged to be unsatisfactory visually. Failures in blending involve a long-term variation in blend composition which may arise because of direct errors in weighing components, a drift of moisture content or other additives which indirectly produces the same effect, or a selective separation of components at some stage during opening.

The tolerability of variations in composition depends very much on the colours of the components; critical light shades may require blend accuracy within 1% whereas a 2% difference in composition may be acceptable for some mixtures and where small shade differences in component colours are concerned, 5% blend accuracy may be acceptable.

The percentage composition also has a bearing on the permissible latitude of blend accuracy: blends in the region of 50/50 are less sensitive to inaccuracies than are blends nearer to the extremes.

Mixing deficiencies

Mixing defects are the result of failure to obtain the required breakdown of groups of fibres into the single fibre elements. This may be the result of insufficient processing, disparity of component fibre lengths, or adhesion of fibre clusters.

Factors which influence the appearance of fibre mixtures include:

(1) Fibre dimensions.
(2) The number of fibres in the cross-section of the strand.
(3) The actual colour of each blend component (e.g. brightly-coloured streaks might show up to an exaggerated extent in an otherwise dark-coloured mixture).
(4) The proportions of components (e.g. a uniformly mixed appearance of a 50/50 blend is more easily achieved than with an unbalanced blend such as 80/20 or 90/10).
(5) Where a colour mixture of different types of fibres is to be made it is better to introduce the colours equally in each fibre type so that any tendency for fibre grouping does not cause a preponderance of streaks in one shade only. A further advantage of this practice is that differential wear of components will not cause a change of shade.

Limitations of blending and mixing

Because the relative success of blending and mixing processes can be assessed and described most easily in terms of different coloured fibres, this method of description has been adopted in the following discussion, mainly using black and white for illustration. Nevertheless the same principles also apply to blends of different fibres which happen to be the same shade as each other. The usual convention of describing blend proportions by mass has been used, e.g. 50B/50W means a blend composed of 50% by mass of black fibres and 50% by mass of white fibres. However it is important to appreciate that similar proportions by mass can be produced in which the proportion by fibre number may differ considerably. This may have important implications regarding dyeing, finishing, and handle.

In a 'perfect' blend of black and white fibres, there would be no variation in the proportion of black and white fibres between different points either along or across the fibre strand; each point would have exactly the pre-determined blend proportions.

Because no machine at present available can select or reject individual fibres in order to control component proportionality, the best which can be hoped for is a random distribution of single fibre elements in the two dimensions of the strand cross-section, as well as a random distribution of fibres along its length.

Even in a hypothetical strand where fibres are distributed perfectly at random as single elements, a white fibre frequently will be found next to other white fibres, and a black one next to other back ones because of the statistical form of the distribution.

In practice, machines are not capable of producing a random distribution of individual fibres; they only seem to be capable of producing a random distribution of fibre clusters.

Consequently the best mixtures of black and white fibres inevitably form clusters consisting of varying numbers of similar fibres bounded by dissimilar fibres, and the mean size of these clusters on the surfaces of short lengths of yarn varies from place to place along the length. Even so, successive stages of drafting do appear to be effective in substantially reducing the size of fibre clusters delivered by earlier processes such as carding; for this reason repeated drafting and doubling is often used as a method of *mixing* subsequent to any method of blending.

This point emphasizes the source of confusion between the terms 'blending' and 'mixing'; because sliver *blending* involves the use of drafts and doublings it is easy to fail to distinguish it from the subsequent *mixing* which follows, also using drafts and doublings.

The degree of mixing may influence some fabric properties (such as abrasion resistance) but not others (e.g. crease recovery).

Irregularities in yarn arising from inadequate blending and mixing may be classified in three groups:

(1) Irregularities due to variations in the number of coloured and white fibres in the corss-section of the yarn.
(2) Irregularities due to an uneven arrangement of coloured and white fibres in the yarn cross-section.
(3) Very long-term irregularities.

In a 50B/50W yarn with a mean number of fibres of $\bar{N}$ in its cross-section, approximately $0.5\bar{N}$ doublings should be used to control (1), but to improve (2) approximately $5\bar{N}$ doublings would be required. Further increases in the number of doublings could not be expected to give any further improvement in either (1) or (2).

Fabric streakiness is mainly caused by the second group, and such streakiness can be reduced further by using intermediate levelling colours or Vigoureux printed fibres.

For unbalanced blends, more doublings should be used and it has also been observed that dark unbalanced blends (e.g. 90 dark/10 light) *appear* to be more uniform than equally unbalanced blends which are lighter (e.g. 90 light/10 dark).

Very long-term irregularities of colour (group 3) which might cause weft bars may arise either because of shade variations between different dyeings, or count differences between initial component slivers. In recent years variations of the former type have been minimized by mixing representative proportions of the dyeings in each batch of blend prepared and by using increased package capacities; the latter type have been overcome by using autolevellers.

Benefits of Blending and Mixing

When yarn dyeing or fabric dyeing is used, the product usually has a single overall shade, or, if blends of fibres with affinities for different types of dyes are used, a simple cross-dyed mixture is possible.

By mixing different coloured fibres in a blend, the product can have a 'sparkle' which is completely missing from a solid-dyed product.

A further point is that for yarn and fabric dyeing, top priority must be given to using dyes which give a good shade uniformity, and this may preclude other dye characteristics such as fastness to certain agencies which may be of greater importance in some products; uniform dyeing may be of less importance when subsequent fibre mixing is to take place.

Further reading

Regain Allowances in Blends
Statutory Instrument No 2124, Trade Descriptions Regulations, Schedule 3 (1973)
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4

CARDING

This process involves subjecting the fibres to the action of a large number of pins in an attempt to separate each fibre from its neighbours in order to form a fluffy but coherent mass. This is necessary to facilitate further fibre manipulation and to release particles of impurity. On the swift (alternatively known as the 'cylinder'), there may be as many as 15 to 50 times as many pins as there are fibres on the roller.

General carding objectives

There are four main carding objectives, they are:

(1) To separate each fibre from the others in each original tuft of feed material with a minimum of fibre breakage.
(2) To remove impurities and fibre entanglements.
(3) To mix the fibres together to provide a uniform distribution.
(4) To form a bulky sliver of overlapping, partially aligned fibres.

Cotton carding has the additional aim of removing some short fibres and neps. A nep is a small cluster of entangled or knotted fibres forming a compact ball which is not likely to be disentangled by drafting; neps are found in most card slivers regardless of the fibre type. Paradoxically neps usually are first formed during the carding process; in the case of wool, from fibres with a diameter of only about 65% of the mean fibre diameter being processed; and in cotton from immature or thin-walled fibres.

Instead of objective 4 above, woollen carding has the objective of dividing the full-width web of fibres into narrow round cross-sectioned twistless threads of equal thickness wound on to a condenser bobbin ready for spinning.

Carding of the bast fibres involves extensive cleaning and the splitting of fibre bundles into finer compound bundles to enable finer yarns to be spun. It is not usual to use the bast fibre card for blends of different grades of material because of the different settings required for each grade.

Alternative methods of sliver formation have been tried at various times for cotton and for wool, but apart from processes for longwools and for man-made fibres, these have not been very successful.

Card Rollers

Modern card rollers are usually made from aluminium alloy mounted on steel shafts with ball-bearings; wooden plugs are inserted at suitable points around the circumference to accept nails which hold the card clothing in place.

Card clothing

The term 'card clothing' is used to describe the large number of pins covering the roller surfaces. There are two main types of card clothing: flexible wire mounted into a foundation, and rigid metallic.

Flexible wire card clothing

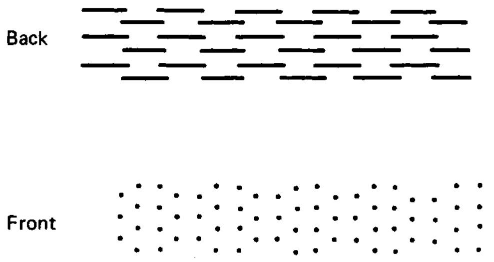
This type of card clothing was developed to simulate the flexibility of the natural teazles used in the past because it was believed that this was essential in order to minimize fibre breakage during carding.

It is made from two major components, the wire, and the foundation. Hard-tempered steel wire which has a high value of Young's modulus and is springy and hard wearing is used to form the pins which may have a round, oval, rectangular, or other cross-sectional shape, and may be tin or cadmium coated. A wedge-shape with a wider trailing edge has been found to produce fewer neps when carding wool.

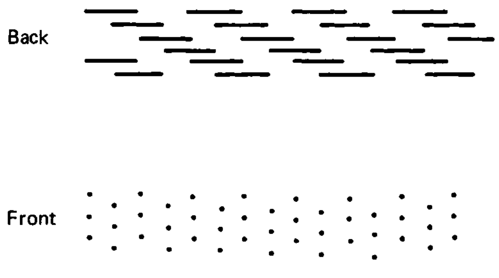
Wire diameters range from about 200 μm to 600 μm and pin concentrations from 20 pins/cm^2 to 140/cm^2 are used in both wool and cotton carding; flexible wire card clothing is rarely used on bast fibre cards.

In wool carding it is usual to have an equal number of pins/cm both along and across the card clothing. Increased pin concentrations are usually associated with finer wire diameter, but wire diameter must be sufficient to provide adequate pin rigidity for the particular application in hand.

Pins may be inserted into the foundation in different layouts, such as plain, or twill *(Figure 4.1)*. Because it is important that the swift roller pins should permit easy entry of the pins of the fancy roller in wool carding, they should be arranged so that there is a 'gate' (i.e. lengthwise spaces) along the length of the clothing.



Plain



Twill

Figure 4.1 Flexible card clothing pin arrangements

The foundation must provide strength, elasticity, and resistance to the chemical additives on the fibres. Two types of foundation are used for flexible wire clothing:

(1) Oak-tanned leather sheet. This is still used for fancy rollers in woollen carding because it minimizes the formation of undesirable air currents across the swift.
(2) Fillet card clothing. Multiple layers of cotton fabric are used, sometimes incorporating a layer of woollen and/or linen fabric to improve resilience or rigidity. The layers are bonded together, usually with vulcanized rubber, and cut into strips of the required width (e.g. 50 mm or 62.5 mm) before the wire pins are inserted from the back in the form of a two-pointed staple; the projecting pins are then bent to the necessary angle.

Sometimes for carding wool a layer of felt or rubber may be incorporated on the face of the foundation to give more support to the wires up to or slightly above the knee, permitting higher carding speeds, and preventing the accumulation of fibre and debris at the bottom of the pins, or protecting the foundation from chemical additives on the fibres. This type of clothing tends to produce a card web which is less clear of nep and entanglements, although fibre breakage is not significantly different from ordinary fillet clothing. The use of felt also permits the use of finer wire for a given pin concentration which provides more 'mouth' (i.e. space between the pins).

The fillet is finally wrapped on to a cylinder and precision ground before the points are given a final hardening. The long length of fillet is then wound spirally on to the roller of the carding machine.

Flexible wire pin geometry

If a simple straight wire *(Figure 4.2(a))* is subjected to a force in the direction of f, then the height of the wire point B will tend to increase from h to h_1. Such an action could cause pins of adjacent rollers to be damaged by touching each other, and sparking might cause an outbreak of fire. This possibility is avoided by having wire bent with a knee *(Figure 4.2(b))* where β is about 5°; in this way a minimum change of h is achieved.

The angle θ has an influence on the retention of short fibres and impurities by the card wire. This is more important in the earlier part of the wool carding process, and hence θ may be about 65° and pin concentration may be at a minimum to provide space for the collected debris. Later on in the machine the angle may be increased progressively to a maximum of about 85° and pin concentration may be increased.

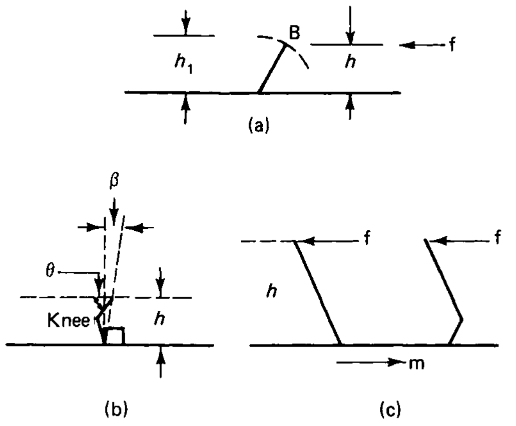


Figure 4.2 Flexible wire card clothing

An exception to this arrangement is used for wire on the fancy rollers of wool cards which may be one of the two types shown in *Figure 4.2 (c)*. In this case the direction of surface movement of the card clothing *m* is such that the force *f* applied to the pins can only cause a reduction of *h*. For fancy wire θ is usually about 68° or less, and *h* is about 20 – 25 mm, whereas for other types of flexible wire clothing h is only about 10 mm.

Rigid metallic card clothing

This is manufactured in two forms: rigid metallic wire, and inserted pin.

Rigid metallic wire card clothing has been used extensively in USA and Continental Europe for the carding of wool and high-production cotton carding and has become increasingly popular for worsted and semi-worsted carding in the UK. Wool regain should not exceed about 25% and fat content should be less than 0.6%; within these limitations wool fibre breakage is not significantly different from that caused by flexible wire clothing, but roller eccentricity is more critical when two adjacent rollers have rigid clothing on them.

The wire is made in long continuous lengths with a rectangular cross-sectioned pliable base from the face of which project the hardened teeth *(Figure 4.3(a))*. It is wound on to the card roller in spiral form, either fitting into a groove which is cut into the card roller like the thread of a very large screw, or where greater pin concentrations are required, being wound edge-to-edge on to a smooth surfaced roller. The base width *a*, tooth height *b*, tooth pitch *c*, and tooth width *d*, are variable factors, and for different purposes a variety of tooth shapes and angles is manufactured *(Figure.4.3)*. Where appropriate the clearance or trailing angle α is specified as well as the face angle θ .

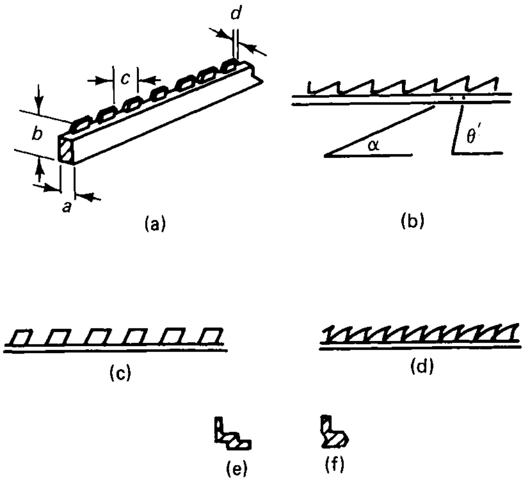


Figure 4.3 Rigid metallic card clothing

The type shown in *Figure 4.3 (b)* is used on the takerin roller of a cotton card. The leading angle θ varies from about 80° for dirty cottons shorter than about 30 mm staple length to 90° for longer and cleaner cottons, rising to more than 90° for long staple synthetics where no cleaning and a less severe action is required. The swift has an angle between 70° and 80° with short teeth giving a low retaining power which permits easy transfer of fibres to the flats and doffer. To enable effective collection of fibres from the swift, acute angled retentive wire is used for the flats, and the doffer wire has long teeth with an acute angle. Transfer of fibres from swift to doffer is insufficient with a doffer leading angle of more than 70° with the result that overloading of the swift causes overworking of the fibres and increased nep formation; on the other hand a doffer leading angle of only 45° causes too much transfer of fibres, thus reducing the mixing power of the card, and causing irregularities in the product.

Flat-topped wire *(Figure.4.3(c))* is used in wool carding where burr removal is required. Dense pinning prevents the burrs from sinking between the pins and improves the action of a burr beating roller.

A saw-tooth clothing which might be used in Garnetting of threads and waste is shown in *Figure 4.3(d)*. Besides the ordinary base shape, interlocking and interlinked types are made as shown in *Figure 4.3(e)* and *(f)* respectively.

In wool carding the use of flexible wire on the worker rollers in conjunction with rigid metallic wire on the swift may reduce danger of damage to the swift clothing, but they do require fettling (described on p 34).

Rigid metallic wire card clothing usually has a lower pin concentration than flexible and has a

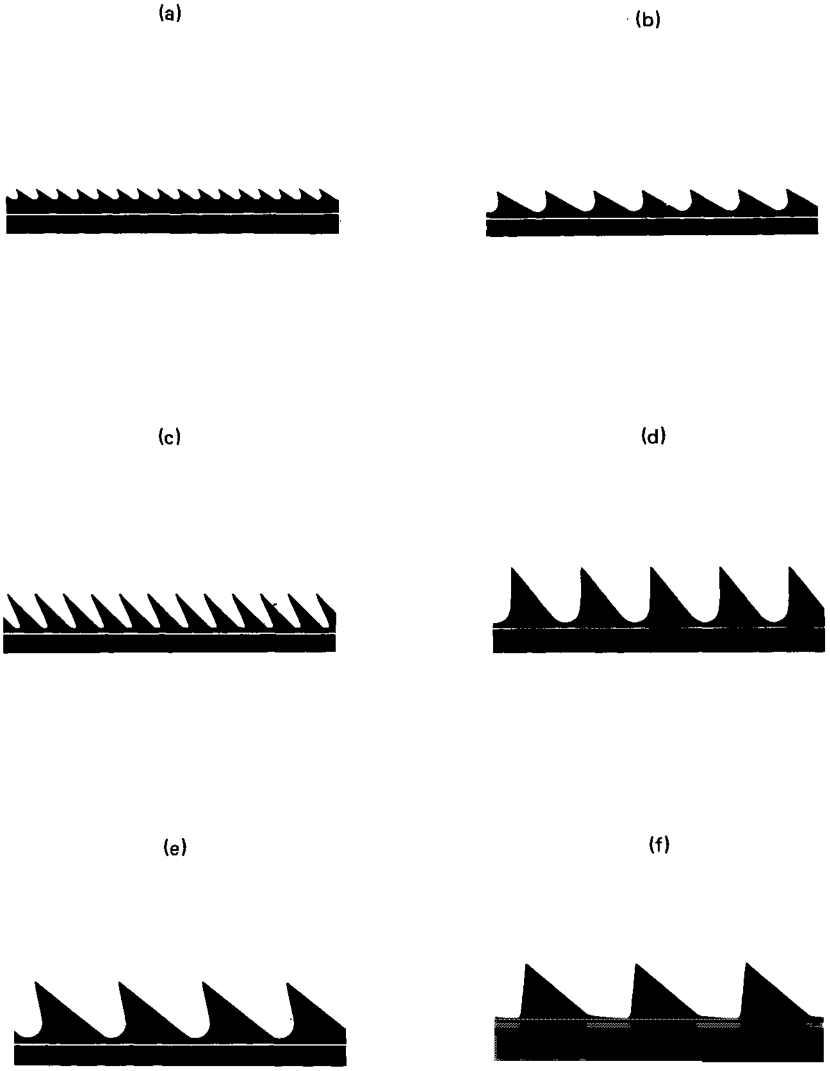


Plate 3. Rigid metallic wire profiles. (a) Fine wire for use on a swift (b) Medium wire of swift and stripper rollers (c) Doffer or worker wire (note the acute face angle) (d) Wire for use on licker rollers (e) Coarse wire for swift or licker rollers (f) Licker wire for processing fine delivate man-made fibres (note the obtuse face angle)
Courtesy of English Card Clothing Co Ltd

much lower efffective working height which is an important factor in reducing fibre retention and therefore fettling.

In cotton carding an increase in nep count and card droppings indicates that regrinding may be necessary. This is confirmed if under a microscope the teeth appear to be smooth and rounded. Regrinding restores the short flat-topped land with grinding marks on the surface and a sharp leading point. Regrinding should be as infrequent as possible.

Eventually the repeated regrinding of metallic wire reduces the pin height into the softer metal near the base of the pins; regrinding should not reduce the tooth height more than about 0.75 mm. Regrinding of rigid wire clothing for wool carding is rarely necessary after the initial grinding of a newly-clothed roller.

The other type of rigid metallic card clothing where the pins are set in a rigid foundation such as metal or wood, may be used on the early rollers of a wool card where strong coarse pinning is required. Small rollers such as feed rollers may have the pins set into hollow brass or phosphor-bronze sleeves from the inside; the sleeves are then slid on to the steel core of the roller, being located positively by a keyway. For larger rollers the pins may be set into a wood or an alloy stave which is screwed to the bare roller to be clothed; a number of these staves being fixed around the roller.

This method is widely used in flax and jute carding, where the pin concentrations (pin/cm^2) are usually within the following limits: jute breaker card 0.3 – 1.25; jute finisher card 0.8 – 1.4; flax breaker-finisher card 5.6 – 9.0

Carding actions

The effect on the fibres placed between a pair of adjacent rollers depends on the inter-action between the two surfaces. For this reason emphasis here is place on *surface* movement rather than rotational movement, although this is mentioned where appropriate. The action is determined by the following machine factors:

(1) The relative direction of movement of the roller surfaces; they may either move in the same direction, or in opposite directions *(Figure 4.4 (a))*.
(2) The direction of inclination of the card clothing pins; this may be points leading or backs leading, *(Figure 4.4 (b))*.
(3) The relative surface speeds of the points of the card clothing.
(4) The distance between points on the adjacent rollers; this distance is called the setting.

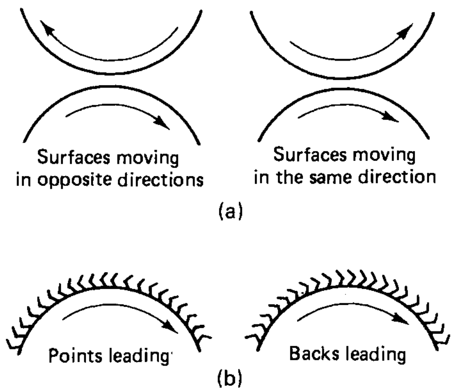


Figure 4.4

The intensity of the action can be modified by altering one or more of the above factors, but although the effects of altering these factors may differ quantitatively when different materials are carded, they remain qualitatively the same over a very wide range of fibre lengths and qualities. A change in over-all carding speed (as opposed to changes in *relative* speeds) causes no essential change in the carding action, and although higher speeds may lead to more fly waste, it does not necessarily lead to more fibre breakage except at the feed roller/ takerin point; this is why takerin speeds of 760 m/min are seldom exceeded on cotton type cards. A higher speed may give improved nep removal, and it does not materially affect the width-way uniformity.

Nevertheless an undue increase in over-all carding speed does lead to problems arising from centrifugal acceleration. A 1.4 m diameter swift running at 100 rev/min develops a centrifugal acceleration of approximately 8 *g* whereas at 140 rev/min the acceleration is about 16 *g* at the roller surface. This acceleration is not only applied to the fibres, but also to the card clothing. At 140 rev/min strong fillet card clothing has been observed to lift away from the swift surface. Rigid metallic wire clothing is less prone to this effect at high speeds.

High carding speeds also accentuate the influence of air currents which then become an important factor in the process, even though they do not in themselves contribute significantly to the actual mechanics of fibre separation; in general they may be more detrimental than helpful.

There are three basic pin relationships which can be obtained in carding: point to point; point to back; and back to back.

Point to point

This action always results in some fibres being retained by both surfaces.

When it is used to open and disentangle the fibres it is called working or carding. The setting depends mainly on the thickness of the fibre layer between the rollers — a closer setting is needed for a thinner layer. The two ways in which this action may be achieved between two moving surfaces are shown in *Figure 4.5*, with the flow of fibres indicated.

The action shown in *Figure 4.5(a)* is used at the licker/divider interface of a worsted card forepart. The action shown in *Figure 4.5(b)* takes place between the swift and workers, or between the swift and flats. The proportion of fibres picked up by the worker out of the total fibres presented to the

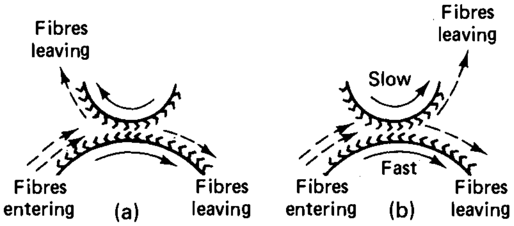


Figure 4.5 Point-to-point working actions

swift/worker interface is called the 'collecting power' of the worker. A fraction of a second later the fibres are returned via the stripper roller to the swift to be re-presented to the same swift/worker interface; this action provides a series of doublings, doubling some of the previous fibres with those which were fed in later, and it contributes to mixing and uniformity. At the same time the slow pins of the worker help to spread out the fibres which remain on the swift surface.

A point to point action is also used by the doffer roller to collect the thin layer of fibres carried on the fast moving surface of the swift. The action of the doffer is represented in *Figure 4.6*. On a wool card, doffing takes place following the action of the fancy (described later under 'back to back' action), but a fancy is not required in cotton carding, or in wool carding, if the swift is clothed with rigid wire.

Because the swift has a surface speed 20 to 30 times faster then the doffer, it deposits fibres on to the doffer in a thick layer which is then stroked by the high speed swift. This causes many of the fibres to be reversed in position and to become hooked; this is the major factor influencing hooked fibre formation but it may be influenced by previous actions on the card.

Fifty per cent or more of the fibres have hooks at the trailing end as they leave the card; this is the biggest group of hooked fibres. In the case of the cotton flat card, the extent of the trailing hooks is greater than in the other groups regardless of fibre configuration before carding, and the majority of hooks are formed by the tips of cotton fibres which are finer than the root end. In the case of wool, the trailing hooks are in a numerical majority but the hook lengths are not necessarily different although an increased fibre length leads to an increase in the proportion of trailing hooks.

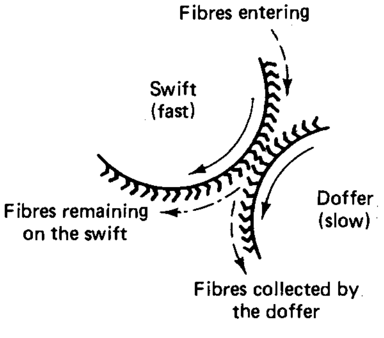


Figure 4.6 Doffing action (point to point)

Transfer of fibres from the swift to the doffer is aided by the doffer having more acute angled pinning which continually presents a clean surface to the already loaded swift which because of its high surface speed generates centrifugal acceleration on the fibres in the appropriate direction. Because a point to point action is used in doffing, some fibres are retained by the swift to be carried round for further treatment before they are re-presented to the doffer. This contributes to improved fibre mixing and levelness of the product.

Attempts have been made to use pneumatically assisted fibre transfer from the swift to the doffer, but without commercial success.

Doffers frequently collect only about 20% of the fibres presented by the swift.

For a given set of conditions, an equilibrium is arrived at between the amount of material on the swift and that on the doffer. For example, this means that if the card production rate is 15 kg/h and the doffer collects 20% of the material presented to it, then there must be 75 kg/h passing over the upper part of the swift, and 60 kg/h passing underneath the swift to be re-cycled.

The collecting power of the doffer has been shown to increase with closer settings and also with an increase of doffer speed. The latter is the main parameter which determines the swift loading (presumably because at higher doffer speeds a greater number of clean doffer pins are presented in a given time), and the effect is more marked at higher rates of feed with both wool and cotton. For cottons which nep easily a slower doffer speed is associated with reduced nep and reduced leading hook formation because more fibres are transferred from the swift to the doffer in the zone approaching the closest proximity of the rollers, but trailing hooks may be increased. For cottons which do not form neps easily, higher doffer speeds may be used, reducing trailing hooks, and slightly increasing leading hooks and neps, but giving improved sliver uniformity. Similarly when carding coarse wools at a high production rate, it may be preferable to increase the doffer collecting power. This can be done by altering the doffer speed, and may also be influenced by the card clothing pin concentration.

A further application of the point to point action is that of a tightening roller which is sometimes used in the forepart of a worsted card *(Figure 4.7)*. Because a wide setting is used the tightener clothing pins only pluck at the surface fibres on the following

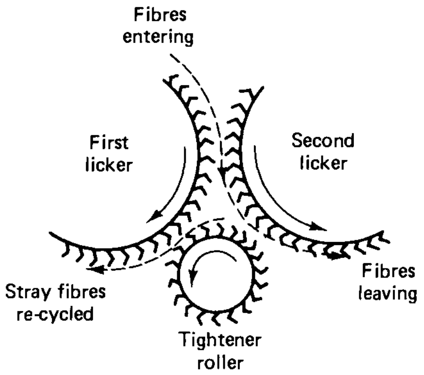


Figure 4.7 Tightening roller action (point to point)

licker roller, causing the fibres to be pulled down into the licker pins. This action is used in preparation for the removal of burrs. The few fibres which are picked up by the tightener are removed by the preceeding licker roller with a point to back action and fed back into the card.

Point to back

This action is used to convey all the fibres from one surface to another, normally using a close setting. In this book a point to back action is called stripping; this action is not confined to stripper (or clearer) rollers. In the Lancashire cotton carding industry this action may be called clearing, and the word stripping is used there to convey the same meaning as fettling.

There are two ways in which a point to back action can be obtained as shown in *Figure 4.8* in which two examples of this action are given with the flow of fibres indicated; it can be seen that any fibres carried by the upper surface would be collected by the lower surface.

If the point to point action shown in *Figure 4.5* is compared with the point to back action in *Figure 4.8*, some similarities can be seen. In both cases when the surfaces are moving in the same direction as shown in part (b) of each respective figure, firstly the relative speeds are important in determining the action, and secondly all the fibres pass between the two surfaces; neither of these statements apply when the surfaces are moving in opposite directions as in part (a) of each figure.

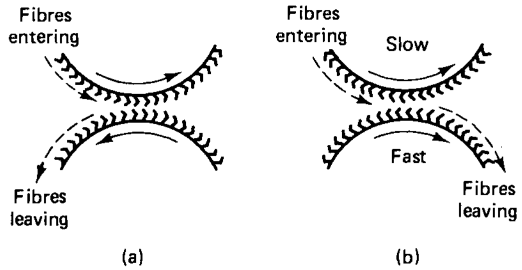


Figure 4.8 Point to back: stripping action (a) surfaces moving in opposite directions; (b) surfaces moving in the same direction

Back to back

This action is called raising and involves moving the fibres being carried by the swift roller towards the tips of the pins by the action of the long fancy wire pins which intersect with the swift clothing pins (*Figure 4.9(a)*).

The roller used for this purpose, called a fancy, has a low concentration of long flexible pins with an angle of about 68° which intersect from 1 to 4 mm into the thinner pins of the swift as shown in *Figure 4.9*. This leads to a flicking action of the fancy pins just after passing the point of maximum penetration, which helps to lift the fibres up to the surface of the swift clothing. Correctly set, the fancy pins are withdrawn end-wise, leaving the fibres on the swift surface.

The surface speed of the fancy roller is critical in obtaining the desired effect. If it is too fast, fibres are thrown into the air, forming fly waste, and if it is too slow, the fancy collects fibres from the swift. The optimum fancy speed depends on a number of factors such as depth of intersection, pin angle, pinning concentration, wire thickness, production rate, and type of fibre being processed. Variation of fancy speed has less influence on doffer collecting power as the load on the swift increases. In wool carding the fancy surface speed may be only about 14% faster than the swift surface speed although it is more usually 20% – 25% faster, and may occa-

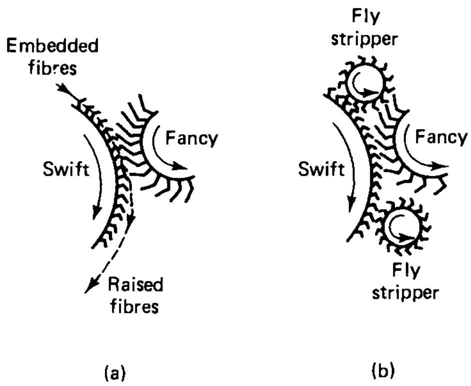


Figure 4.9 Back to back: raising action (a) conventional worsted application with flexible swift clothing; (b) woollen application with fly strippers to clean the fancy

sionally be about 30% faster. In woollen carding fly strippers may be used in conjunction with the fancy as shown in *Figure 4.9(b)*. They help to clear stray fibres from the fancy when its speed has to be limited because of the short fibre length being processed; in conjunction with a closely fitting cover they also help to control air currents, thereby reducing the tendency for the fancy to blow fibres away from the sides of the machine. For this purpose they must be set as close as possible to the adjacent rollers.

The use of a fancy on flexible wire clothed cards improves the subsequent transfer of fibres from the swift to the doffer and also reduces the accumulation of fibres at the base of the swift pins thereby permitting longer runs before the machine has to be stopped for fettling (i.e. cleaning).

In woollen carding and cotton carding a back to back action may also be used for removing the web of fibres from the doffer roller; this is described later under 'doffer draw-off rollers'.

A dick roller clothed with long wire pins may be used on the doffer in woollen carding; in this case a back to back action is employed with the surfaces moving in opposite directions *(Figure 4.10)*. The dick roller intersects with the doffer clothing and helps to maintain the cleanliness and sharpness of the doffer teeth when it is being used in conjunction with a doffer comb; there is no web of fibres involved in the action of the dick roller.

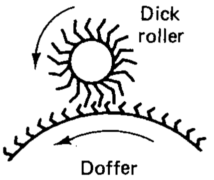


Figure 4.10 Back to back; dick roller in woollen carding

Subsidiary Carding Actions

Doffer comb (or fly comb)

Doffer rollers in the middle of a card section normally have the web removed by an angle-stripper roller using a point to back stripping action; the angle-stripper is in turn stripped by the point to back action of the following swift.

The doffer comb is widely used for removing the web of fibres from the last doffer roller on worsted or cotton cards, and from the last doffer roller of a woollen card section. The full-width doffer comb blade is set close to the doffer roller clothing and is reciprocated as shown in *Figure 4.11*. At each downward stroke of up to 40 mm, depending on fibre length, it pushes fibres down the back of the doffer pins; the web is then drawn away by the drawing-off rollers. The circumferential movement of the doffer roller should not exceed about 12 mm per stroke of the comb, and as the speed of reciprocation is limited to about 3000 strokes/min, this limits the maximum doffer surface speed. This limitation has led to the replacement of the doffer comb by draw-off rollers where high speed carding can be applied. A doffer comb may be seen in *Plate 4*.

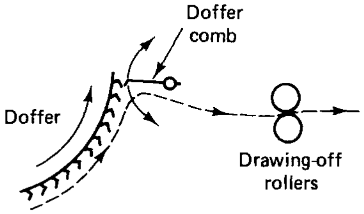


Figure 4.11 Doffer comb removes fibres from the doffer roller

Doffer draw-off rollers

This arrangement is now widely used in high speed cotton carding and on some woollen and semi-worsted cards instead of a doffer comb.

The fibres, which are already held near the tips of the doffer pins may be completely removed by the draw-off roller which may be one of three types:

(1) A wire clothed roller intersecting the doffer clothing up to about 2mm and removing the fibres from the backs of the doffer roller pins with a back to back action *(Figure 4.12)*; this arrangement may be used in woollen carding.

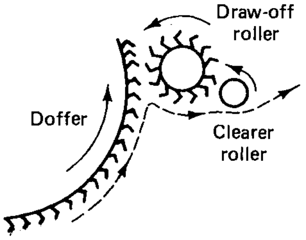


Figure 4.12 Back to back: draw-off roller used as an alternative to the doffer comb

(2) Using flexible straight or rigid wire as shown in *Figure 4.13(a)* and *(b)* respectively, which illustrate arrangements which might be used on cotton cards. The web is then taken away by a pair of smooth rollers.

(3) An alternative arrangement is to use a single fluted draw-off roller in contact with a spring-loaded blade *(Figure 4.14)*; this might be used on a semi-worsted card processing relatively long fibres.

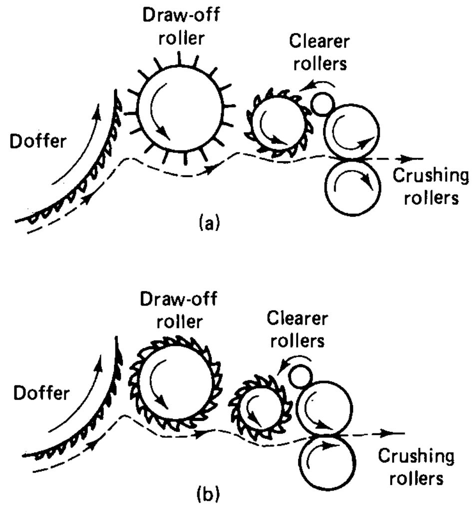


Figure 4.13 (a) flexible wire draw-off roller as may be used in cotton carding (b) rigid wire draw-off roller as may be used in cotton carding

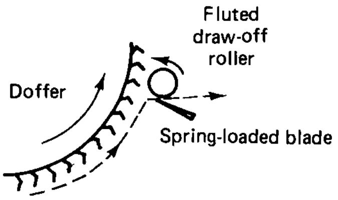


Figure 4.14 Fluted draw-off roller and blade as may be used in semi-worsted carding

Elimination of the reciprocating doffer comb reduces the number of leading hook fibres in the delivered sliver.

Funnel and calender rollers

On a card where the product is delivered in sliver form, the full-width web from the doffer is condensed into a sliver by being passed through a funnel and a pair of pressure rollers, called calender rollers, running at a slightly higher surface speed than the doffer. The plan views of a centre-draw and a side-draw arrangement are shown in *Figure 4.15 (a)* and *(b)* respectively. In this zone the fibres are under minimal control and are subjected to differential drafts ranging from a minimum along the axis of the carding machine to a maximum at the more inclined web edge; under these conditions fibres are likely to change their configuration, which may involve both hook formation and removal. The effect will be less with the centre-draw *(a)* than with the side-draw *(b)* arrangement which tends to produce ragged side edges, but which is useful when short fibres with little cohesion are being processed.

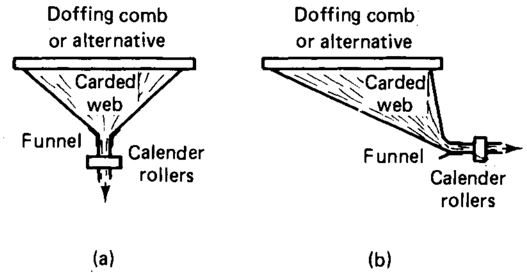


Figure 4.15 Funnels and calender rollers: (a) centre draw; (b) side draw

Brush rollers

These are used in worsted carding to push fibres down into the pins of a roller in preparation for burr removal. In the traditional English application the brush is driven by surface contact with the associated roller *(Figure 4.16(a))*. A light contact is maintained between the brush and the preceeding roller to take any stray fibres from the brush. The traditional Continental card application involves a positively driven brush which is used to strip fibres from the breast roller and transfer them to the following roller as shown in *Figure 4.16(b)*.

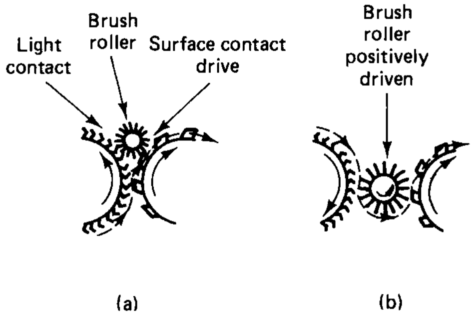


Figure 4.16 Brush rollers

Burr beaters

These rollers are used in wool carding and have up to 32 projecting steel blades which are set close to the tips of the card roller clothing, and moving at a high surface speed of up to 400 m/min in the opposite direction to the card roller surface movement. They are most effective during the early stages of carding before the burrs have the opportunity to open out, and when used in conjunction with Morel rigid wire card clothing with flat-topped teeth. The wool fibres lie below the surface due to the prior action of a brush roller or a tightener, and so the projecting burrs are removed into the burr tray by a sharp blow from the beater *(Figure 4.17)*. Inevitably some attached fibres will adhere to the burrs which are removed.

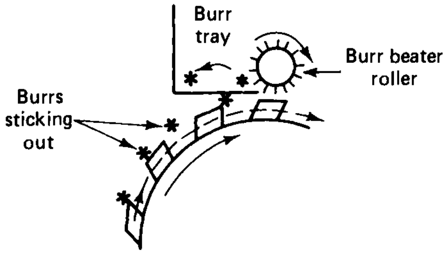


Figure 4.17 Burr beating

Crushing rollers

This principle is widely used in the Crosrol system for cotton and the Peralta system for woollen carding. The fine web of opened fibres is passed between positively driven precision-ground hardened steel rollers under high pressure. Large particles of foreign matter (such as seed particles in cotton, and burrs, threads, and skin particles in woollen) are crushed and broken into small fragments which are more easily removed subsequently whereas the fibres in the thin web remain undamaged; this results in the ultimate yarn being stronger and more uniform.

A similar method, known as the Harmel system, has been tried on the worsted system, but it was found that some of the small particles of vegetable matter tended to remain in the top after combing and this was not acceptable.

Burnishing rollers

In woollen carding where an intersecting draw-off roller is used to remove the web from the flexible-clothed doffer, a plain steel burnishing roller may be run in light contact with the tips of the doffer pins (*Figure 4.18*). The purpose of this is to prevent the intersecting draw-off roller pins from causing the formation of needle points on the tips of the doffer clothing.

Occasionally when a card is being fettled, the fancy rollers may be burnished by a back to back contact with a long-wire clothed roller — this cleans the fancy, but leaves its pins smooth.

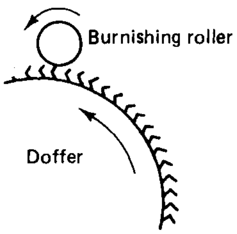


Figure 4.18 Burnishing

In cotton carding, burnishing of the flats is sometimes used to remove impurities from them; in this case burnishing provides a remedy for faults which would be better avoided in the first place.

Pressure-point dust extraction

Cotton cards are enclosed and therefore develop local areas of high pressure. Air is extracted at these points via ducting to remove dust particles. The pressure points are over the takerin roller, between the flats at the rear of the card, and between the swift and doffer.

Carding routines

Fettling

This consists of the removal of dirt, vegetable matter and fibrous debris from the base of flexible clothing pins; it is often called stripping in the cotton carding industry.

Fettling may be necessary either to prevent contamination when changing from one blend to another (this is particularly important when coloured fibres are being carded — which frequently applies in woollen carding) or to clean out the debris which has accumulated after a period of continuous processing.

A large build-up at the base of the pins leads to a deterioration of carding quality — a symptom of which is increased nep formation.

After the card has been 'run off' by running without feed to clear fibres from the rollers, hand cards, called fettling boards or jacks, are used with a point to back action on the stationary rollers to remove the accumulated impurities. With flexible card clothing worsted card fettling may be necessary after 40 to 80 hours of production, and it may take up to $1\frac{1}{2}$ to 2 hours to complete. Woollen card fettling may be necessary at 10 to 100 hour intervals if the full card is to be fettled, but it is more usual to fettle only one card section at a time, when each part-fettle may take about 30 min. This procedure is adopted in order to minimize any variations in yarn count which might ensue. In either case the productive efficiency of the process may be reduced by about 2.5% to 5.0%. For some fibres pneumatic fettling can be used with advantage.

In cotton carding a curved flexible wire clothed roller may be used to remove embedded particles of trash periodically while the card is running; travelling suction devices may also be used. Unaided hand fettling of flexible clothed cards used to be needed at intervals of up to about 4 production hours. Using a continuous fettling device increases the intervals to about 24 or 40 hours. On high production cards with rigid metallic wire card clothing, fettling may only be needed at intervals of up to 600 production hours.

After fettling it is usual to allow a wool card to 'run-on' for from 10 to 20 minutes until the thickness of the delivered sliver has increased sufficiently before resuming normal production — the lightweight sliver produced during run-on being put back into the hopper. This is because after fettling, an accumulation of fibres into the clothing of the cleaned rollers occurs which is rapid for up to 3 running hours on a wool card, and up to almost 30 minutes on a cotton card; it then continues at a slower, approximately constant rate. The actual rate of accumulation is influenced by factors such as the dirt and oil content, the fibre length and type of material being processed, the atmospheric humidity, as well as machine factors such as the efficiency of the fancy and doffer rollers; coarser card clothing retains fewer fibres, and an angle of pin inclination of 65° for the swift and 57° for the doffer seem to give better results than higher angles in the case of wool. It has been shown that if the equilibrium of feed and delivery is disturbed, a wool card tends to retain longer or finer fibres, hence blends of different colours and fibre dimensions may exhibit changes of shade after fettling or if the hopper delivers irregular weighs.

Cotton cards have been shown to exhibit percentages of blend components in the fettlings from the swift, the flats, and the doffer which differ from the percentages in the card sliver produced.

Woollen fettlings have been found to contain higher percentages of oil and dirt than are found in the original blend, the percentages increasing with prolonged running time between the fettlings.

Fibre separation into layers on the card roller has been observed when carding animal fibres which contain widely differing fibre groups such as mohair and kemp from the Angora goat. This is caused by the combined influence of air currents and centrifugal acceleration on the fibres of widely different mass and diameter. In this example a preponderance of kemp is found nearest to the swift surface. This principle, which can be used to facilitate fibre separation, can be applied to other 'double coat' animal fibres such as cashmere, camel, llama, and karakul.

Rigid metallic wire card clothing rarely needs fettling and this is an important factor accounting for its increased popularity in recent years. When necessary a 'running fettle' may be given in which the roller is rotated with backs leading at a high speed while a fettling board of the same pitch as the roller is held against it in a point to back position, gradually traversing from one side of the roller to the other according to the helix angle of the card wire.

Card grinding

The object of grinding flexible wire clothing is to ensure that the wire points have a suitable angle, shape, and surface contour to exert the maximum gripping power on the fibres to be carded. Grinding also ensures that the clothed rollers are concentric at the tips of the pins.

The need for grinding is frequently foreshadowed by a deterioration in carded web quality, including an increase in nep content.

During grinding the card roller rotates with backs leading in light contact with an emery covered roller which has its surface running in the opposite direction at a surface speed from 250 to 500 m/min. The grinding roller shaft should be mounted in the same horizontal plane and parallel to the card roller shaft. Large rollers are ground in situ, but small rollers are removed from the carding machine and mounted in a separate grinding grame. Grinding rollers may be either the full width type, or the narrow traversing type, up to about 100 mm wide. The traverse wheel grinder gives equal treatment across the width of the card roller, ensuring greater accuracy and permitting closer settings, on the other hand it takes much longer to produce the same effect as a full width grinder. In wool carding, grinding reduces nep formation, increases mean fibre length, and increases the collecting power of card rollers; cotton carding quality is also improved by grinding.

Grinding, which is always preceeded by fettling, is carried out at intervals of 200 to 300 hours for cotton and up to 500 hours of production in worsted carding. A worsted card may be out of production for about 6 hours if each small roller is ground for about 1 hour, and the large ones for longer.

It is unusual for fancy wire to be ground, although it may be burnished with a wire brush.

In the case of wool, rigid metallic wire card clothing rarely needs grinding apart from when it is newly mounted on the rollers to ensure concentricity but for cotton carding grinding would be at not less than 6 monthly intervals for 3-shift running. Not more than 0.75 mm should be removed by regrinding from teeth originally 3.5 mm high because the lower part of the tooth is softer metal.

Apart from accidental damage, flexible wire clothing may last 10 years or more depending on production rates and the types of fibre processed, in spite of the regular grinding to which it is subjected; rigid metallic wire clothing may last about four times as long.

Card setting

This consists of adjusting the position of adjacent rollers to give the required distance between the tips of the card clothing pins, and is necessary when changing to a different type or quality of material, and after grinding.

With rigid metallic wire clothing where routine grinding is virtually eliminated, cards may be re-set after about 4000 hours of production.

The gap between the rollers is measured using one of a set of large feeler gauges, or a tapered feeler gauge.

The Shirley flat setting gauge was developed to enable more precise setting of the flats on a cotton card by using a dial gauge to eliminate the subjective judgement associated with feeler gauges.

The settings used depend on the type of material being processed, the carding action, and the position on the card, as well as on the type of card clothing; rigid metallic wire card clothing can be set closer than flexible wire clothing. In general settings are proportional to fibre thickness.

For wools ranging from merino to coarse crossbred, stripping actions are normally set close (400 to 600 μm) unless clearance has to be allowed for impurities at the beginning of the card, but on a woollen card the strippers may be set to touch the workers. Working actions are usually set wide at the feed end (4000 to 5000 μm), becoming progressively closer towards the delivery end of the card where they are about the same as doffer settings (300 to 400 μm). Too open a setting may cause material to roll — leading to nep formation, and too close a setting may cause excessive fibre breakage. The collecting power of a worker increases exponentially as closer settings are used.

Progressively closer settings are usually used in cotton carding as the material approaches the doffer. The settings used normally fall within the following range: feed plate/takerin 250 to 350 μm, stripping 125 to 250 μm, flats/swift 180 to 250 μm, and doffer/swift 125 μm. Each flat is set closer to the swift at its edge nearer to the doffer — this is known as a 'heel and toe' setting and is intended to provide gradual opening.

To check the setting of a fancy roller, chalk may be applied to the swift, and then the fancy is rotated by hand to brush off some of the chalk. If the width of the brushed-off area is not equal across the swift, it indicates that the depth of intersection of the fancy is not constant.

Carding faults

Faulty carding can arise from damaged or inadequately ground card clothing and incorrect settings. An increase in the nep content of the delivered material often indicates the need for relevant maintenance.

Inappropriate setting of burr-beaters and crushing rollers may give a rise in the vegetable content in the delivery.

In worsted and in combed cotton processing, bad carding will usually cause an increased noil extraction in subsequent combing and may also lead to a shorter mean fibre length in the yarn produced, even though the combing process will remove neps, vegetable matter, and fibre entanglements.

Any attempt to increase the carding production rate by adopting an excessive rate of fibre feed to the card will lead to a deterioration in the carded product.

In woollen processing, carding faults usually lead directly to yarn faults; these are discussed later in the woollen carding section.

The arrangement of rollers on a wool card

The basic arrangement of rollers on one 'part' of a woollen or a worsted card is shown in *Figure 4.19*, although the actual number of workers and strippers may differ. Fibres are subjected to working actions between the swift and each respective worker. Stripping actions take place between each worker/stripper and each stripper/swift interface.

The proportion of fibres collected by a worker is called the 'collecting power', and is usually expressed as a percentage.

Given the same settings between a swift and each of its workers, the collecting power of each succeeding worker is less than that of its predecessors. However, the worker collecting power can be increased as the worker is set closer to the swift giving better nep removal and hence a closer setting of each subsequent worker to the swift compared with the previous worker can help to equalize the collecting power of each worker. Within limits the worker collecting power increases considerably as the worker speed is raised. On the other hand the

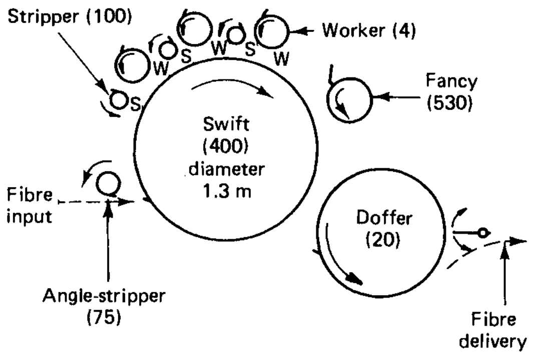


Figure 4.19 Basic arrangements of rollers on a wool card. Figures in brackets represent surface speeds in m/min

fibres are then returned to the swift at closer intervals which may reduce the mixing effect. Slower worker speeds are associated with increased mixing power and the mixing power of the part should be better if the equally-spaced workers are run at different surface speeds. Increased mixing power is associated with better product levelness.

The collecting power of workers can range from 60% on the first worker to 30% on the last worker on a swift, and lower collecting power has been found to be associated with shorter fibre length.

A greater worker collecting power will increase the delay factor, that is the average length of time which is spent by a fibre after being fed on to a swift until it is removed by the doffer. Increased doffer collecting power will reduce the delay factor and hence the mixing power. Delay factor can also be determined for a combination of swifts; for a two-swift combination delay factors range from 80 to 150 seconds.

The paths of fibres passing through a card part can vary from the extreme of a single passage from feed to doffer without passing round any workers, to a complex path leading round each worker a large number of times, and repeat passages underneath the swift before doffing finally takes place.

Under normal conditions the directions of rotation are as shown in *Figure 4.19*, but reversal of both the workers and the doffers may be used for shoddy on a woollen card, and reversal of the doffer may be used in worsted carding for slippery animal fibres such as mohair.

In modern wool carding with rigid metallic wire clothing the formation of neps at high rates of production is minimized by: ensuring roller concentricity to permit accurate and close settings; sharp wire (especially on doffers and workers); the inclusion of a fancy roller; and as high a doffer speed as is possible.

Worsted carding

Worsted cards frequently have at least two 'parts' of the type shown in *Figure 4.19*, and they may have further additional rollers.

The web of fibres delivered by the first doffer of a worsted card usually is conveyed to the following swift by using an angle stripper roller which strips the fibres from the first doffer, and in turn is stripped by the second swift. In this way the flow of partially parallelized fibres is not interrupted.

The fibres on a worsted card are normally removed from the second (and usually last) doffer by a doffing comb before they pass through a funnel and calender rollers to form a card sliver.

The sliver from a worsted card may be delivered either into a large coiler can, as described in Chapter 8 and shown in *Plate 4*, or alternatively a battery of

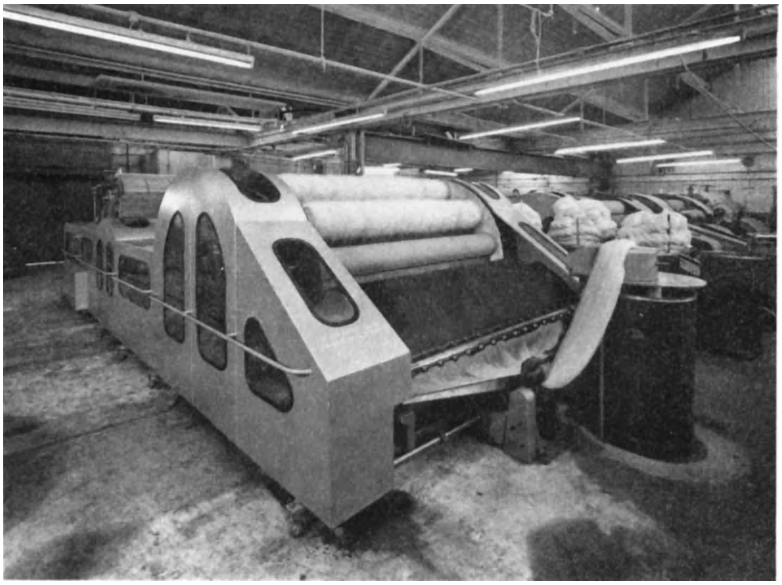


Plate 4. Worsted carding machine. This view clearly shows the worker rollers surrounded by fibres and the doffer roller in the foreground, with the doffing comb removing the web of fibres which is then conveyed through the drawing-off rollers and via the coiler head to the can delivery. All the rollers have rigid metallic wire except for feed rollers and brushes. The working width is 2.44 m, with overall width and length 2.97 m and 10 m, respectively, including the hopper feed and can delivery. A machine of this type can achieve a production rate of up to 300 kg/h when processing 100% wool. Courtesy of Haigh-Chadwick Ltd

cards may have their slivers carried by a transverse conveyor direct to the back rollers of the first intermediate gill box.

Semi-worsted carding

The carding and combing of man-made fibres is rarely used on the worsted system because tow-to-sliver converters provide a better alternative. On the other hand semi-worsted yarns may be produced by carding and gilling followed by ring spinning to counts in the region of 100 to 300 tex for upholstery and carpet pile yarns; in this case the process of combing is omitted.

For this purpose fibres from 9 to 16.5 dtex with a mean fibre length of 100 mm or 150 mm are usually used; the mean fibre length should not be less than about 65 mm, and grease content must not exceed 1% because rigid metallic card clothing is used. These limitations restrict the range of wools which can be processed on the semi-worsted system.

Long runs of spun-dyed or stock-dyed fibres are usually processed, and because rigid metallic wire clothing is used, fettling is not normally required when changing to a different shade.

A semi-worsted card normally has only one swift with four or five sets of workers and strippers, and usually twin doffers to facilitate a high production rate.

The semi-worsted process may also be used for hand knitting yarns.

Woollen carding

In the woollen section of the industry there is a greater variation in both the range of materials processed and in the end-use for the yarns produced compared with the worsted section of the industry; consequently a wider range of woollen carding machines is available to cope with this greater variety.

A woollen card may consist of three sections: the scribbler; the intermediate section; and the carder section as represented in schematic form in *Figure 4.20*. Sometimes the intermediate section may be omitted, making a two-section card, as shown in *Plate 5*.

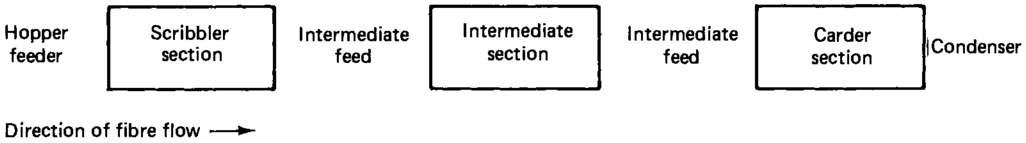


Figure 4.20 Schematic diagram of a woollen card

Plate 5. Semi-continental woollen carding machine. The double hopper in the foreground is designed to give accurate weighings at a high production rate. The card has two sections: a two-part scribbler; and a two-part carder. The condenser is at the far end of the machine. The working width is 2.44 m, overall width is 2.97 m, and the overall length is about 23 m including the hopper feed and the condenser delivery. When producing a slubbing from 200 to 500 tex from an 80/20 wool/nylon blend for carpet yarns, the production rate is about 300 to 350 kg/h. Courtesy of Haigh-Chadwick Ltd

Each section may include one or more 'parts': e.g. a three-part scribbler would have three swifts and their associated rollers, with each part in the section linked to the adjacent part/s by an angle-stripper. In this way a range of carding machines can be produced which vary in the number of sections and in the number of parts per section.

Between each section of a woollen card there is an intermediate feed to convey the fibres from the back doffer, i.e. the last doffer of a section, to the feed rollers of the following section; after the last doffer of the carder section there is a condenser delivery.

The purpose of having sections linked by intermediate feeds is to improve the mixing power of the machine and to reduce variation both along and across the card web, thereby improving the product levelness.

Intermediate feeds may be of either the intermittent or the continuous type. Intermittent types produce a series of packages in sequence which are then fed simultaneously to the following section. Continuous types, which are more popular because of their lower labour requirement, convey an unbroken web or a sliver to the following section in such a way that an effect similar to that obtained by using doublings is achieved without interrupting the continuous flow of fibres.

Intermediate feeds may feed the fibres perpendicular, parallel, or at an intermediate angle, to the axis of the feed rollers which they are about to enter; these types of intermediate feed are known respectively as straight, cross, or diagonal, fibre feeds. Whichever type of feed is used, the fibres rapidly become aligned generally in the direction of movement after passing through the feed rollers of the following section.

The condenser delivery represents the last operation before spinning. The purpose of the condenser is to divide the carded web into flat ribbons of uniform width, to rub them thereby forming soft twistless slubbing, and to wind the slubbing on to a condenser bobbin ready for spinning.

The tape condenser is the most widely used type; the basic principles are represented in *Figure 4.21*. The web of fibres from the back doffer of the carder section passes between a pair of grooved taking-in rollers so that the web is divided into narrow strips by the upper tapes passing downwards between the lower tapes, and vice-versa. Each narrow strip of fibres is then conveyed by its tape to a pair of reciprocating rubbing aprons which are similar in principle to the aprons indicated at B in *Figure 8.3*; tandem rubbing aprons may be used when additional rubbing is needed.

There is a limit to the maximum transverse speed of the aprons, and frequently it is this factor which limits the production rate of a woollen card.

Each pair of rubbing aprons delivers a slubbing with a round cross-section to a condenser bobbin which is supported and rotated by contact with a positively driven surface drum.

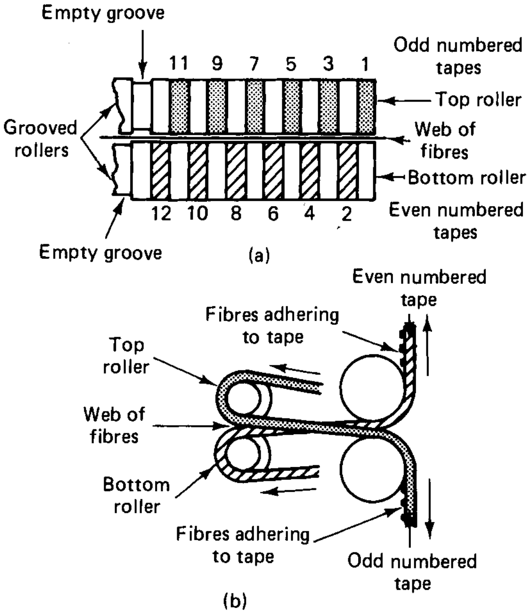


Figure 4.21 Basic principles of tape condenser: (a) front elevation; (b) side elevation

At each side of the doffer, the web is thinner than the rest of the web and so it is standard practice to discard about two or three ends at each side of the condenser and to return the fibres to the hopper via pneumatic ducting.

Each full condenser bobbin as shown in *Plate 6*, contains the required number of slubbings cross-wound next to each other, with a small space separating adjacent slubbings, with the distance between centres equal to the spindle pitch of the spinning machine which is to follow.

Carpet yarn production

In the production of carpet yarns up to about 320 tex, the production rate of a woollen card is closely related to the yarn count; for counts finer than about 280 tex, costs are increasingly unfavourable compared with semi-worsted processing.

Consequently for the finer carpet yarns, the semi-worsted system is preferred when fibre type permits, because high-production carding is possible regardless of yarn count.

However, many carpet wools are either too short or too variable in length for semi-worsted carding and they need to be lubricated for carding; consequently they are normally processed on the woollen system.

Plate 6. Six-tier twelve-drum tape condenser. The full condenser bobbins of the four lower tiers have been doffed and replaced by empty condenser bobbins which can be seen resting against the surface drums which drive them. The right-hand condenser bobbin next to the top is about to be doffed. This condenser is 2.5 m wide and delivers 144 slubbings from the 1.5 m working width card which is feeding it. Production rates vary widely according to the type of material and the slubbing count delivered. For example, when producing slubbings of 50 to 125 tex from 100% Shetland or a blend with man-made fibre, the output would be from 10 to 50 kg/h. Courtesy ofHaigh-Chadwick Ltd

In general woollen-spun carpet yarns are weaker and more irregular than semi-worsted yarns, hence the latter are preferred for tufted carpet production, leaving woollen-spun yarns to be used in woven carpets.

Woollen carpet yarns are usually processed as undyed fibre, which reduces fettling requirements when small lots are processed; for multi-coloured woven patterns small lots are yarn dyed.

Woollen carding and condensing faults

Because of the brevity of the woollen system, faults in the product of the carding process are likely to form yarn faults; the spinning process involves very little relative fibre movement, hence the saying: "the standard of a woollen yarn is determined at the carding process".

Insufficient burr beating and crushing can give rise to the presence of vegetable matter and thread waste in woollen yarns and the presence of neps may also be apparent if carding is inadequate.

Woollen slubbing count variation may be divided into two distinct groups: variation *along* the individual threads, and variations *between* threads across the width of the condenser.

Medium and long term count variation along woollen yarns normally can be traced to the carding process. Most of the variations along the slubbings are of a random form and they arise out of the nature of the carding process itself. As might be expected, the causes which introduce variations *along* the slubbing operate across the full width of the card, and simultaneously affect all the threads of slubbing being produced.

It is rare for periodic slubbing variations to be caused, but possible causes of such faults are described below:

> Periodic yarn faults repeating at intervals greater than about 50 m might be caused at the hopper or at the carder feed sheet, whereas faults repeating over lengths of about 6.5 m or less probably would arise in the last part of the carder section. Some periodic faults repeating at intervals from about 4.5 m to 9.0 m might be traced to an incorrect setting of an intermediate feed.

The rate of change of count along a yarn gives a clue as to where on the card the fault has been caused; sudden changes indicate a fault near the output, and very gradual changes suggest faults at the hopper or scribbler section, although a gradual drift in yarn count can be caused by fibre retention in the card clothing after fettling, by changes of regain, and by changes of condenser bobbin winding-on tension as the bobbin fills.

Variations between different threads *across* the width of the card may be due to three main groups of causes:

(1) Uneven fibre distribution across the doffer web. This may be caused by a faulty intermediate feed, by air currents, or by non-parallel setting of card rollers.

(2) Individual condenser tape differences, arising from variations in tape tension, effective width, or surface properties.

(3) Variation between the mean count on different condenser bobbins. Differences of this kind may be caused by differences either of tension between whole banks of tapes, or the surface speed of the rubbing aprons or condenser surface drums.

Variation between the mean count of yarns spun from different condenser bobbins can also arise at the spinning process itself because of differences between the tension of the slubbings being fed to the drafting zone of the spinning machine.

The arrangement of a cotton card

The basic arrangement of a cotton card is shown in *Figure 4.22*. Fibres are subjected to intensive opening between the feed roller and the takerin, and between the stationary combing bar and the takerin. Of all the trash held in the cotton fed to the card, about half is removed at the takerin section. Maximum cleaning at the takerin is required in order to minimize the amount of waste which is retained by the flats and removed from them by the flat doffing comb. Higher takerin speeds give better cleaning efficiency but excessive speeds may cause fibre damage. In practice takerin surface speeds rarely exceed 760 m/min.

Fibres are transferred in a fine uniform flow from the takerin to the swift by a point to back stripping action. At this point the fibres then become almost airborne and are flung into the pins of each flat prior to it moving into a working position. An interchange of the projecting fibres takes place between the flats and the swift; short fibres, neps, and trash will tend to remain in the flat clothing. The fibres and trash particles retained by the flats are removed by the flat doffing comb and cleaning brush. The proportion of short fibres, neps and trash is higher in the flat fettlings than it is in the fibres fed to the card, although about two-thirds of the flat fettlings comprise good length fibres. Higher flat speeds may be used if more trash and nep is to be extracted, but the minimum satisfactory speed is used in practice to minimize the amount of waste extracted.

In the early 1980s English Card Clothing introduced their XL system for cotton carding, which consists of using stationary flats with rigid metallic card clothing in addition to the conventional revolving flats. The XLR system usually consists of two card flats mounted between the takerin and the revolving flats, and working in conjunction with the swift. This gives further opening prior to the revolving flats and thereby improves their performance. An alternative arrangement, the XLX system, consists of from 2 to 5 stationary flats working in conjunction with the swift, and mounted between the revolving flats and the doffer. This improves fibre transfer from swift to doffer, and thereby leads to an improved yarn quality.

The fibres retained by the swift are transferred to the doffer and in turn are removed from there by the doffing comb or a doffer draw-off roller arrangement. Crushing rollers are usually employed to pulverize any remaining trash particles *(Figure 4.13)* before the fibres are delivered into a large can with a capacity for up to 60 kg of sliver.

Tandem cotton cards (i.e. with two swifts) are increasingly used when better cleaning is required. They are recommended when slivers are being prepared for open-end spinning; frequently the second swift has a stationary-top (described below) mounted over it instead of slowly revolving flats. A tandem card of this type is shown in *Plate 7*.

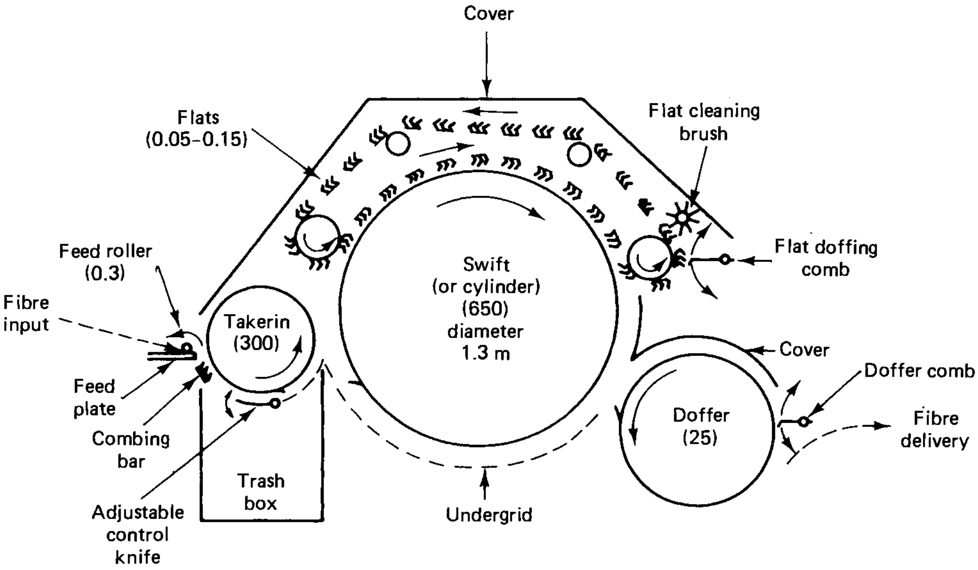


Figure 4.22 Basic arrangement of a cotton card with revolving flats. Figures in brackets represent surface speeds in m/min

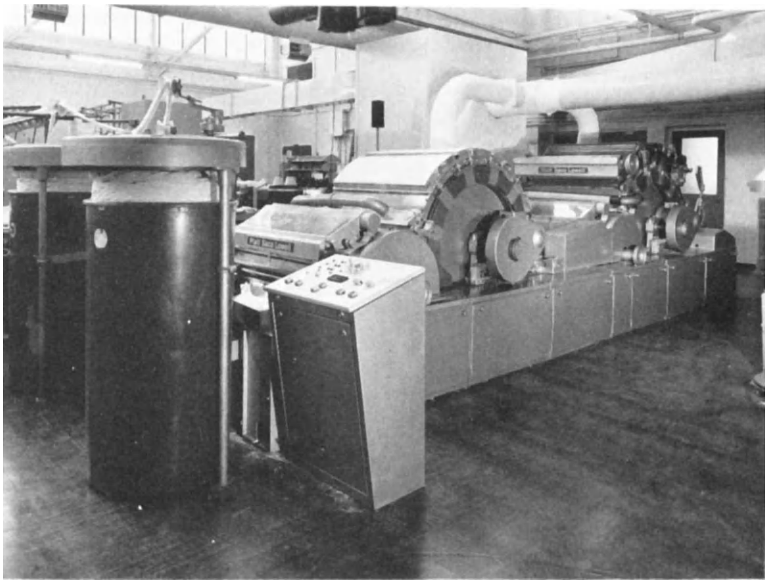


Plate 7. Tandem cotton card. The fibres enter the card at the far end. The first cylinder (or breaker card) at the far end of the machine has revolving flats with a flat doffing comb. The second cylinder (or finisher card) has a stationary top working surface. The fibre web is removed from the doffer by a draw-off roller and divided to form two slivers which are each conveyed to a hypocycloid coiler head mounted above its respective stationary can. Production rates may be up to 70 or 90 kg/h for cotton or man-made fibre, respectively. The working width is 1 m. Overall width is 1.83 m and the overall length is 6.49 m plus the can delivery. Any combination of revolving flats or stationary top can be supplied to the two cylinders (swifts). Courtesy of Platt Saco Lowell (UK) Ltd

Carding short staple man-made fibre (MMF)

Tow-to-sliver conversion has not yet been developed and adopted on a large scale for short staple MMF processing. Consequently normally short staple MMF is delivered in bales to the spinning factory and an opening line is used, usually with only two beaters, to provide either laps, or opened fibre to chute feeds, for the carding machines which follow.

In the case of viscose a revolving flat card, as shown in *Figure 4.22* may be used, with the flats removing waste composed of faulty fibre and lumps of amalgamated fibre.

Polyester may be processed on stationary-top cards which do not extract any waste. Instead of slowly moving flats, there may be stationary segments with granular material on the inner surface which can be set very accurately to the swift surface; alternatively a stationary surface of card clothing can be used. Working takes place between the rigid metallic wire clothing on the swift and the stationary-top, which does not retain any fibre or waste.

The introduction of the XL system by English Card Clothing has provided aluminium flats clothed with 'HI-TECC' non-loading rigid metallic clothing. When no cleaning is required these may be mounted above the swift and used as revolving flats, as fixed flats, or on fixed segments. Additionally they may be used to provide a carding surface working in co-operation with virtually any other carding roller, such as the takerin, for example. This system enables very close and accurate settings, and progressive grading of pin concentration, card wire angles, etc.

A stationary-top may be used on the second swift of a tandem card when cotton is being processed, as shown in *Plate 7*.

Yarns made from 100% MMF are usually of the carded quality, but polyester/cotton blends are usually made from combed cotton and carded polyester, blended during drawing by three processes of drawframes using 6 or 8 doublings, which may be followed by bobbin lead roving and ring spinning.

Flax carding

Flax tow from processes such as scutching and hackling are passed through a carding process. The tow is finer and shorter from each succeeding process prior to carding. To cater for this variation three carding arrangements are possible:

(1) a breaker card and a separate finisher card for dirty matted scutching tow.
(2) a breaker-finisher card, or
(3) a finisher card for good hackling tow. The finisher card is the most common type in use.

Tow may consist of a combination of single ultimates and some fine bundles which have been stripped from the line fibres, fibre strands torn from the line more-or-less intact, plus dirt, and naps (i.e. neps) which have been formed in the earlier processes.

In addition to the general objectives of carding, the flax carding process aims to split the fibre bundles to form fine structures which can then be treated as fibres.

The roller arrangement of a flax breaker-finisher card is shown in *Figure 4.23*. This particular machine arrangement is described as a down-striking, seven-pair, full-circular card with double doffers. This means that the cylinder pins move downwards at the point of feed, there are seven sets of workers and strippers (in addition to the feed stripper), the full circumference of the cylinder is utilised, with the two doffers which are used to remove the fibres from the cylinder mounted above the feed point.

The tin rollers mounted with the first three sets of workers and strippers underneath the cylinder help the strippers to pick up long fibres which otherwise might be lost.

The web of fibres removed by each doffer is divided into three equal widths to form three slivers, each about 75 mm wide. The corresponding slivers from the top and bottom delivery rollers are combined and the three slivers thus formed are doubled to feed a roller drafting drawing head with a draft of about 2, before being delivered into a can as a single sliver of about 6 to 12 ktex.

Jute carding

In addition to the general objectives of carding, the jute carding process is intended to break the jute reeds into separate 'fibres'. The 'fibres' may be composed of single, branched, or intermeshed structures. Reduction of 'fibre' diameter can only be achieved at the cost of reduced 'fibre' length, and a point is reached at which a considerable length reduction would be the price paid for a modest reduction of diameter.

The 'fibre' length of a carded jute sliver is very variable, with a small number of long 'fibres', and a large number of short 'fibres'.

Usually two cards are used; a breaker card followed by a finisher card. Jute cards are described in a similar manner to that used for flax cards : up- or down-striking; number of pairs of workers and strippers; full- or half-circular; and number of doffers.

Breaker cards are usually down-striking and half-circular because bits of bark, stick, and small fibres fall down from the point of feed. The delivered sliver is usually about 60 to 90 ktex. About half of all the work done on jute 'fibre' to make it spinnable takes place at the breaker card. Spinnable jute

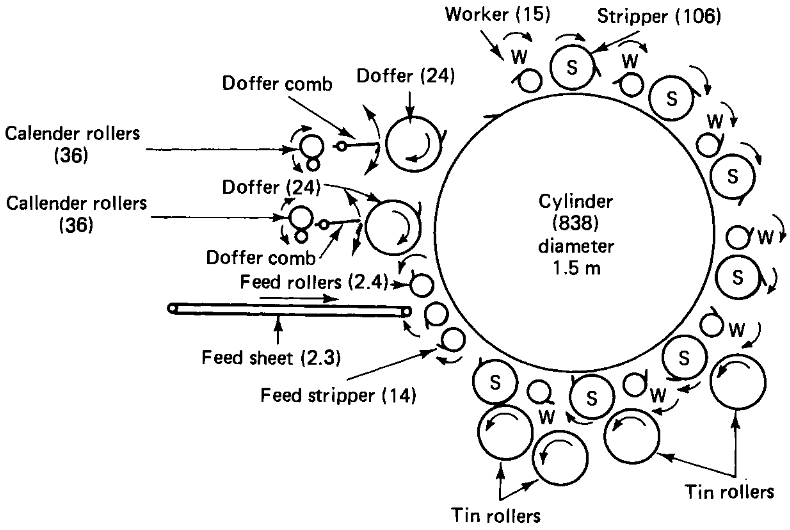


Figure 4.23 Roller arrangement on a porcupine-feed, down-striker, seven-pair, full-circular, double-doffer, flax breaker-finisher card. Figures in brackets represent surface speeds in m/min

'fibres' range from about 1 to 5 tex, with a mean of about 2 tex.

Finisher cards, as shown in *Plate 8* are usually downstriking and full-circular and deliver a sliver of about 90 ktex; the main function of the finisher card is to clean the 'fibre'.

The general roller arrangements of jute breaker and finisher cards are shown in *Figures 4.24* and *4.25*, respectively.

The Appendix flow charts indicate the position of carding in the sequence of operations used in the different systems of yarn manufacture.

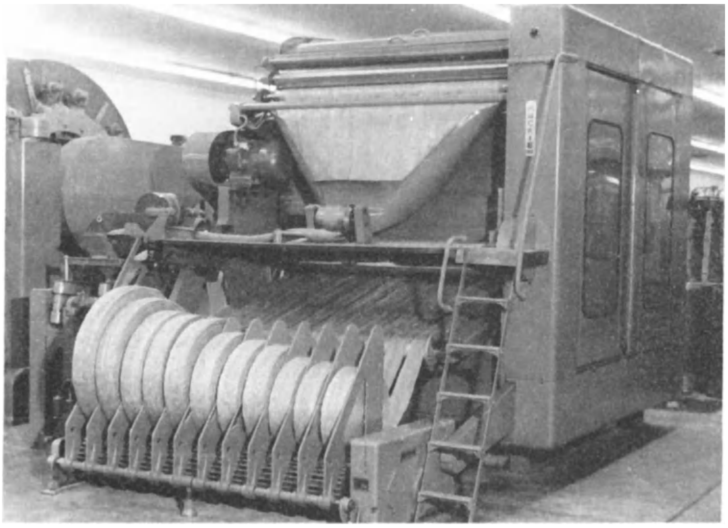


Plate 8. Jute finisher card. This is a full-circular card with a 1.5 m diameter cylinder (swift) which may have either four or five pairs of workers and strippers. The eleven rolls of fibre from the breaker card are fed in from the low feed creel. The delivered web of fibres passes down the conductor and is condensed through the central rollers and conveyed along the sliver plate to the roll former on the left-hand side of the machine. Production can be up to 200 kg/h at a delivery speed of 65 m/min. Courtesy of James Mackie & Sons Ltd

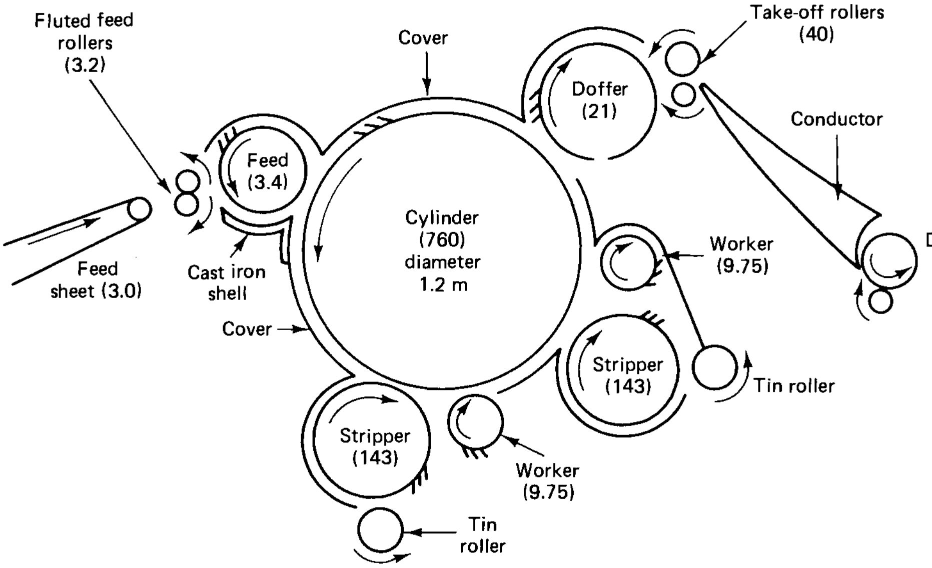


Figure 4.24 Roller arrangement on a shell feed, downstriker, two-pair, half-circular, single-doffer jute breaker card. Figures in brackets represent surface speeds in m/min

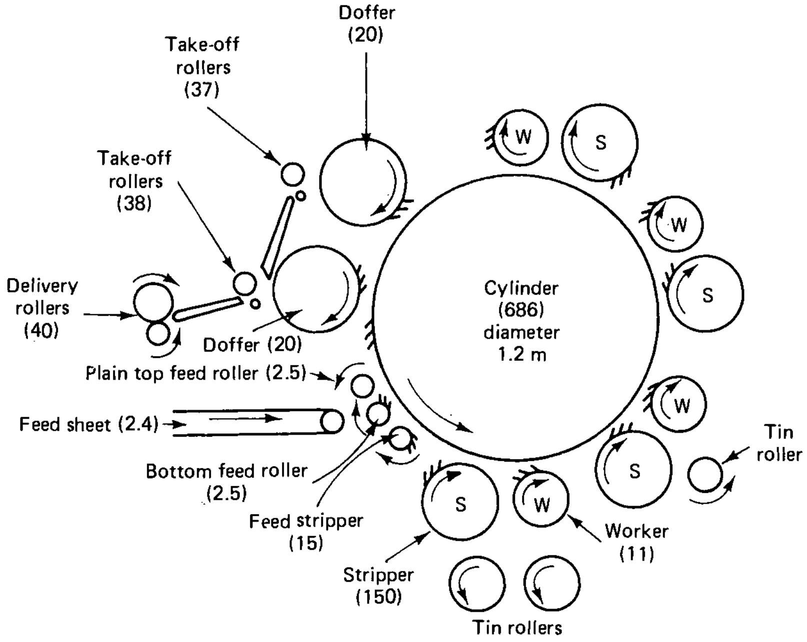


Figure 4.25 Roller arrangement on a pinned-and-plain feed, down striker four-pair, full-circular, double-doffer jute finisher card. The figures in brackets represent surface speeds in m/min

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5

ROLLER DRAFTING, DOUBLING, AND FIBRE CONTROL

In yarn manufacture successive operations involving the repeated use of drafts and doublings are widely employed to manipulate the strand of fibres until it is sufficiently thin and regular to form a satisfactory yarn. This method is used to convert card sliver into a form ready for combing or spinning, and to prepare comb sliver for spinning.

The machines used for drafting are frequently called 'boxes' or 'frames', e.g. cotton speed frames and drawframes or drawboxes, worsted gill boxes, and drawing boxes.

Although the basic principles may be the same, it seems inevitable that there should be different forms of drafting devices for different fibres at different stages of processing. The name 'frame' spinning was originally used for spinning machines which use roller drafting zones and spindles mounted in a stationary spindle rail to distinguish them from the mule method of drafting.

Draft

The use of draft, which was defined on page 2, gives a reduction of sliver thickness and also contributes to improved fibre orientation when processing card slivers.

Calculated and actual draft

Calculated draft D is obtained when the draft is determined from the dimensions of the machine parts, but the value arrived at when the calculation is based on the material being processed is called the actual draft D'. D' is usually less than the theoretical or calculated draft D because of differences in fibre cohesion, recoverable fibre crimp, and sliver elasticity due to fibre entanglement and disorientation. The ratio D'/D decreases with greater fibre entanglement in the feed sliver, and increases at higher drafts.

$$\text{Calculated draft, } D = \frac{\text{Front roller surface speed}}{\text{Back roller surface speed}}$$

$$\text{Actual draft, } D' = \frac{\text{Total input to the back rollers (ktex)}}{\text{Total delivery from the front rollers (ktex)}}$$

The D'/D ratio usually ranges from about 0.85 to 0.95, being lower when card sliver is processed at low drafts, and higher when more parallel fibred slivers are subjected to higher drafts.

The amount of draft employed in a particular situation depends on the design of the drafting zone, the fibre length distribution, the fibre extent, and the disposition of hooked fibres. Fibre extent is the distance between two planes perpendicular to the sliver axis which just enclose the fibre (*Figure. 5.1*); it may be expressed as a fraction or as a percentage of the straightened fibre length. As a general rule more draft may be applied to longer fibres, to fibres with a low coefficient of variation of fibre length, and when fibres have a majority of trailing hooks.

The general relationship between the irregularity of mass per unit length of a product, and the draft used to produce it is of the form shown in *Figure. 5.2*, where it can be seen that there is an optimum range of drafts for a given fibre or a given machine. This effect may be reflected in an optimum draft range for maximum yarn strength in spinning.

The use of higher drafts necessitates a higher standard of accuracy of machine construction and adjustment if yarn levelness is not to suffer; at spinning it permits the use of thicker rovings to be

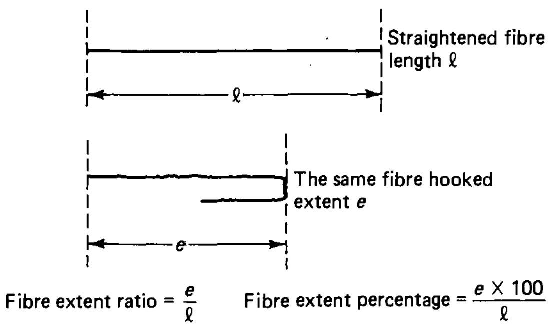

Figure 5.1 Fibre extent

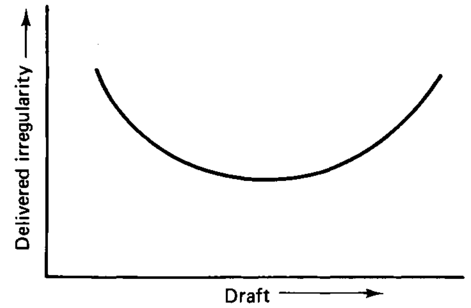

Figure 5.2 Relationship between draft and irregularity

fed in, thereby reducing the number of roving deliveries required to provide a given rate of production.

When the draft of a process is known, the delivered sliver thickness can be calculated from the known input sliver thickness:

$$\text{delivered sliver count} = \frac{\text{input sliver count}}{\text{draft}}$$

Doublings

The slivers fed together into a drafting zone are called doublings, as defined on page 3; in yarn manufacture it is correct to refer not only to two doublings, but also to three, four. . . , theoretically up to any number of doublings, although in practice there will be an upper limit imposed by the capacity of any given machine.

Under normal conditions in yarn manufacture each doubling is the same count as any of the other doublings being fed into a drafting zone.

The use of doublings serves three purposes:

(1) Reduced irregularity

In general, the coefficient of variation of count of the combined slivers is less than that of each individual sliver: $\mathrm{C.V._c = C.V._s\sqrt{}}D$ where $\mathrm{C.V._c}$ is the C.V.% of the combined slivers, $\mathrm{C.V._s}$ is the C.V.% of each individual sliver, and D is the number of doublings.

Doublings cannot be relied on to eliminate the effects of strictly periodic thickness variations, i.e. variations which repeat at regular intervals.

The short-term irregularity of a yarn is not greatly affected by the number of doublings used in the drawing processes which preceed spinning.

Although autolevelling has provided an alternative means of controlling irregularity, the use of doublings for this purpose is still important in most methods of yarn manufacture because present commercial methods of autolevelling do not correct short-term irregularities.

The use of repeated drawing operations, with doublings equal to drafts, leads to a certain sliver levelness which cannot be improved by further similar processing.

(2) Blending and mixing

The use of repeated drafting and doubling ensures that the end-product is a homogeneous mixture within the limits described in Chapter 3.

(3) Fibre alignment

The use of doublings necessitates a greater total draft product in order to obtain a given amount of reduction of sliver thickness; the higher total draft product applied to thicker slivers thereby contributes to better fibre paralellization and hook removal in uncombed slivers, which usually implies greater yarn strength and better yarn levelness.

Combination of drafts and doublings

There are three possible basic relationships:

doublings > draft
doublings = draft
doublings < draft

The first of these is only used where mixing is of prime importance. The second is used where mixing is important but an increased sliver thickness must be avoided — under this arrangement the delivered sliver is the same count as any one of the doublings fed into the drafting zone; hence repeated drafts may be applied to improve fibre alignment without a reduction of sliver thickness. The third arrangement is used to obtain a reduction of count, the rate of reduction being dependent on the ratio draft/doublings. This ratio is frequently increased towards the latter part of a drawing set immediately prior to spinning.

The ultimate irregularity of a drawn and spun yarn is largely determined by the opposing effects of drafts and doublings, and consists of a complex combination of all the variations introduced at each successive stage of processing; open-end yarns may be an exception to this statement.

The final result from any set of drawing, as far as product irregularity is concerned, is a compromise between the beneficial effects of doublings and the detrimental effects of the extra draft which doublings entail. This statement is still substantially correct even though autolevelling has reduced the dependence on doublings.

The drafting zone

Various theories have been advanced to account for the increase of product irregularity introduced by drafting due to the complexities of fibre movement in drafting zones. They have been largely influenced by the form of drafting zone studied, e.g. low draft and high draft, cotton and worsted, and consequently they have tended to emphasize different aspects of the same basic problem.

For a complete solution to many problems in drafting it is necessary to know the construction of a sliver in detail. What is required is the position of one end, say the right-hand end, and the length, of each individual fibre. Mathematically it is possible to express the sliver construction by an equation relating its thickness at any point to the end-densities of the fibres of different lengths at points along it. In practice it is possible only to measure the sliver thickness; so the equation relates one measurable quantity to two immeasurable quantities: the fibre-end density at each point, and the manner in which the fibre lengths are distributed throughout the sliver.

The description which follows outlines the common features which may be deduced from theoretical and experimental work.

The earliest drafting zones known were horizontal, presumably to ulilize gravitational forces on self-weighted rollers. Later when a twist-inserting delivery was to follow it became usual to have the drafting zone sloping downwards towards the delivery rollers at an angle of 30° or 45° from horizontal, and Ambler Superdraft spinning had an angle of about 80° in order to permit better twist penetration into the roller nip. Some machines have been introduced with vertical drafting; it is claimed that at high speeds it is easier to control fibres travelling vertically downwards; an example is shown in *Plate 9.*

Back and front rollers

The basic requirement for roller drafting consists of a pair of back rollers and a pair of front rollers. The bottom roller of each pair is positively driven by the shaft on which it is mounted and usually has a fluted surface, which on some machines may be helical, to improve its grip on the fibres and on the top roller without an excessive load being applied. A stationary pad held in contact with the bottom front roller collects stray fibres and dirt, which are known collectively as 'rubber waste'. The top roller may have flutes which intermesh with the bottom roller flutes or may have an apron passing round it or a compressible covering — usually made of a synthetic compound in which case the bottom roller may have 'hunting' flutes (i.e. irregularly spaced) to avoid ridging and soiling of the top roller surface.

Although the flutes produce some movement of the roller nip, the pitch of flutes is usually so small that it does not give rise to periodicity in the product; the heavy tooth-and-pinion flutes of the Bradford type gill box are an exception to this statement.

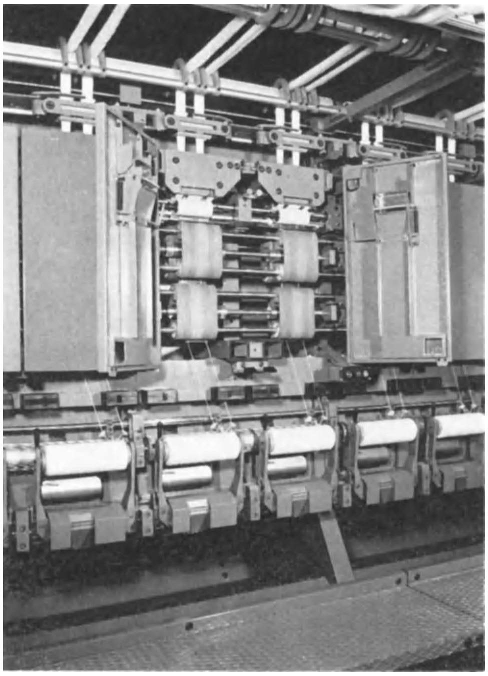

Plate 9. Vertical drafting zone with balling head delivery. The feed slivers pass round the creel rollers at the top and enter the back rollers of the drafting zone vertically downwards. Two of the doors which normally enclose the drafting and rubbing zones are open to reveal the white front press (equivalent to top) rollers of the drafting zone, beneath which can be seen a tandem set of rubbing aprons. These consolidate each pair of rovings before they pass down to the traverse guides to form double mêche roving bobbins near the bottom of the machine. The winding head provides a delivery speed of about 230 m/min with automatic doffing and replenishment. Courtesy of N. Schlumberger & Cie

The top roller of each pair rotates by virtue of its firm surface contact with the fibres and the respective bottom roller to provide a positive nip; devices such as self-weighting, additional weights, levers, springs, hydraulics, pneumatics or magnetics are used. On spinning frames loads up to about 200 N per pair of front rollers may be applied for high drafts, and up to about 350 N for superdraft spinning; the magnetic arrangement has the virtue of reducing the actual load applied to the bottom rollers and their bearings. Drawframes may use loads up to 2000 N on back rollers and 4000 N on front rollers, depending on fibre properties, draft, and count of sliver produced.

Beard fibres

In consequence the fibres held in the back roller nip theoretically enter the drafting zone at back roller surface speed and are known as back beard fibres. The fibres held in the front roller nip are called front beard fibres; they theoretically leave the drafting zone at front roller surface speed. Normally both these groups of fibres may be regarded as being under positive control.

In practice the nipping of the leading ends of fibres does not occur in a geometrically straight zone of zero width, but in a rectangular zone which is a few micrometres wide and equal in length to that of the drafting rollers, and which has a rapid horizontal vibratory movement of varying character with a maximum amplitude of several tens of micrometres. This has important implications regarding the irregularity of slivers.

Roller slip

In practice it is possible for fibre slippage to occur between intermediate rollers where a number of consecutive drafting zones are involved when it gives rise to wave-like irregularities; it may also arise between the front rollers and the front beard fibres. This is more likely when a high drafting force is necessary to pull the fibres apart. Such a situation arises when:

(1) processing thick slivers,
(2) processing card slivers where the lack or orientation increases inter-fibre cohesion,
(3) compact slivers are being processed,
(4) high drafts are used, and when
(5) fibres with high frictional properties are processed.

Roller slip may be avoided by modifying the amount of draft applied in a zone, by suitable design of fluted bottom rollers, and by applying higher roller pressures. With high drafts and the associated heavy loadings of up to 350 N per pair of spinning frame front rollers, the draft gearing systems must be arranged to give correct torque ratios and transmit the power required to drive the rollers.

Ratch

The distance between the nips of the back rollers and the front rollers is called the ratch, reach, or roller setting. Under normal conditions any fibres extending longer than the ratch will be held by both the back and front rollers at the same time, and therefore may be broken; hence ratch cannot be set much closer than the length of the longest fibres in cotton drafting depending on the fibre extent and orientation of the fibres, particularly with card sliver, and is usually set longer than the longest fibre which is not to be broken in worsted processing (*Figure.5.3*).

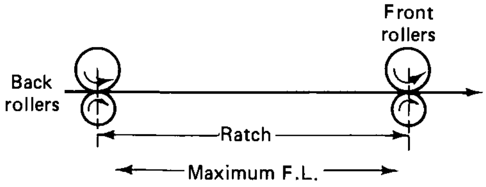

Figure 5.3 Ratch on an empty machine

If the ratch is set just too close, the front rollers may deliver small undrafted tufts of fibres; in cotton processing this effect is known as 'spewing'.

It may be necessary to increase the ratch when thicker fibre assemblies are processed because the roller pressure spreads out through the fibres to form an arc of contact rather than a nip point (*Figure.5.4*). Under such conditions the distance between the effective grips of the back and front rollers will be less than the ratch as measured on an empty machine.

Floating fibres

These fibres which lie between the back and front rollers, without being held in the nip of either of them, are not under positive control; for their

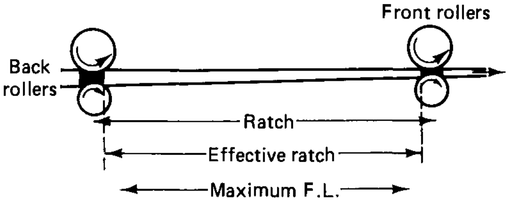

Figure 5.4 The influence of slivers on effective ratch

movement through the drafting zone they depend upon their chance contacts with each other and with other fibres.

A merino worsted sliver with a mean fibre length (MFL) of 68 mm and a maximum fibre length (Max.FL) of 150 mm may have about 60% of floating fibres when processed with a ratch of 150 mm. The thickness profile of such a sliver is shown in *Figure.5.5*.

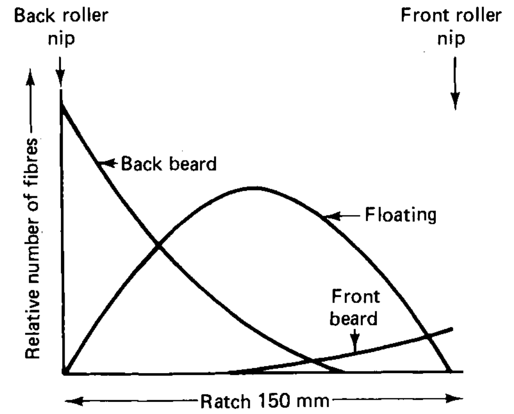

Figure 5.5 Fibre profile in a drafting zone

There may be from 33% to more than 80% of floating fibres in cotton spinning, and 75% in a Conventional Continental Worsted drawing box.

Because it is not possible positively to control the floating fibres it is inevitable that variations in the thickness of the delivered sliver will arise which is usually called either 'irregularity' or its reciprocal 'levelness'.

A greater *variation* of fibre length will lead to an increase in the number of floating fibres and a greater product irregularity hence the main problem in roller drafting is to develop some form of control over the short fibres. Better fibre control permits higher drafts and thereby reduces the number of operations required to provide a given reduction of sliver thickness. An increase of ratch will increase the proportion of floating fibres in a drafting zone, but this does not necessarily lead to greater irregularity in the product.

Factors involved in drafting theory

'Perfect' sliver levelness

A perfectly uniform sliver made from fibres of equal and uniform thickness would have exactly the same number of fibres in its cross-section at any point along its length. The production of such a hypothetical sliver would involve the control of each individual fibre. As millions of fibres are processed per minute during drafting, it is clear that individual fibre control would be a complex matter which in present circumstances would be uneconomic even if it were found to be possible.

Random fibre distribution

As individual fibre control is not practicable, the best fibre arrangement which can be hoped for is a perfectly random fibre distribution.

Because of the random manner in which fibres are handled by a carding machine, the card sliver contains fibres which have an equal chance of appearing in any cross-section of the sliver. In other words a card sliver is as near a random fibre distribution as can be achieved at such an early stage of processing.

The irregularity arising from a random distribution of identical fibres in a strand is described by the Poisson distribution, in which the variance equals the mean. If the average number of fibres per cross-section equals n which equals the variance, then

$$\text{C.V.}_n\% = \frac{\sqrt{n} \times 100}{n} = \frac{100}{\sqrt{n}}$$

where $\text{C.V.}_n\%$ = percentage coefficient of variation of n, and this applies whatever the fibre length characteristics may be. If all the fibres are identical in cross-sectional area and density then the above term for $\text{C.V.}_n\%$ is also equal to the coefficient of variation of cross-sectional area, and hence to the coefficient of variation of mass per unit length of a strand of fibres in yarn or sliver form. It frequently arises that fibres vary in cross-sectional area, and this fibre variation is an additional source of strand irregularity.

Hence

$$\text{C.V.}_a = \frac{100\sqrt{(1 + 0.0001\,V_A^2)}}{\sqrt{n}}$$

$$= \frac{100\sqrt{(1 + 0.0004\,V_D^2)}}{\sqrt{n}}$$

where C.V._a = C.V.% of strand cross-sectional area, V_A = C.V.% of fibre cross-sectional area, and V_D = C.V.% of fibre diameter.

These formulae give a value for the irregularity of a strand in which the fibres are randomly arranged and therefore they represent the limit of perfection beyond which no ordinary roller drafting machinery could improve even if it were free from all defects;

this is known as 'limit irregularity'. They have been simplifed for average fibre variation values to $\text{C.V.}_a = 112/\sqrt{n}$ for wool, and $106/\sqrt{n}$ for cotton. For unblended man-made fibre $\text{C.V.}_a \approx 102/\sqrt{n}$.

Hence one would expect slivers and yarns made from different fibre diameters, but with n equal, to have similar irregularities; this has been demonstrated over a wide range of wool qualities. As slivers become thinner and eventually reach the yarn stage, the irregularity due to the randomly arranged fibres becomes a greater proportion of the total short-term irregularity.

'Perfect' drafting

Given a random fibre distribution of fibre leading ends, the best that any roller drafting machinery can do is to preserve the original random fibre arrangement up to and including the spinning stage. Such an arrangement would involve 'perfect' drafting in which all fibres including floating fibres would move at the back roller surface speed until the leading end of each fibre was gripped by the nip of the front rollers and instantaneously accelerated to the front roller surface speed.

Under these conditions of complete fibre control the distance between any two fibre leading ends after drafting would equal the distance before drafting, multiplied by the draft. This is represented in idealized form in *Figure.5.6* which shows a draft of 3 being applied to only four 'streams' of fibres out of the many 'streams' present in the sliver; it is shown in a sequence from (*a*) to (*g*). If this could be achieved then the random distribution of the leading ends provided by the carding machine could be retained through to the spinning process. Even so, however many doublings were used, the ultimate yarn would inevitably contain considerable short term variation because of the preserved random fibre distribution.

In practice perfect drafting cannot be achieved. The probability that a fibre of a given length will have been accelerated increases as the leading end approaches the front roller nip; the shorter the fibre and the sooner it is likely to accelerate. Furthermore, fibres of the same length as each other may accelerate at different distances from the front roller nip which itself will probably be moving back and forth as mentioned previously under 'Back and Front Rollers', leading to the formation of fibre 'bundles'.

At any instant the velocity of an individual fibre in the drafting zone may range from back roller surface speed, through any intermediate velocity, and finally achieve front roller surface speed only when near to the nip of the front rollers; futhermore many fibres which do accelerate may be retarded subsequently and even return to back roller surface speed.

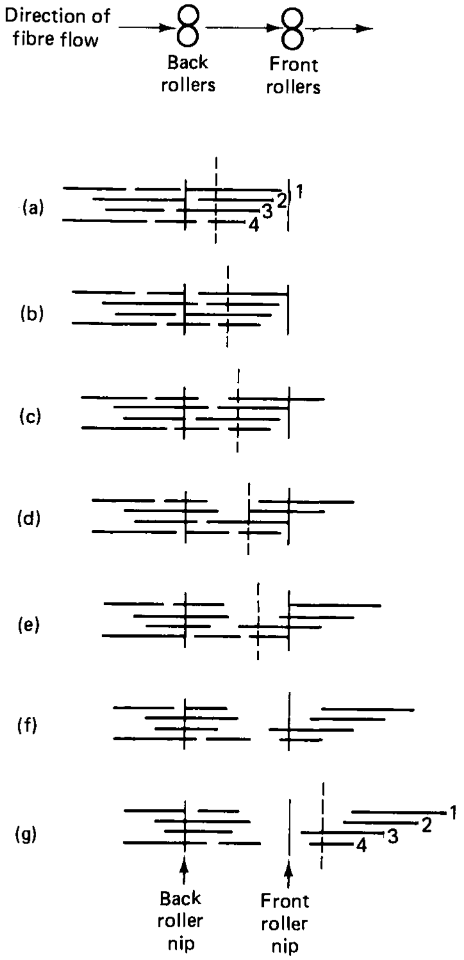

Figure 5.6 Idealized fibre movement during drafting

It seems, therefore, that whilst differences in the speed of individual fibres tend to make the slivers more random in fibre arrangement, a variation in the average speed of all the fibres — caused largely by fluctuations of the front beard length — produces the opposite effect.

Fibre end distribution

It is as well to recall that thickness variations of slivers are approximately equal to fibre end density variations only when variations between lengths l greater than about twice the length of the longest fibre are considered; for shorter values of l there is no simple relationship between the two different measures of irregularity of a given sliver. If the fibre leading ends have the same fibre length distribution throughout a sliver, and the density of those leading ends has a periodic variation, then the length distribution related to the fibre trailing ends is no longer uniform; there is a segregation whereby the trailing ends of long fibres are concentrated in regions of low fibre end density. Furthermore, short term variation of fibre end density which may not contribute appreciably to thickness variation of a sliver before drafting may have a large effect after drafting. This is shown in simplified form in *Figure.5.6* where in (*a*) the broken line passes through four fibres. In (*g*) the leading ends of fibres 1, 2, 3, and 4 are in the same relative positions as they were in (*a*), with the distance between the right-hand ends increased by the draft of 3, but the broken line in (*g*) only passes through two fibres; the broken line is shown at the same distance from the leading end of fibre 4 in each case.

Drafting waves

Unfortunately 'perfect' drafting is unattainable because of the lack of positive control of the floating fibres. These are acted on by frictional forces due to contact with other fibres which are moving at speeds between those of the back rollers and the front rollers; it is on these frictional forces that the motion of each floating fibre depends.

In practice some fibres released from the back rollers tend to accelerate before they reach the front roller nip; short fibres tend to do so in bunches, forming a thick place. When such a thick place arrives at the front rollers a greater force is necessary to draft it and so the following portion between the rollers is drafted to a greater extent thereby forming a thin place. When this thin place later reaches the front rollers, the drafting force decreases and so the thin place will be followed by another thick place, and so on.

Irregularities of this sort, called drafting waves, are quasi-periodic and are independent of any mechanical imperfections of the drafting machinery. They have been observed in cotton processing, where they are an outstanding feature, with individual wavelengths varying from about half to about twice the mean wavelength, which is usually about twice the maximum fibre length; and also in worsted processing although to a much less pronounced extent.

Drafting force

The mean force required to draft a sliver depends upon the frictional properties of its constituent fibres which may be influenced by factors such as lubrication and dyeing. For a given sliver it depends greatly on the degree of fibre entanglement and fibre crimp, more-parallel fibres requiring less force, it is approximately inversely related to the ratch, and generally varies almost inversely as the draft because with higher drafts there are fewer fibres to be drawn away from the main mass by the front rollers; consequently there is less acceleration of other fibres before they reach the front rollers. An exception to the last statement is found at drafts between 1.2 to 1.6, where a peak in the curve of drafting force v draft occurs, particularly with man-made fibres; consequently because such low drafts may cause roller slip, they should be avoided. For a given draft the drafting force increases with increased input sliver thickness and with increased bulk density.

For slubbing there is a disproportionate increase in the force at lower drafts. A slubbing may be defined as a sliver which has been consolidated either by twist insertion or by compression between rubbing aprons but which permits satisfactory drafting at a subsequent process. The force required to withdraw fibres from a body of fibres is on average proportional to the fibre length. However, there is a large random scatter of individual fibre withdrawal forces (C.V. from 60% to 100%) which are influenced by the number of chance fibre contacts, the frictional force per contact, fibre maturity in the case of cotton, and on the directional frictional effect (DFE) in the case of animal fibres.

This random scatter means that at any instant identical fibres at a given distance from the front rollers may behave differently; their movement may involve decelerations as well as accelerations, therefore the irregularity introduced in drafting has a large random component.

At the same time the variations in total drafting force may have a wavelike formation which appears to be a secondary manifestation of drafting waves; high values of drafting force being associated with a plucking or snatching action on the passage of a thick place through the front rollers. Both the spinning performance and the yarn levelness are closely correlated with drafting force and also with drafting force variation.

In addition, it seems that an increase in drafting force leads to a stretching of undrafted sliver thereby dragging additional fibres into the front roller nip; this is followed by a subsequent retreat caused by the internal elastic forces in the sliver when the force decreases. This elasticity effect is a further contributory cause of the irregularities introduced by drafting.

Mechanical defects

Irregularities introduced mechanically are usually independent of the variations already present in the feed material. Some of these faults may give rise to apparently random irregularities, an example being slippage of fibres between the drafting rollers.

Mechanical defects more commonly give rise to faults which repeat at strictly regular intervals along the product, these faults are usually called periodic faults.

Eccentric or non-circular drafting rollers cause the roller nip to move alternately into and away from the drafting zone. This means that the number of fibre ends gripped by the front rollers varies in a regularly repeating manner. An exaggerated diagram of this type of machine defect is shown in *Figure 5.7* where the bottom roller is concentric on its shaft and the top roller is eccentric, rotation being centred at A instead of at the true centre B. This causes the roller nip to oscillate between C and D. Usually such a movement of the back rollers is of minor importance, but oscillation of the front roller nip can introduce periodicity. As the front roller nip moves away from the back rollers it will produce an effect similar to that caused by an increase of draft, making the delivered sliver thinner, and vice-versa. This effect will be manifested in the delivered sliver with a repeat length equal to the eccentric roller circumference.

When higher drafts are used in order to produce a given count of delivered sliver, the feed sliver must be thicker, hence at higher drafts the number of fibre ends presented to the front roller nip will be greater per revolution of the front rollers, and so an increased number of fibres will be affected by a given range of nip movement; the amplitude of irregularity will therefore be greater and it follows that roller accuracy is much more critical at higher drafts.

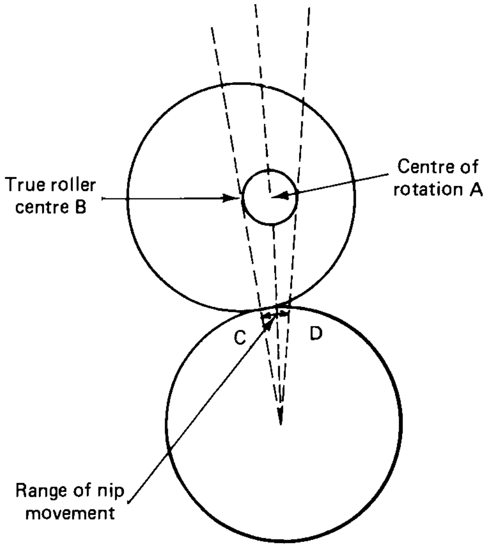

Figure 5.7 Roller nip movement caused by an eccentric top roller

Work on cotton drafting has shown that the amplitude of the irregularity introduced by this cause is directly proportional to the extent of the nip movement, inversely proportional to the roller circumference, and proportional to $\sqrt{\text{draft}} - 1$; higher amplitudes being associated with decreased yarn strength in the case of the spinning process.

A further cause of a moving nip point can be a variation in thickness, adhesion, or compressibility of a top roller covering, a damaged covering, or oscillations associated with the elastic properties of the roller cover.

Eccentricity of a bottom roller not only introduces a moving nip, but also causes the surface speed of the rollers to fluctuate regularly; a given amount of eccentricity in a bottom roller will cause a greater amplitude of strand irregularity than would a similar eccentricity in a top roller. A similar effect to bottom roller eccentricity may be caused by bent shafts and/or faulty roller-shaft couplings.

Roller speed variation may also be caused by eccentric gear wheels. In this case roller speed variation will arise, but if the rollers are concentric the amount of draft will not affect the amplitude of the irregularities caused.

Fluted front rollers can cause short-term irregularities, and so can worn gear wheels, but the amplitude is much lower than that due to other causes.

A further cause of roller speed variation may be roller vibration. This fault is more likely to arise when there is a high frictional resistance to turning of a roller shaft, low rotational speed, and elasticity in the drive. The basic cause is that on starting up a machine the force applied at the end of a roller shaft must increase until the static friction has been overcome. The roller then rotates, but because the kinetic friction is usually less than the static friction, the excess force causes the roller to accelerate to a speed above that of the drive. The excess speed finally causes the shaft to flex in the opposite direction so that a retarding force then arises to bring the roller to rest. The process is then repeated, usually at a frequency of 20 to 40 Hz, so that the roller moves in a series of rapid jerks. This causes a series of alternating high and low concentrations of fibre-leading-ends in the delivered sliver, usually at a wavelength much shorter than the fibre length. This effect can be reduced to an acceptable level by suitable machine design. Irregularities of such a short wavelength may be completely concealed by the overlapping fibre lengths so that the sliver appears reasonably uniform. If the sliver were drafted again in the same direction with sufficient draft, the wavelength would be increased to a length longer than the fibre length; the wavelike variation of fibre leading-end concentrations would then be apparent as a wavelike thickness variation. Given a variable fibre length and drafting in the opposite direction, the amplitude will be reduced. Other mechanical sources of irregularity include accidental drafting of material caused by tension variations during delivery and package formation.

Reversal of draft direction

Under normal conditions the last end of a sliver fed into a can or on to a bobbin will be the first end to be fed into the drafting zone of the next machine. This means that at each consecutive operation the leading end of a fibre will be the end which was trailing in the previous machine.

This provides an important method of minimizing the short-term irregularities in a sliver formed by a succession of drafting operations provided that the material being processed has a variable fibre length. *Figure 5.8* (*a*), (*b*), and (*c*) illustrate the arrangement of a tuft of fibres delivered from a drafting zone in the direction indicated. If such a sliver is processed in the same direction at the next operation there will be a tendency for the fibres to remain bunched together as shown in *Figure 5.8* (*d*) and (*e*), thereby causing an increase in the amplitude of thickness variations. On the other hand if the sliver is fed into the the next drafting zone in the opposite direction as shown in *Figure 5.8* (*f*), then under idealized conditions the fibres will tend to be drafted at different times and the distance between the leading fibre ends will be increased by a factor equal to the draft, therefore the original tuft will be dispersed along the length of the sliver produced, thereby reducing the amplitude. The effect is only appreciable for irregularities with wavelengths not longer than the maximum fibre length.

Drafting waves and eccentric roller periodicities appreciably exceed the fibre length in cotton processing, but to a smaller or negligible extent in worsted processing; this may account for the lower incidence of these yarn faults in worsted processing.

In cotton processing the use of consecutive drafting zones on a single machine, one following the other without reversal of draft direction, has been widely applied. This method is useful when processing card sliver in order to obtain a gradual breakdown of fibre entanglements. It is also used in high draft processing of thin slivers; in this case avoidance of the second zone emphasizing the irregularities formed by the first zone may be achieved by passing the sliver through a funnel, condenser, or quarter-turn as it passes from one drafting zone to the next. In this way high frame drafts can be obtained without using excessively high drafts in each individual zone. An example is shown in *Plate 23*. Even so, the practice of using two consecutive drafting zones is not recommended on machines immediately following cotton combing where the slivers contain periodicities caused by the method of comb delivery. Similarly it is preferable to use single-zone drafting at all drawframe operations after cotton carding except the first one where there is a high degree of fibre disorientation.

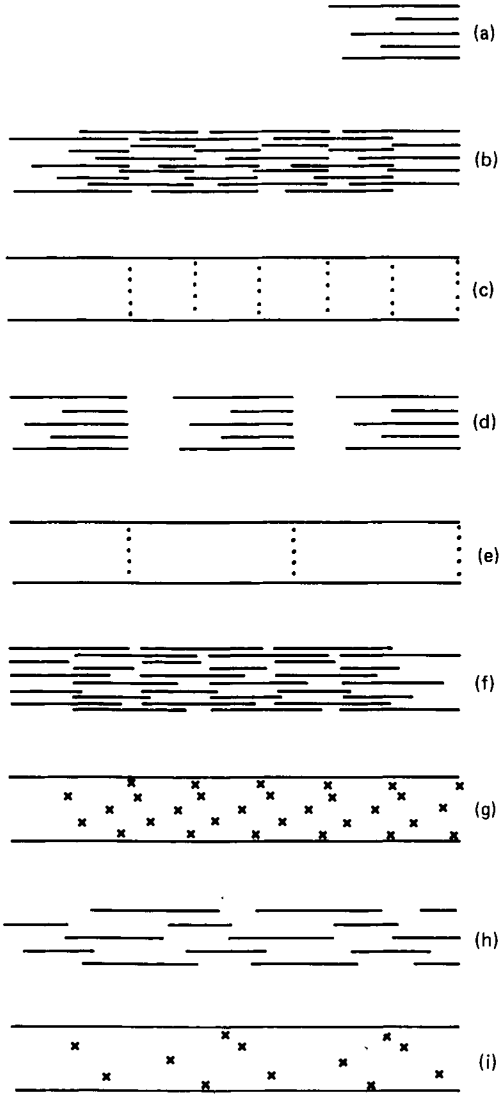

Figure 5.8 Reversal of draft direction: (a) one tuft of fibres after drafting from left to right; (b) fibres in sliver before second drafting; (c) fibre leading ends before second drafting; (d) fibres in sliver after second drafting in same direction as (a); (e) fibre leading ends after second drafting in the same direction as (a); (f) fibres in sliver (b) reversed before second drafting (g) fibre leading ends of reversed sliver before second drafting; (h) fibres in sliver after second drafting in opposite direction to (a); (i) fibre leading ends after second drafting in opposite direction to (a)

The benefits of reversal apply to various processing systems.

Reversal of draft direction in the processes immediately following carding also has an important bearing regarding the direction in which fibres are presented to a process. As previously described, there is a majority of trailing hooks in card sliver as it leaves the card, under normal conditions of reversal these become leading hooks as they enter the next machine. During drafting a fibre with a leading hook will tend to remain hooked and therefore behave in a manner similar to that of a short fibre equal in length to its extent; this effect will be accentuated at higher drafts because of the smaller number of front beard fibres present.

On the other hand a fibre with a trailing hook will tend to be straightened when it accelerates away from the majority of slower moving fibres which surround its trailing hook, the effect being greater at higher drafts. This effect is most noticeable at the drafting process immediately following the card, and decreases at each subsequent process. Hooked fibres which have both limbs of the hook of approximately equal length — called U hooks — are more difficult to straighten in drafting; consequently they tend to remain in the sliver and their percentage of the total number of hooked fibres tends to increase as the unequal-limb hooked fibres are straightened.

In the first drafting process after worsted carding it is preferable to gill the fibres with a majority of leading hooks; this method gives less noil in the subsequent combing process, presumably because of the increased fibre breakage caused by hook removal and fibre alignment if a majority of trailing hooks are fed to the process. A greater drafting force is required when drafting a majority of trailing hooks, the effect being greater at higher drafts. Therefore when high drafts are used in drawing it is important to have a majority of trailing hook fibres fed to a drafting zone; the effect with low drafts is less noticeable.

Because a high draft may be applied at the spinning process, it is preferable to arrange to have the majority of hooked fibres entering the spinning frame drafting zone as trailing hooks. In carded cotton, and semi-worsted yarn production, for example, it follows therefore that an odd number of machines is required between the card and ring spinning, provided that the normal reversal takes place at each operation. The incorrect direction of feed to the spinning process can lead to a reduction of yarn strength, but this does not apply in open-end spinning.

It is also important that the majority of hooks should be fed into the combing machine in the correct direction because, as will be explained later, the performance of the comb may be influenced significantly by the direction and magnitude of the majority of hooks fed to it. The preferred direction of feed depends on the type of comb and is described in Chapter 7. The hook removal during drafting between the card and comb will also contribute to a better combing performance.

Square-cut staple fibres

If man made staple fibres were made all the same length, then reversal of draft direction would not improve the distribution of fibre leading ends, and this would lead to poor drafting. Hence a variable fibre length is preferable, particularly with strong synthetic fibres which may not be subjected to much fibre breakage during processing. Variable fibre length in conjunction with draft reversal contributes to improved levelness and improved mixing.

Methods of fibre control

The amplitude drafting waves may be minimized by increasing the effective control over the movement of short fibres, which may be done by the application of suitable additives to increase inter-fibre friction.

Alternatively it may be achieved by controlling the pressure between the back beard and floating fibres, or between the floating fibres and machine parts such as pins or aprons which move at a known speed.

As the bulk density of the sliver increases it leads initially to an increase in the number of fibres contacting each other; as pressure rises further the existing areas of contact are increased. In practice there is a limit to which the bulk density of the sliver may be increased without causing fibre breakage.

There are four widely used basic methods of fibre control:

(1) Pins
(2) Direct pressure
(3) Twist
(4) A combination of twist and direct pressure

(1) Pin control

This method, which is only suitable for twistless slivers, is based on the fact that if pins penetrate through an already tensioned sliver, the pressure between the fibres will be increased. Successful pin control depends on the fibres being long enough to permit a suitable pin device to be fitted between the back rollers and the front rollers; this is why pin control is not used in cotton processing. Pin control helps to minimise fibre entanglement and nep formation, particularly with fine fibres.

The amount of inter-fibre and fibre/pin pressure will depend on pin length, thickness, population density, and depth of penetration, as well as on the total count and fibre density of the sliver processed.

This principle was applied on Conventional Continental Worsted drawing boxes where a porcupine cylinder was used, but because this machine was limited to a maximum draft of about 4 for most fibres, and to 6 for long fibres with a low C.V.% of fibre length, it is not now used.

Pin control has been widely used in the processing of relatively long fibres such as jute, flax, spun silk, and worsted. The development of high speed gill boxes has led to their increased use in modern worsted drawing sets.

A side elevation/section diagram of the main working parts of an intersecting gill box is shown in *Figure 5.9*.

The fallers are bars which carry a row of pins along their length (which is parallel to the axis of the rollers); they are usually supported by a metal 'saddle' near each end, and driven by a rotating screw at each end. As each faller approaches the

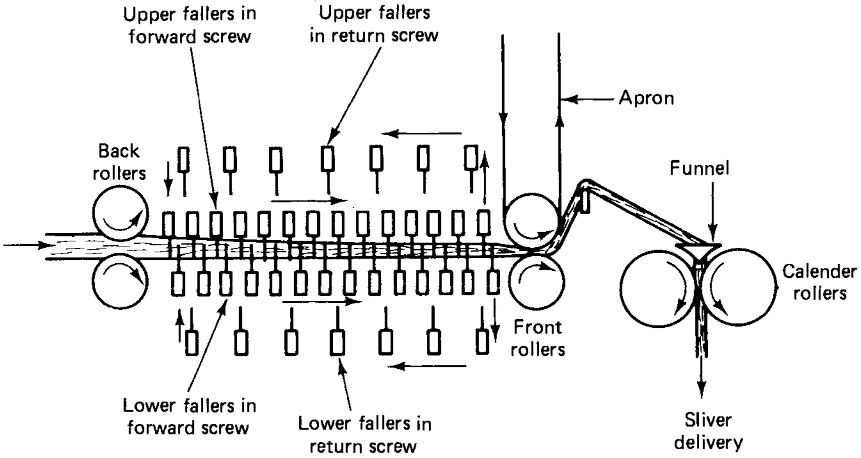

Figure 5.9 Intersecting gillbox: side view of main working parts

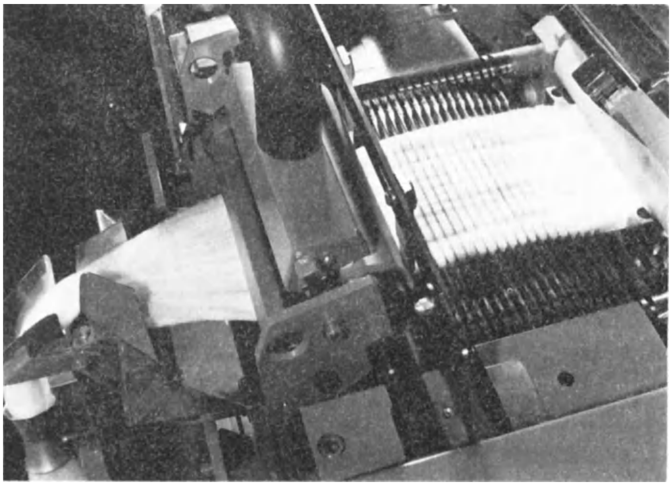

Plate 10. Close-up of an open screw gill box. An open gill box is one with only a single set of fallers with pins pointing vertically upwards. A faller driving screw is clearly visible at the far end of the fallers, and the cams at each end of the screw at the near end of the fallers can be seen. The saddle which supports the faller ends provides progressive entry of the pins into the fibres and there is a suction device mounted above the top front roller, to the left of which can be seen the downward path of the delivered sliver. This machine is popular for following top dyeing and drying, and it operates at up to 2000 faller drops/min to give production rates up to about 150 kg/h. Courtesy of N. Schlumberger & Cie

front rollers it is knocked by cams so that the pins are withdrawn from the fibres and the faller then moves backwards under the influence of the return screw towards the back rollers. The forward surface speed of the fallers on an intersecting gill box is usually about 5% faster than the back roller surface speed. The position of the back rollers can be adjusted so that the distance between their nip and the fallers can be altered to suit the fibre length being processed; the distance from the back roller nip to halfway along the faller bed is usually longer than the longest fibre being processed. The closest distance from the foremost faller pins to the front roller nip is called the front ratch, and it is usually set at the minimum distance permitted by the mechanism except in the case of longwools and hairs.

The Bradford type gill box which was originally designed for processing good length wools (e.g. merino wool top with a mean fibre length of about 70 mm, C.V.50%) has a minimum front roller diameter of about 50 mm, and minimum front ratch of about 48 mm, whereas the Continental and American types which were designed to process shorter fibres may have a roller diameter of about 25 mm and a minimum front ratch of about 22 mm.

Back beard fibres do not enter into the control of fibre movement during drafting on a gill box; the principle of fibre control is that a thick twistless body of fibres is fed forward at faller surface speed so that the faster moving front rollers can continually draw the approaching fibres away at a higher speed. The intention is that the faller pins should restrain fibres to the faller surface speed until the fibres are gripped by the front rollers, but in practice some fibres accelerate under the influence of faster moving fibres before they are actually gripped by the front rollers, partly because there is no pin control over the distance of the front ratch. In addition, when a faller is transferred to the return screw the steady flow of fibres is momentarily interrupted, causing a thin place which inevitably will be followed by a thick place. The cycle is repeated when the next faller is withdrawn forming what is known as 'faller-bar marking', with a wavelength in the delivered sliver approximately equal to the pitch of the fallers (i.e. the distance between the faller centres) multiplied by the draft; their amplitude is increased by increases of either draft, front ratch, or the number of short fibres in the sliver. Selection of suitable processing conditions renders faller-bar marks unobjectionable provided that reversal of draft direction occurs at the following operation.

It is the faller mechanism which limits the maximum speed of a screw gill box, and which is responsible for the high level of noise produced. Because of this, alternative methods of driving the fallers have been tried in order to obtain higher processing speeds. Unfortunately the noise advantage of quieter mechanisms sometimes have been cancelled out by the use of higher speeds. One of these alternatives has proved successful; the fallers are chain-driven, giving a faller speed equivalent to about 5000 faller drops/min maximum (i.e. the number of fallers transferred from the forward to the return screw), compared with about 650 drops/min for the Bradford type gill box, and up to about 2000 drops/min for high speed screw-driven fallers.

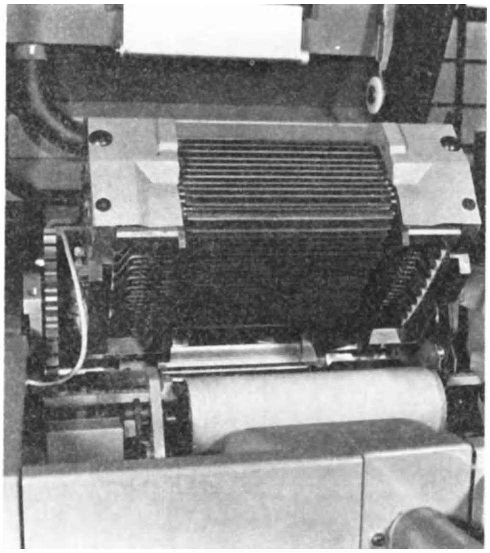

Plate 11. Chain gill box. This close-up of the chain gill mechanism, with the top head raised, clearly shows each pinned 'faller' and the crank at each end which controls the pin angle. The pin length is shorter than for a screw gill box; with clean material of good fibre length the production rate may be up to 400 kg/h. Courtesy of N. Schlumberger & Cie

Other alternatives to screw-driven fallers for pin control have included various arrangements of rotating pinned cylinders which are reminiscent of the Conventional Continental porcupine drawing box mentioned previously on page 56, but these have not yet been adopted widely, presumably because of the difficulty of obtaining a short enough distance between the pins and the front roller nip.

The drafts applied by gill boxes on merino wools are usually about from 6 to 8 on the Bradford type, and about 8 to 10 on the smaller high speed gill boxes.

For fibres shorter than about 55 mm mean fibre length or for fibres containing impurities (such as flax), the screw gill box is still preferred. Chain gill boxes are favoured for longer fibres which are clean, when they may give about twice as much production or more. Modern gill boxes permit high rates of production, with good fibre control.

(2) Direct pressure control

This method consists of applying lateral pressure to a twistless fibre assembly thereby increasing inter-fibre friction and yet permitting fibre slippage; this principle is often referred to as 'slip-draft'. Several ways in which this can be done are illustrated in *Figures 5.10* to *5.15*.

(1) Carriers and tumblers

The positively driven carrier rollers shown in *Figure 5.10* support the fibres while a set of heavy tumblers rest on the material and rotate by surface contact. The tumbler mass and/or distance from the front rollers may be adjusted to alter the degree of control. This method was widely used in Conventional Continental worsted processing where maximum drafts of about 10 were used.

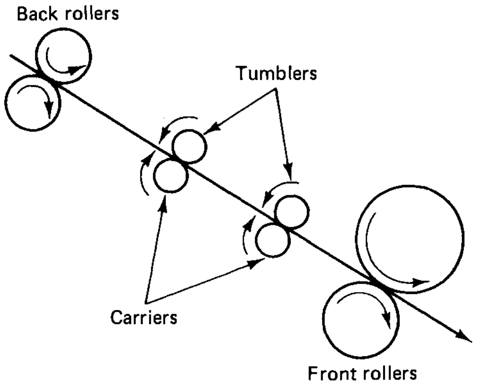

Figure 5.10 Carriers and tumblers

(ii) Apron and tumblers

As shown in *Figure 5.11* the positively driven apron provides continuous support for the fibres in place of the carrier rollers of method (i). The tumbler ends are located in slots which make it easy to alter the distance of the tumblers from the front rollers. Drafts of from 15 to 25 may be applied in this system. An alternative arrangement is to have an apron passing over the top of a roller, with both of them positively driven; such an arrangement, known as top apron drafting, has not been used widely.

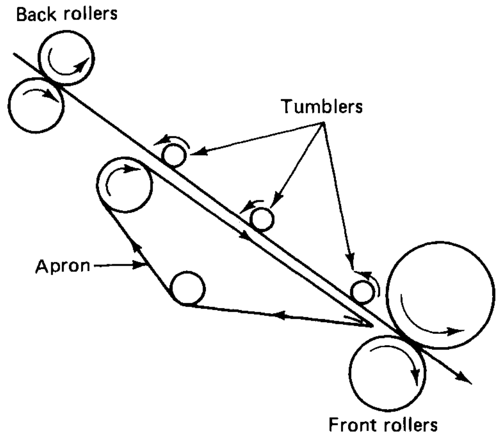

Figure 5.11 Apron and tumblers

(iii) Double aprons

It has been suggested that double apron fibre control is probably the most efficient method for frame spinning; its widespread use in both worsted and cotton ring spinning confirms this, and there are many versions of this system of fibre control produced.

The aprons (*Figure 5.12*) are made from synthetic rubber-like laminates which offer a long working life, high tensile strength, and resistance to fibre additives.

Aprons do not effectively control fibre movement when processing thick slivers because although the outer layers of fibres may be controlled by the aprons, the inner fibres remain urestrained; for this reason this method is restricted to use in roving and spinning operations.

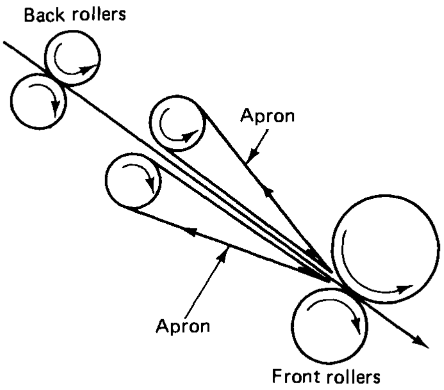

Figure 5.12 Double apron

The fibres are lightly compressed between two positively driven aprons with both speed and pressure adjustment. The cradle opening (i.e. the gap between the two aprons near the front roller nip) is also adjustable, and there is an optimum setting for yarn irregularity and spinning performance; too wide an opening increases the yarn fault content.

A close setting between the front end of the aprons and the front roller nip is possible because the aprons can be guided round stationary tensor bars without danger of fibre lapping; this reduces the number of uncontrolled floating fibres and thereby permits higher drafts than the previously described methods. Drafts from about 10 to 40 may be used in an apron drafting zone. It is usual to apply a small draft of about 1.1 to 1.3 between the back rollers and the aprons; this is known as the 'break' draft, and it initiates relative fibre movement before the main draft is applied between the aprons and the front rollers. The total draft equal the break draft multiplied by the main draft.

Total draft up to about 600 may be achieved by using two consecutive apron drafting zones on one machine, in which case the precautions mentioned on page 54 must be observed.

(iv) Amblerdraft

This was developed as an alternative to the pressure drafters (method (vii) on a worsted drawing box; it is extremely versatile, being suitable for merino and crossbred wools, man-made fibres, and blends, oil combed or dry, because of the wide range of adjustments provided.

The unit itself (*Figure 5.13*) basically consists of two pairs of rollers, all four of which are positively driven and with the two nip points set at the fixed distance of 50 mm apart, but the unit as a whole may be moved to alter the distance between the front rollers and the small front tension rollers from 38 mm to 90 mm. The larger pair of rollers are scratch-fluted and the top tongued roller fits into the groove of the bottom roller so that the material is compressed into a rectangular cross-sectional shape (Similar rollers are shown in *Plate 12* and *Figure 6.10*). The load applied to the small rollers is fixed at about 340 g, and the load applied to the tongued roller may be adjusted up to a maximum of about 5.5 kg when short fibres are processed, but when front beard fibres extend between the tongued and grooved rollers a lower pressure must be applied to avoid fibre breakage.

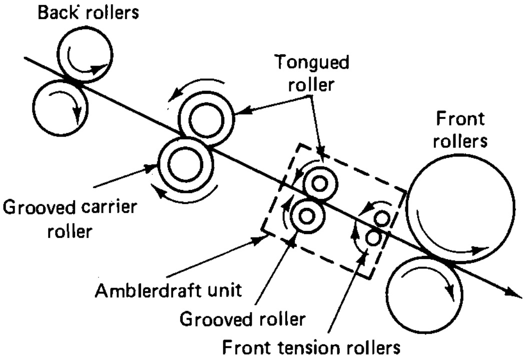

Figure 5.13 Amblerdraft

(v) Pressure-bar

This method of direct pressure control, (*Figure 5.14*), was introduced on cotton drawframes where owing to the short fibre length there is not much room available for fibre control devices. The stationary pressure bar A deflects the sliver as it approaches the front roller nip and thereby applies lateral pressure which helps to control the floating fibres. The setting of the top middle roller B about the centre of its respective bottom roller C is linked to the pressure bar, maintaining the distance between the centres of A and B constant. Hence the pressure bar can be set backwards or forwards in sympathy with roller B. At the same time the top front roller D also can be moved about the centre of the lower roller E so that a wide range of staple lengths can be accommodated with optimum settings and drafts ranging from 4 to 10.

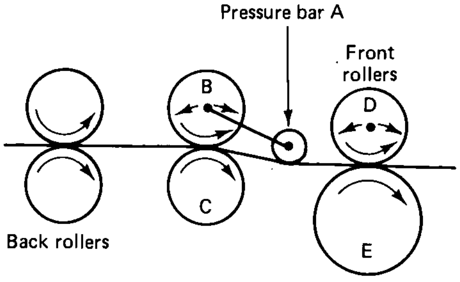

Figure 5.14 Pressure bar

(vi) Apron and pressure pads

The Schlumberger worsted drawing machine ET11 is a machine of this type; it incorporates 60 hollow plastic pads which are familiarly known as the 'caterpillar top' and are mounted over a bottom apron (*Figure 5.15*). When set correctly, wool and synthetics, either separately or blended, may be delivered with very low sliver irregularity at up to 250 m/min, the delivery speed being limited by considerations of package formation rather than drafting. Drafts within the range of 5 to 15 may be applied to deliver 2 or 4 slivers of from 2 to 15 ktex. The main disadvantage of this type of machine is that unlike on a gill box, it is not possible to make a sliver piecening without forming a torpedo-shaped thick place in the delivered sliver, but the need for piecenings can be avoided by arranging for a full set

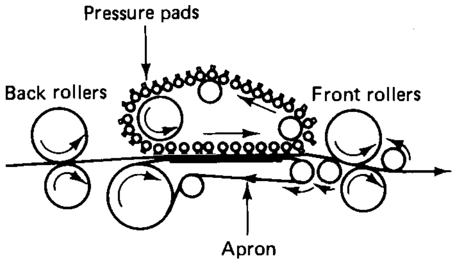

Figure 5.15 Apron and pressure pads (ET11)

of supply cans to give an exact number of full cans of delivered sliver. The apron and pressure pad system is losing ground to the chain-driven faller mechanism.

(vii) Pressure drafters

These were invented by G. F. Raper for use on Raper autoleveller drawing boxes. The basic idea was to provide a stationary rectangular-cross-sectioned channel through which the sliver passed from the back to the front rollers; minor feed sliver faults which might be acceptable for gill box drafting could lead to the formation of thick places in the sliver delivered by a pressure drafter. The applied lateral pressure could be adjusted by means of calibrated control knobs to obtain optimum settings for levelness.

Pressure drafters are no longer manufactured.

(3) Twist control

This method is based on the principle that if longitudinal tension is applied to a twisted slubbing, then inward radial pressures will be exerted. Under free conditions, twist redistributes itself by rotation of the slubbing, so that more twist accumulates at the thin places. In a drafting zone without some means of control this would lead to a very high twist content in the thin material near the front roller nip where the drafting occurs, giving an excessive increase in the grip of front beard fibres on the floating fibres, complemented by a reduction of twist near the back rollers, and a consequent loss of control over the floating fibres. This would tend to lead to alternating thick and thin places being formed in the delivery similar to drafting waves.

By controlling the distribution of twist in a drafting zone, the pressure applied by the twist to fibres at various points along the drafting zone can be modified, but this is only possible when the fibre length is long relative to the thickness of the slubbing being processed. In the early stages of both cotton and Continental worsted processing this condition is not satisfied and therefore twist is not then used. In the Bradford system of worsted drawing where twist is used, its distribution is controlled by using light-weight tumblers supported by carriers; the mass of the tumblers is only just sufficient to prevent unwanted rotation of the slubbing in the drafting zone.

Strictly speaking, therefore, some direct pressure is applied, but as this is only just sufficient to prevent rotation of the slubbing, the amount involved is insignificant compared with that developed by the twist; an increase of tumbler mass has no significant influence on the irregularity of the product.

By using carriers and tumblers, the twist near the back rollers is maintained at a level high enough to help the back beard fibres to restrain the movement of floating fibres, and the twist near to the front rollers is kept at a low enough level to avoid excessive front beard control.

The penetration of twist into the front roller nip also helps to limit the lateral spread of fibres thereby improving the disposition of the delivered fibres.

In Bradford worsted drawing the approximate amount of twist required in 100% wool slubbing = $3040 \{\text{count(tex)}\}^{-2/3}$ t/m, with a tolerance of ± 15% this formula has been shown to be effective from 96 tex to 15 ktex.

For cone drawing or man-made fibres the mean twist may be reduced from the above by 20% to 30%.

There seems to be an optimum roving twist as far as spinning performance is concerned. The usual correlation between wool fibre length and fibre diameter permits a similar amount of twist to be used for widely different qualities, but a significant increase of fibre length with a given mean fibre diameter permits the use of less twist. Cottons containing a greater proportion of fibres shorter than about 9 mm require increased roving twist for efficient drafting during spinning.

Twist control is used in the frame spinning of untwisted condensed slubbings on the woollen system by using a false-twist tube to insert the twist. In this case the fibres are disorientated and entangled with the result that the maximum satisfactory draft is only about 2.

(4) Combined twist and direct pressure control

In this method a reduced amount of twist is used, but the pressure applied is more than should strictly be required to prevent rotation of the slubbing. Carriers and light-weight tumblers, or apron arrangements may be used.

The use of twist permits the projection of some degree of control into the front roller nip which can have a significant effect on the product quality, giving better fibre control in drafting and a lower end-breakage rate in spinning.

The most sophisticated form of control of this type which found commercial application was the Ambler Superdraft system (ASD), (*Figure 5.16*), and the Uniflex system which was developed from it for worsted spinning. This enabled drafts from about 80 to 200 to be used under commercial conditions on wool which previously would have only been spun with a draft of 6 on the conventional machinery in use at that time (i.e. about 1950). Fibre control derives mainly from the ASD unit and as a result normally the ratch is set not less than 50

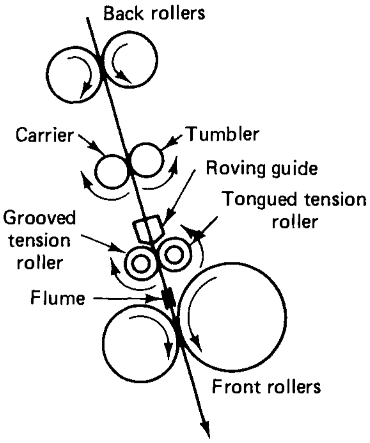

Figure 5.16 Ambler superdraft

mm greater than the longest fibre. The unit arrangement consists of a guide which condenses the roving before it passes between the positively driven tongued and grooved tension rollers running at a surface speed about 14% faster than that of the back rollers. The load applied to the top tension roller may be from about 1.1 N to 3.5 N, depending on the fibre properties; excessive load at this point may lead to undue fibre breakage. The tension rollers are responsible for almost half of the total drafting force produced. The material then passes through a narrow channel called the flume which restricts rotation of the slubbing and thereby controls the twist distribution. The distance from the front end of the flume to the nip of the front rollers can be set from a maximum of 50 mm to a minimum of 8 mm or 12 mm, depending on the diameter of the front rollers. Hence fibre control can be brought very close to the front rollers, permitting high drafts and good yarn levelness. The drafting force, spinning performance, and yarn properties are not critically dependent on the amount of twist in the roving. With such high drafts top front roller covering standards become very critical as regards concentricity, compressibility, and uniform adhesion, therefore vigilant quality control must be exercised. This may account for the fact that the system has never been adopted widely and is now no longer manufactured.

It seems that single or double apron drafting is now established as the preferred method of fibre control for high drafting at the ring spinning frame because although yarn irregularity may be greater than with ASD, the roller requirements are much less critical.

Further reading

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6

AUTOLEVELLING

Alternative names for autolevelling include; autoregulator; leveller; draft-o-matic; servo-drafter; although these different names are used by different machinery manufacturers, the basic principles remain the same.

The object of an autoleveller is to measure the sliver thickness variations and then continuously to alter the draft accordingly so that more draft is applied to thick places, and less to thin places with the result that the sliver delivered is less irregular than it otherwise would have been. Besides an improvement in product appearance, autolevelling can also contribute to better productive efficiency, fewer end-breakages in subsequent processes, less waste, and constant process conditions.

Theoretically there are two distinctly different ways in which this may be done:

(1) Radical autolevelling

Autolevelling as at present applied is a radical process in the sense that not only is the irregularity of the product reduced, but also the mean count of the product is determined by the setting of the autoleveller unit itself.

(2) Conservative autolevelling

This means an autoleveller by which local thickness variations are corrected, but the mean count of the product is beyond the control of the autoleveller; it is already pre-determined by the mean count being fed into the conservative autoleveller.

The first time the autolevelling principle was applied to textile yarn manufacture was in the nineteenth century when the pedal-feed regulator of the cotton scutcher was introduced to improve lap regularity. Even so, manual correction was necessary, based on the weighing of the laps produced along with the rejection and re-processing of laps deviating by more than about ± 1% from the intended mass.

The first sliver autoleveller to be commercially successful was the Raper autoleveller initially used in woolcombing on the first top-finisher gill box, invented by G. F. Raper; this was followed by the invention being extended to the Raper autoleveller drawbox in the early 1950s. Soon many other machine makers produced their versions of autolevellers and applied them to various sections of yarn manufacture, such as short-staple and jute processing as well as to other machines such as cards and drawframes.

Although sliver autolevelling was a relatively late development in spun yarn technology, it is now very firmly established and it is inconceivable that any machine maker could contemplate not making use of its many advantages.

Autolevellers may be classified into three main groups according to the basic principle of operation: Open loop; Closed loop; Combined loop (this may be defined as the use of two or more separate control loops to correct a single process).

(i) Open loop autolevellers

The open loop control principle, which can be used for the correction of fairly short-term variations, is represented in *Figure 6.1* where the solid lines indicate the flow of fibres through the machine, and the broken lines represent the flow of information in the autoleveller unit. The control unit compares the measurement signal with the reference signal which

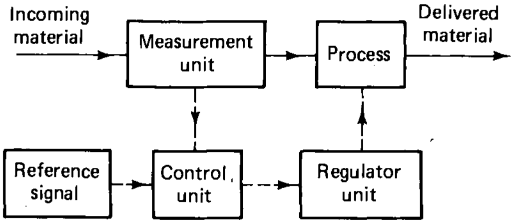


Figure 6.1 Schematic diagram of open loop control system

in this case represents the mean output count required. The control unit accordingly increases, leaves unaltered, or decreases the output of the regulator which in turn provides a variable speed to the back or front rollers of the process to give the required draft when the measured material has reached the point at which draft is applied. The magnitude and direction of each change in draft is determined by the magnitude of the change of count previously indicated by the measuring unit.

If the direction of the arrows in *Figure 6.1* is followed from any starting point, it always leads 'out into the open' from the diagram at the place marked delivered material; there is no check on the delivered material by the control unit. Measurement always takes place on the material prior to the point where corrective action is applied to the material. Thus if measurement is made on the input material, the correction may be applied to either the back rollers or the front rollers as shown in *Figure 6.2 (a)* and *(b)* respectively, where, for convenience, the process (a card, gill box, or drawframe, for example) is represented as a single drafting system.

The Raper autoleveller and most other autolevellers designed for worsted processing are open loop autolevellers. Open loop autolevellers are easier to design than closed loop ones, and they cannot 'hunt' — a problem which must be considered in the design of closed loop systems.

(ii) Closed loop autolevellers

The closed loop principle is illustrated in *Figure 6.3*; this system is used for the correction of long-term and medium-term variations. Again the measurement signal is compared with the reference signal by the control unit which then determines the output of the regulator which provides the variable speed to the process to give the required draft.

However, if the direction of the arrows in *Figure 6.3* is followed from any starting point except the delivery, it always leads to a never-ending circuit of the loop which links the process and the control unit together; hence the name 'closed loop'. Measurement always takes place on the material after the point where corrective action is applied. Thus if measurement is made on the output, the correction may be applied to either the back rollers or the front rollers as shown in *Figure 6.2(c)* and*(d)* respectively.

It is immediately apparent that the control unit continually checks the results of its own actions because measurement is taken from the product of the process; this may be regarded as a basic advantage of the closed loop system, but it is obtained at the price of increased complexity.

Because the flow of fibres in the process forms part of the control loop, this means that the amount of control which can be applied is restricted not only by the limitations of the control unit itself, but also by the characteristics of the process.

A closed loop system must be designed so as to avoid hunting, i.e. an unwanted oscillation in the output — in this case sliver thickness.

(iii) Combined loop autolevellers

A combined loop autoleveller can be designed to correct long, medium, and short-term variations. Various loop arrangements can be envisaged, for example, the combination of an open and closed loop in order to correct short-term irregularities with a fast response which may best be achieved by an open loop system, and long-term stability provided by the closed loop, or alternatively the combination of two separate closed loops *(Figure 6.2(e)* and *(f)*.

A further member of this group which combines both open and closed loop characteristics arises when measurement is made on the material of intermediate thickness between the back and front rollers of a drafting zone *(Figure 6.2(g))*; the sliver thickness at the point of measurement depends on both the input and output fibre-end densities, hence this is a combined loop autoleveller.

When drafting force within a drafting zone is used as a measure of sliver thickness, this also corresponds to a combined loop system.

As the understanding of automatic control systems improves along with the reduction of cost and greater reliability of electronic circuitry, it is to be expected that increasingly-sophisticated autolevellers will become commercially available.

The design of a closed loop control system

An autoleveller has to take acccount of the random nature of many of the irregularities in the incoming material. In practice, because of time lags in the measuring and control systems, an instantaneous control cannot be achieved. Some of the factors which influence the design of a controller are summarized below.

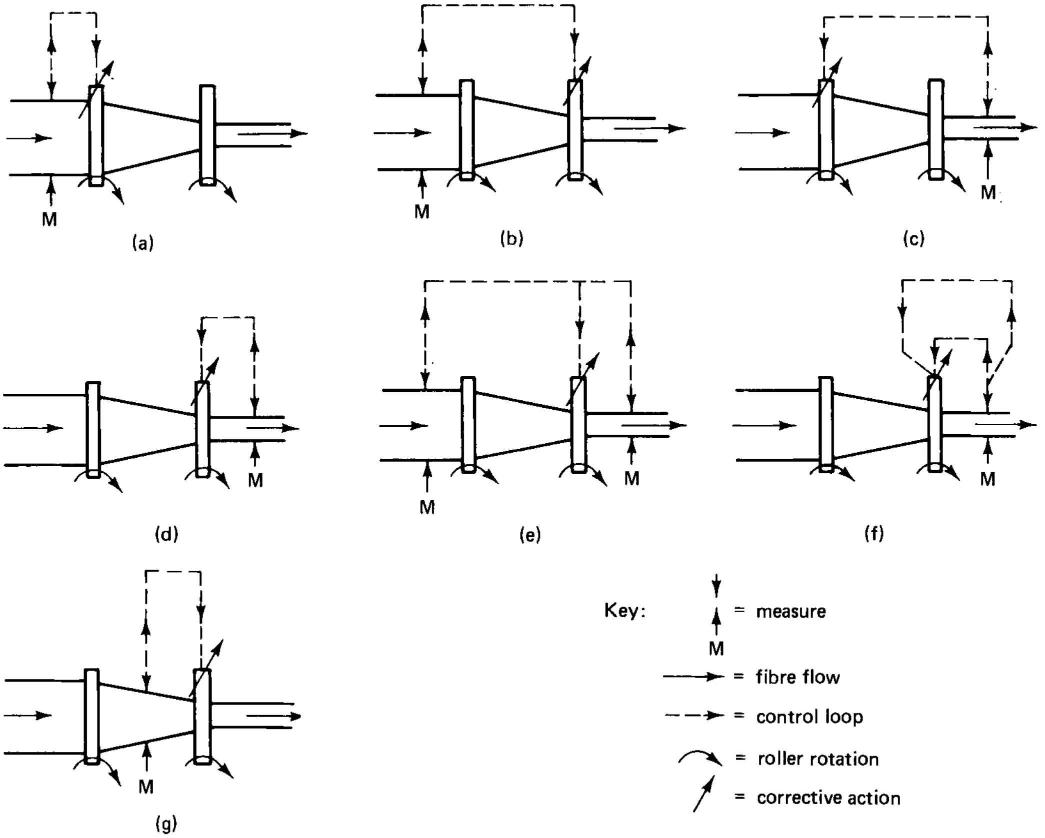


Figure 6.2 Types of autoleveller control systems (a) and (b) open loop control systems; (c) and (d) closed loop control systems; (e) open and closed loops combined; (f) fast and slow loops combined; (g) intermediate measurement

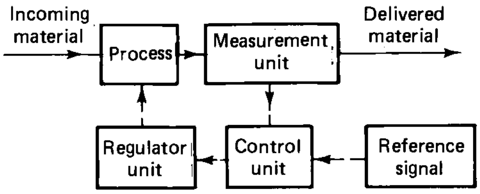


Figure 6.3 Schematic diagram of closed loop control system

(1) Deviation reduction factor (DRF)

This is a measure of the minimum deviation which must inevitably arise, because of the nature of the process itself, before measurement of the deviation can be made.

$$\mathrm{DRF} = \frac{\text{input deviation}}{\text{output deviation}}$$

It gives a measure of the results which might be obtained from a process if it were fitted with a hypothetical ideal controller. A process with a larger DRF can be subjected to tighter control.

(2) Gain/frequency response

The dynamic response of the process and regulator combined together may be characterized by feeding a sinusoidal signal of known frequency and amplitude into the regulator with the control loop disconnected between the control unit and the regulator. The output indicated at the measuring unit is recorded along with the input (*Figure 6.4*).

$$\text{Response gain} = \frac{\text{output amplitude}}{\text{input amplitude}}$$

Without control applied to the process, the gain is less than unity. This is measured for a range of frequencies and the results may be presented graphically by plotting response gain against frequency (*Figure 6.5*); the gain of a given control system will be lower at higher input frequencies.

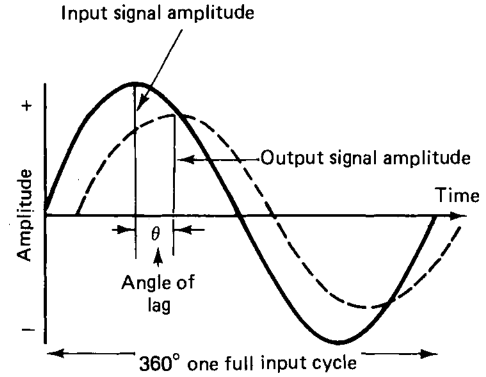


Figure 6.4 Input/output time lag

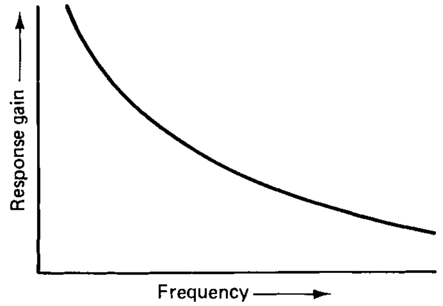


Figure 6.5 Hypothetical gain/frequency response curve

Phase-lag/frequency respoonse

When the sinusoidal signal is fed as described above, the output indicated by the measurement unit reaches its maximum amplitude later than the input because of time lags in the regulator and the process. The time lag is usually expressed in degrees, taking the time for one complete cycle to represent 360° as shown in *Figure 6.4*. A graph of the results for a range of frequencies may be made by plotting phase-lag against frequency as shown in *Figure 6.6*. where it can be seen that phase-lag is greater at higher frequencies.

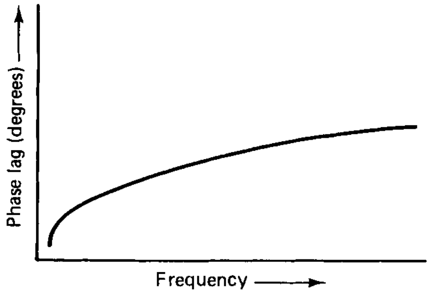


Figure 6.6 Hypothetical phase-lag/frequency response curve

(4) Control loop characteristics

From a knowledge of the control unit characteristics and the combined regulator and process gain and phase response characteristics it is possible to obtain the characteristics of the complete control loop.

One important feature is the frequency at which the phase-lag causes the correction signal to be in phase with the error. At this resonant frequency it is important to ensure that the overall loop gain is low so that the error signal cannot be increased, otherwise the loop would oscillate or hunt. A measure of this low gain is the *gain margin*, which is the reciprocal of the gain at the resonant frequency — a greater gain margin indicates better stability.

Another important loop characteristic arises at the frequency where gain is unity. At this point it is important that the phase-lag should not be 180° because if it were it would put the correction signal, which is already 180° out of phase for a given error, back in phase with the error, so that with a gain of unity hunting would arise. The *phase margin* is the difference between the phase-lag with a gain of unity, and 180°. A greater phase margin indicates better stability.

Unfortunately increased values of gain margin and phase margin imply a reduced amount of correction being applied. Hence the problem of design is to find a compromise between the two desirable features which are opposed to each other: stability and close control. The object is to keep maximum gain to the highest possible frequency, i.e. to cover a wide band-width, but to ensure a safe gain margin at the resonant frequency; this must be achieved by a suitable control unit design.

$$\text{Control unit gain} = \frac{\text{correction}}{\text{error}}$$

This represents the vigour of response made to any detected error. Excessive gain causes hunting, insufficient gain results in a sluggish reaction.

In practice as gain is increased beyond the optimum the output irregularity becomes worse and drafting eventually breaks down; the maximum effective gain varies with the input sliver irregularity. With higher gain or greater input irregularity the controlled speed variation becomes larger, but it has a maximum limit because the speed of the roller cannot be reduced below zero.

One method of assessing the overall control loop characteristics is by making a step-change to the input. The response may range from being very rapid as illustrated in *Figure 6.7(a)* to the slower and more stable performance shown in *Figure 6.7(c)*. A sluggish control action has no tendency to hunt, and can give very accurate long-term control, but short-term irregularities will remain uncorrected. In some cases the response characteristics can be accompanied by mechanical resonances which means that the response time is not necessarily a simple factor.

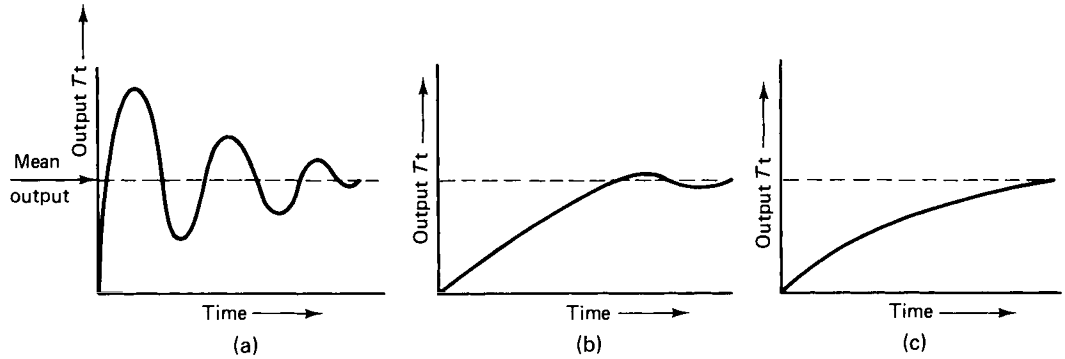


Figure 6.7 Output response to a step-change of the input (a) rapid response (b) medium response (c) slow response

It follows, therefore, that the selection of a suitable form of response depends upon the type of process and the type of irregularities to be corrected.

The likelihood of hunting may be minimized by having:

(1) Measuring as close as possible to the process
(2) Minimum time delays in the control loop.
(3) A suitable value for the gain of the control system

Autoleveller perturbation

All autolevellers are subject to aberrations which lead to perturbation of the autolevelling action. Most autolevellers measure the compressed sliver thickness and some perturbation may arise from the material itself because of variations in moisture content and compressibility. Other perturbations may arise due to slow changes such as those caused by wear, dirt, and temperature drift. Factors such as non-linearity of the measuring systems, non-linearities in the control unit response, and inertia may cause the performance of the autoleveller to vary when different wavelengths of irregularity are present in the measured sliver. Hence the ability of an autoleveller to correct irregularities is limited, but the limit is not the same for different wavelengths of input irregularity.

Consequently the perturbing factor limiting the performance must be considered as a spectral function of wavelength in the sliver. This function is called the perturbation spectrum of an autoleveller.

Hence the perturbation spectrum is a characteristic of the machine, material, and environment, combining all the perturbing factors present.

So long as input variations are within the levelling capacity of the machine, the spectrum of output variation will correspond to the perturbation spectrum, to which will be added the short-term irregularities introduced by the drafting zone of the autolevelling machine itself.

Thus the efficacy of an autoleveller depends on the relationship between its perturbation spectrum, and the spectrum of variations in the sliver to be processed. For the conditions shown in *Figure 6.8*, sliver A will be improved at all wavelengths, apart from the additional short-term irregularities introduced by the drafting zone. On the other hand although the short-term irregularities will be improved for sliver B, the long-term irregularity will be increased to the level of the perturbing signal at wavelengths exceeding λ_c. In practice a clear-cut point corresponding to λ_c cannot be achieved; instead there must be a transition band (*Figure 6.9*).

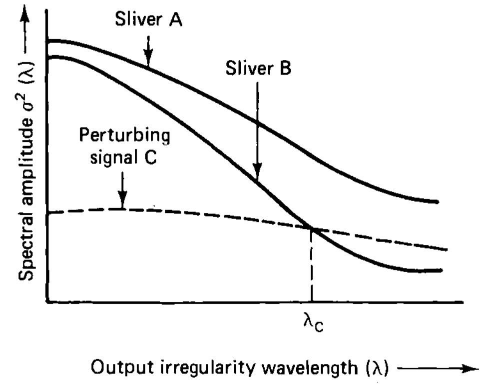


Figure 6.8 the perturbation spectrum and sliver variation spectra

Applications of autolevelling

The controlled speed variation may be applied to the back rollers or the front rollers. Variation of the

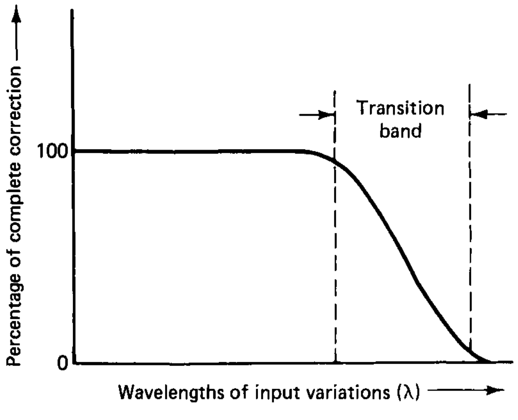


Figure 6.9 transition band of conservation

back roller speed gives a constant rate of production from a given machine, but in the case of a gill box, the maximum faller speed must correspond to the top end of the autoleveller control range; this means that the *average* faller speed must be lower than the normal production speed. On the other hand if the front roller speed is varied, this may entail the continuous acceleration and deceleration of large masses, such as coiler cans and their associated drives.

From the ultimate yarn levelness point of view the greatest benefit is to be obtained by having autolevelling as late as possible in the sequence of processing — theoretically the optimum location would be on each spinning spindle drafting zone. However, such an arrangement is at present uneconomic because of the large number of autoleveller units which would be involved, and although an autolevelling arrangement for roving has been proposed, it has not yet proved to be commercially viable.

From the cost point of view, a relatively expensive autoleveller unit would be applied most economically on a single delivery machine with a relatively high production rate.

Because all the commercial autolevellers have been of the radical type, in practice a compromise solution has been to apply autolevelling at a process near enough to spinning for the benefits of long-term levelness to be retained in the yarn produced; if there were too many intervening processes then the short-term irregularities introduced by the drafting zones on the machines following the autoleveller would be drafted out to form long-term irregularities in the ultimate yarn.

In worsted processing the direct feeding of a number of carding machine deliveries into an autoleveller gill box has been used in some factories, but this application has not been widely adopted. Automatic control of combing machines has also been developed, but in this case a uniform rate of noil removal may be of as much interest as is the maintenance of a uniform sliver. Autolevelling also has been used on the first gill box in worsted top finishing where a reduction from 1.7% C.V. to 1.3% C.V. between 5m lengths of top sliver has been achieved; the advantages in using autolevelling at this stage, however, are mainly economic, i.e. higher productive efficiency, higher productivity, and the elimination of the need to re-process slivers of incorrect thickness.

In most worsted drawing systems a single-delivery autoleveller gill box is used; all the material processed through the drawing set passes through the one autoleveller, hence all yarns spun from the rovings produced by the drawing set have been subjected to the same autolevelling treatment. The most common arrangement is to have three operations between autolevelling and the middle-draft spinning which follows.

In short-staple processing, autolevelling has been widely applied to single delivery drawframes with one or two processes between autolevelling and spinning, and to the drawbox head of combing machines. It also has been applied, with the advent of chute feeds, to the carding process for short-staple fibres where long-term variations must be minimized. With the advent of open-end spinning, and the concomittant reduction in the number of operations between carding and spinning, this application of autolevelling may be particularly beneficial. If the correction is applied at the feed of the card, the more uniform feed may help to maintain constant carding quality; this could also lead to lower long-term yarn irregularity. On the other hand if the feed material contains varying amounts of impurities which are removed during carding (as may apply in woollen carding) then the maintenance of a uniform input will not guarantee a uniform delivery.

On the woollen system autolevelling has been applied to the carding process which is immediately followed by spinning; this form of autolevelling may ensure uniform sliver levelness after fettling, but it does not guarantee shade uniformity where different coloured components are also of different fibre dimensions.

It seems that the ideal arrangement might be to have a radical autoleveller at an early stage in drawing to provide long-term uniformity, and to have relatively cheap conservative autolevellers at a later stage. The latter could be designed so that wavelengths greater than a pre-determined wavelength (represented by λ_c in *Figure 6.8*) would not be autolevelled and yet short-term irregularities could be corrected. In practice a clear-cut point corresponding to λ_c in *Figure 6.8* could not be achieved; instead there would be an appropriate transition band of the form indicated in *Figure 6.9*.

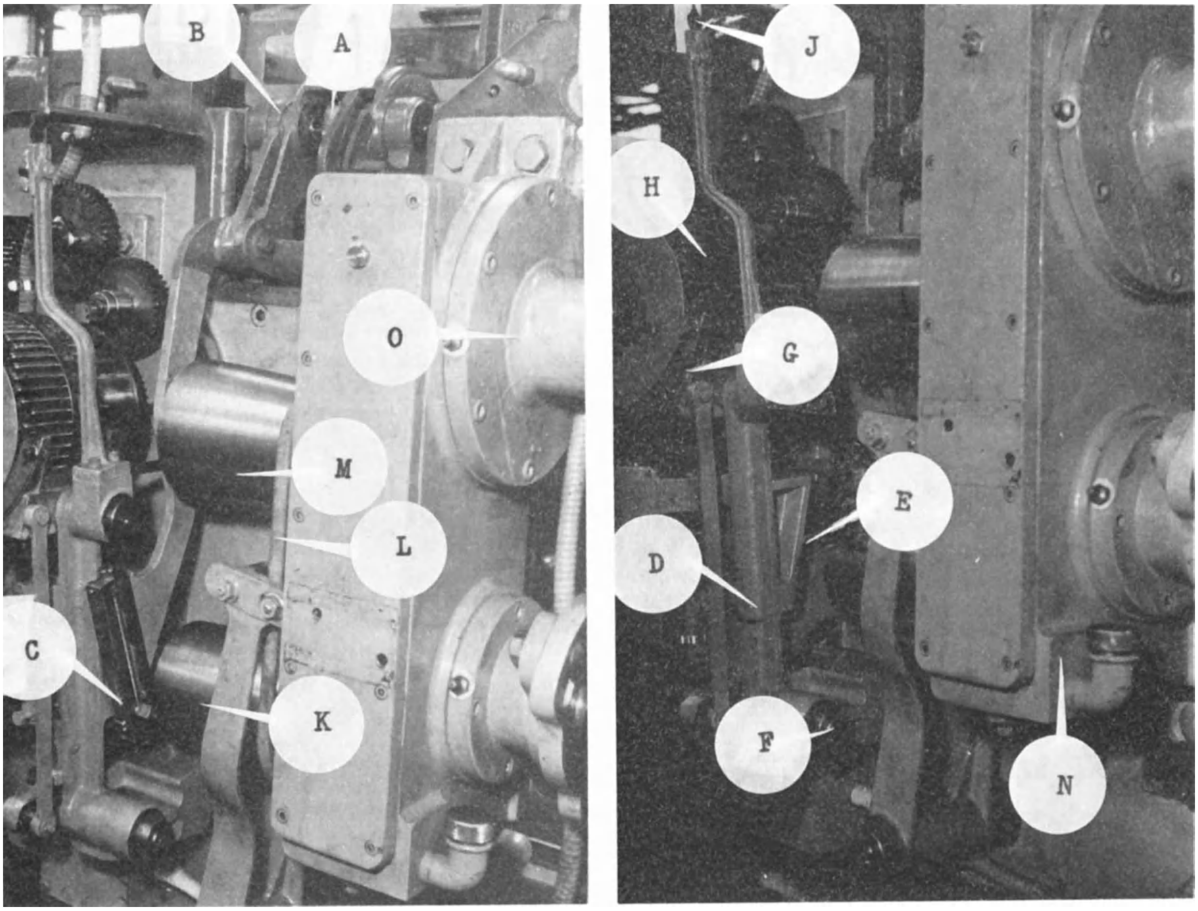


Plate 12. Raper autoleveller mechanism. These two slightly different views of the Raper autoleveller show: A, top measuring roller; B, fulcrum of the measuring roller arm; C, contact pin at the bottom of the measuring roller arm – this presses against E and gives a magnified version of the measuring roller movement; D, rod setting lever; E, contact plate on rod setting lever (in contact with C); F, fulcrum of rod setting lever; G, rod setting guide; H, relay cylinder rods; J, pointer at the top of the rod setting lever — it indicates the deviations from the mean on a scale calibrated in percentages; K, bottom cone running at a constant speed; L, belt — driving from the bottom cone to the top cone; M, top (driven) cone running at a variable speed which depends on the position of the belt; N, cone gear box; O, variable speed output from the gear box to the drafting zone.

Autoleveller construction

The following section gives a brief survey of the methods used in practical open loop autolevellers; reference should be made to *Plate 12* throughout this section. This is followed by two specific examples of closed loop autoleveller machines.

Measurement

Strictly speaking the ultimate levelness of a delivered sliver depends on maintaining a suitable fibre-end density in it, but no direct measure can be obtained for fibre-end density and this is a fundamental limitation of any autoleveller.

For slivers with fibres of constant length there is a direct relationship between leading fibre-end density and sliver thickness, therefore in practice a related variable such as sliver thickness is measured as an approximation to fibre-end density. Under these circumstances leading fibre-end density may be regarded as the controlled variable.

For slivers with variable fibre length the fibre-end distribution function varies along the length of the sliver; constant sliver thickness is no longer directly related to leading fibre-end density. In this case, therefore, when sliver thickness is measured, the fibre-end density can no longer be regarded as the controlled variable.

Because it is impracticable to obtain a continuous measurement of the variation in fibre-end distribution, the action of an autoleveller at wavelengths comparable with the fibre length is inevitably subject to some degree of uncertainty. The result is that below a limiting wavelength no useful improvement in sliver levelness can be obtained no matter how rapidly the controller responds.

The most widely used method of measurement for sliver autoleveller machines is tongued and grooved rollers, the very slow drift due to mechanical wear being negligible; it is limited as far as speed is concerned, and would not be suitable, for example, at the delivery of a cotton drawframe. A criticism of the method is that it consolidates the slivers and that they may be difficult to disperse sufficiently for the drafting to follow on an open loop autoleveller.

As represented in *Figure 6.10*, measurement is made by passing the incoming material between tongued and grooved rollers under compression. The bottom roller is mounted on a fixed-height centre and is positively driven. The top roller has a surface-contact drive and its height is determined by the total sliver thickness which is compressed into a rectangular cross-sectional shape *(Figure 6.10(a)*. On the Raper autoleveller the top roller movement is mechanically magnified and conveyed to the rod setting lever. Some machines have a horizontal roller arrangement, but the principle is the same.

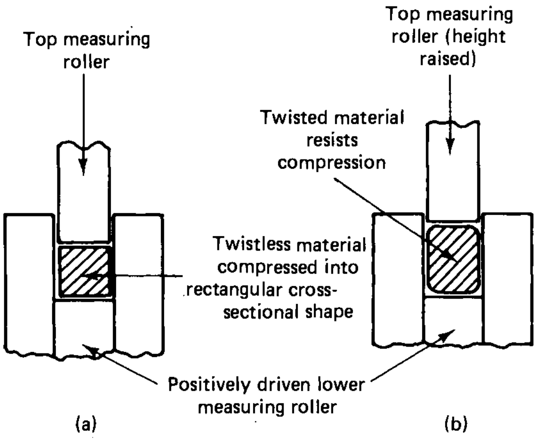


Figure 6.10 Rear view of tongued and grooved measuring rollers

This method is not suitable for use with twisted slubbings because the material resists being compressed into a rectangular cross-sectional shape *(Figure 6.10(b))*, and so the height of the top roller may vary periodically with the twist even when there is no change in the sliver count. The method is hardly influenced by the moisture content of fibres provided that sufficient compression is applied, but materials with different compressibilities or different degrees of fibre orientation may register different thicknesses for the same count; however, such differences are easily catered for by altering the mean draft if necessary when a new lot of material is to be processed in order to deliver the required mean sliver count. For obvious reasons care must be taken to avoid the lapping of fibres round the measuring rollers.

Alternative methods of measurement include: electrical capacitance, photoelectric, pneumatic, sliver funnel pull-through force, resistance strain-gauge, drafting force, and Beta-radiation. Control based on drafting force measurement gives a much lower limiting wavelength compared with methods based on thickness measurement and has a basic advantage for the automatic control of short-term variations. Beta-radiation is claimed to give very accurate long-term measurement.

In an experimental top-to-yarn spinning machine the yarn withdrawal tension was used as a measure of irregularity to control the twist insertion rate, and thereby improve the yarn levelness.

Delay

In an open loop autoleveller after measuring the thickness at a point in the incoming sliver, it is necessary to wait until that point reaches the drafting zone before the appropriate draft can be applied.

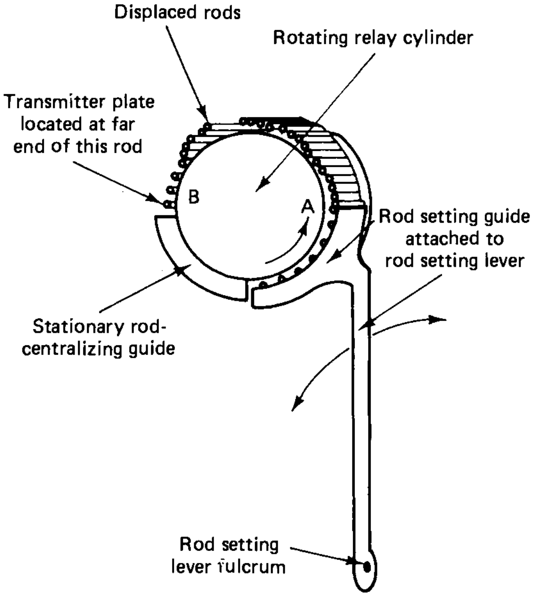


Figure 6.11 Relay cylinder

In the Raper autoleveller the relay cylinder carries a series of rods each of which is laterally displaced by the rod setting lever by an amount which corresponds to an instantaneous thickness measurement *(Figure 6.11)*. It takes the same length of time for a relay rod to pass from A to B as it does for the sliver to pass from the point of measurement to the point at which draft is applied in the drafting zone. For practical purposes on the Raper autoleveller the point in the drafting zone at which draft is assumed to take place is taken to be at a distance equal to 0.5 (mean fibre length) from the front roller nip. Therefore on a gill box, where a considerable delay is required, for a longer material the relay cylinder must be made to rotate faster; a change-wheel is provided for this purpose. Care must be taken to ensure free movement of the rods for setting purposes, but rod slip must be avoided during transit and at the transmitter. Mechanical wear causes a gradual drift, but this takes place at such a slow rate as to be unimportant.

The rod type'memory wheel' is the most widely used delay system on open loop autolevellers, but various other methods have been described, including electronic.

Transmitter

On the Raper autoleveller the transmitter plate is mounted on a lever which has its fulcrum parallel to the axis of the relay rods. A shown in *Figure 6.12*, the face of the transmitter plate is not parallel to the fulcrum and so lateral rod displacement on the relay cylinder causes the transmitter plate to move closer to or further from the relay cylinder as shown in *Figure 6.12(a)* and*(b)* respectively. The movement of the transmitter plate is magnified mechanically and conveyed to the variable speed unit by a connecting link. The rod which at any instant actuates the transmitter plate represents the sliver at the point in the drafting zone where draft is assumed to take place.

Variable speed unit

On the Raper autoleveller this consists of a pair of opposite-facing cones *(Figure 6.13)*. The concave bottom cone receives its constant-speed drive from a speed step-up in the gear box (not shown). The convex top cone receives its drive from the belt, the position of which is determined via the linkage from the transmitter plate. The variable speed output of the top cone is fed via a step-down in the gearbox to all the moving parts of the drafting zone which are in contact with the fibres, except for the front rollers; it is also fed to the relay cylinder and if necessary to the supply package creel.

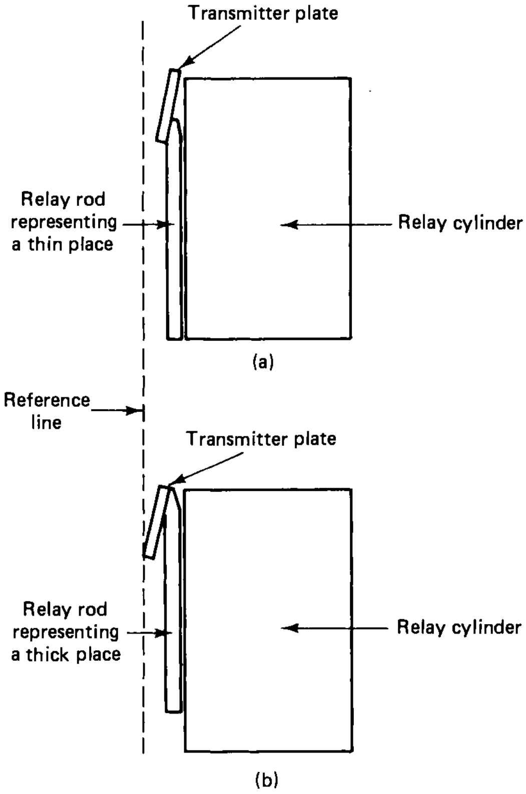


Figure 6.12 Plan view of transmitter unit

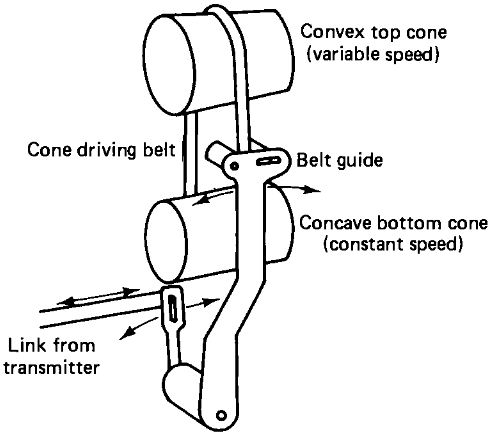


Figure 6.13 Variable speed unit

The reason for the cone shaping is apparent when it is appreciated that the back rollers should supply a constant mass of fibres per unit of time. It follows that input count × back roller surface speed is a constant. When back roller surface speed is plotted against input count to satisfy this condition, a graph of the form shown by the broken line in *Figure 6.14*

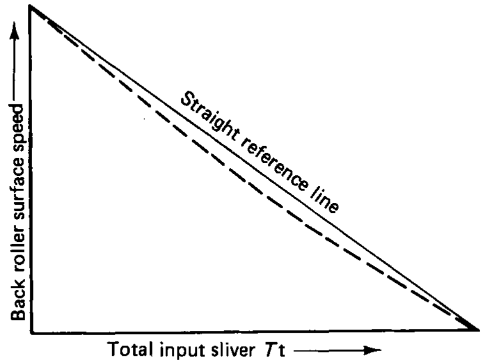


Figure 6.14 The relationship between back roller surface speed and input sliver *T*t

is obtained which clearly indicates the non-linear relationship.

The cone type variable speed unit has been used widely even though it has been criticised because it is claimed that belt slip and sluggish belt traverse can introduce unwanted variations. On the other hand it is claimed that the high surface speed of the cones reduces any tendency towards drive slippage, while permitting rapid sideways traverse of the belt. A weekly check takes only a minute or so to ensure that the unit is functioning correctly, and belt replacement is inexpensive and infrequent.

Alternative methods used for transmitter and variable speed control include hydraulic, differential gearing, electrical, electro magnetic, electronic, PIV gearing, pneumatic, and variable-speed motor; many of these are more expensive than the cone drive.

Most open loop autolevellers cater for a total range of variation from the intended mean input count of about 50%; this may be ± 25%, or it may be +15% to −35%, for example — the latter arrangement allows for more latitude in ends down. Beyond those limits the machine is automatically stopped and a warning light is illuminated. The delivered sliver variations are usually within ± 1%, based on the mass of 5 m lengths.

The advantages arising from the use of autolevellers in drawing include:

1. Fewer operations. This also implies fewer operatives, less floorspace, less power, fewer faults, and less waste (an important factor if the fibre being processed is expensive).
2. Long-term count variation is kept at a controlled level.
3. Less frequent wheel-changing and hence higher productive efficiency.

The introduction of autolevelling in drawing has led to shorter processing sequences, therefore adequate fibre mixing must be ensured prior to the drawing process.

Any irregularities introduced by the drafting mechanism itself cannot be corrected, hence short-term irregularities remain unimproved by the autoleveller and reliance must be placed on doublings to reduce their amplitude.

Platt Saco Lowell autoleveller drawframe

This is a closed loop autoleveller designed to be fitted between the creel table and the back of the main drafting system on the first passage drawframe after short-staple carding; the manufacturers consider this to be the most effective control point, especially when chute feeds or short-cut processing is used. Long-term input variations of ± 20% are reduced to ±1% and medium-term variations down to 5 m are significantly reduced. In this context for short-staple processing, medium-term sliver variation is defined as the variation between 10 m to 1000 m lengths. The positioning of the autoleveller permits the drawframe to run at its normal high delivery speed. The autolevelling system is shown schematically in *Figure 6.15*. Measurement is by tongued and grooved rollers linked to a differential transformer transducer. The mean setting of the transducer can be adjusted by a micrometer screw to control the mean output sliver thickness. The transducer output indicates the error both in phase and amplitude. The signal is amplified and phase-sensitively rectified to activate a pair of magnetic powder clutches driving the control rod of an infinitely variable speed unit. The variable output is

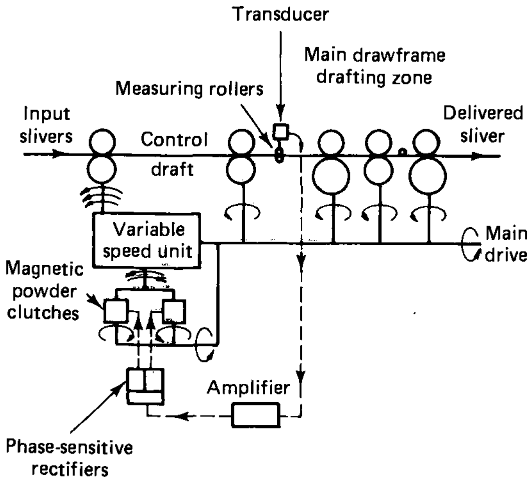


Figure 6.15 Schematic diagram of Platt Saco Lowell autoleveller drawframe

supplied to the back rollers of the control draft zone to correct the thickness error indicated by the measuring rollers until this error has been eliminated; then the clutch disengages and remains inoperative until otherwise signalled. This variable speed unit acts as a mechanical integrator operating within a narrow band of sliver error to which the clutch pair does not respond.

The Wira autocount for woollen carding

This device uses a light source and photoelectric cell to measure web thickness between the carder back doffer (i.e. the last doffer) and the condenser. The error is the difference between a standard light source and the measured light; it is then used to adjust the speed of the doffer and condenser accordingly.

Its function is to reduce variations *along* the web. There is a considerable time delay of about 10 seconds between altering the web thickness collected by the doffer at point A and its measurement at point B as shown in *Figure 6.16*. Furthermore a change of doffer speed alters the swift and worker loadings and this takes some time to reach equilibrium.

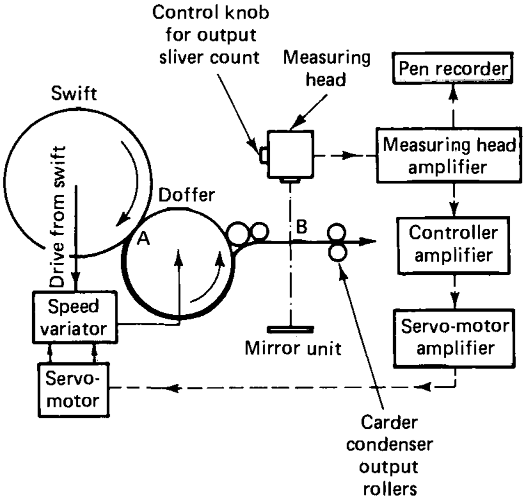


Figure 6.16 Schematic diagram of Wira autocount for woollen carding

Hunting has been avoided by having a low controller gain and an integral controller whereby the doffer speed is controlled by the integral of the errors measured over a given distance rather than being controlled by instantaneous error measurements. The result is a sluggish control action which has no tendency to hunt, but which gives highly accurate long-term control. This is exercised over low frequency irregularities up to 65 cycles/hour with a 0.9m diameter doffer. The main sources of such irregularities are the hopper bin run-down, and card clothing fill-up after fettling; short term irregularities are not corrected by the controller.

Advantages claimed for the Autocount include the following:

(1) Irregularities are reduced to within approximately ± 6% for irregularities exceeding about 12 m lengths.
(2) Extreme variations in the region of 15% to 20% lasting for over 10 minutes at the output, caused by hopper run-down or over-filling, can be reduced to not more than 5% lasting for less than 1 minute.
(3) A reduction of waste is achieved by delivering the correct slubbing count only two or three minutes from starting up after fettling except where differences of composition may arise for certain blends.
(4) The Autocount provides the carding engineer with a useful tool for changing from one lot to another, and a permanent record when required.
(5) The production rate can be increased gradually without any change in slubbing count until the maximum production rate for a given web quality is achieved.

Further reading

Woollen Carding, Wira (1968)
CATLING.H and DAVIES.I., *Text.Inst. & Industry,* **3** 196 (1965)
CATLING.H and DAVIES.I., *J.Text.Inst.,* **57** T395 (1966)

7

COMBING

The combing operation may be used to enable the ultimate yarn to be smoother, finer, stronger, and more uniform than otherwise would be possible.

As a general rule combing is confined to the better grades of natural fibres which have a longer and more uniform fibre length. It is used in the production of combed cotton yarns, worsted yarns, some flax yarns, and spun silk yarns. Sometimes a second combing operation may be used to produce double-combed yarns, and after dyeing on the worsted systems a process called re-combing may be used; a similar process called hackling may be used in flax processing.

The basic objectives of combing are:

(1) Removal of the short fibres
(2) Removal of non-fibrous impurities which may be called trash, and imperfections such as neps and slubs
(3) Straightening and parallelization of the long fibres which are retained

The continuous assembly of parallel fibres delivered by the comb is known as comb sliver; the fibres are not uniformly distributed and in practice some short fibres are present either from fibre breakage by the comb, or from some of the original short fibres fed into the comb. The incidence of fibre breakage in combing will be greater as fibre length, fibre weakness, fibre disorientation, fibre friction, and intensity of combing are increased.

The material rejected by the comb is called noil (although in the Lancashire cotton industry it is usually called waste) and it is used in the production of condenser-spun yarns.

The amount of noil produced may be expressed in two different ways:

The first is percentage noil

$$= \frac{\text{mass of noil} \times 100}{\text{mass of (noil + comb sliver)}}$$

This method is used in the cotton industry and in the re-combing section of the worsted industry; re-combing is a second combing operation which may follow the dyeing of about 60's quality wool, or finer wools, on the worsted system. An alternative expression often used in first-time woolcombing is the tear ratio.

$$\text{Tear ratio} = \frac{\text{mass of comb sliver}}{\text{mass of noil}} : 1$$

A change in the tear ratio gives a very sensitive index which when converted to noil percentage appears less impressive; on the other hand, percentage noil is a linear expression whereas tear is not.

The relationship between the two expressions is indicated below:

$$\text{Percentage noil} = \frac{100}{(\text{tear} + 1)}$$

$$\text{Tear} = \left(\frac{100}{\text{percentage noil}}\right) - 1$$

e.g. 10% of noil is equivalent to a tear ratio of 9:1.

In practice three factors contribute to *fibre* removal as noil, they are short fibre removal, long fibre loss in the noil, and fibre breakage. In the case of woolcombing the ridiculous arrangement of conventional regain allowances can also influence the calculation of noil percentage and of yield of top and noil.

Combing cycle of operation

All methods of combing follow the same basic sequence:

(1) Feeding

The fibres are fed into the comb so that they present a projecting fringe held either by pins or by nip jaws.

(2) Initial combing

The projecting fringe is combed by pins so that short fibres not held will be removed by the pins. Longer entangled fibres will either be straightened or broken thereby forming short fibres which may be removed by the pins. The fringe then consists of parallel fibres free of short fibres and entanglements.

(3) Final combing and drawing-off

The projecting fringe is gripped so that the remaining length of fibre can be drawn through pins to remove entanglements and short fibres.

(4) Sliver formation

The withdrawn fibres are overlapped to form a continuous sliver.

(5) Noil removal

The short fibres, trash, and imperfections are removed from the pins so that clean pins are ready for use in the next cycle.

Machine combs

The most important machine combs in use today are of the rectilinear type. The invention by Heilman in 1846 was originally intended for cotton, and was succeeded by the Nasmith cotton comb; the same basic principle was applied to the combing of short wools and became known by the alternative names of French or Schlumberger combs.

Although in the wool trade it was originally regarded as a comb for short wools, its capacity for combing longer wools was known but not exploited because of its economic disadvantages. In the UK the rectilinear combing of wool has become more popular because of increases both in its speed and of the supply and delivery package capacities, leading to higher production and productivity.

In general, compared with the Noble comb, the rectilinear wool comb produces a comb sliver with a greater proportion of short fibres at a similar rate of production, but with fewer neps even when the percentage of noil is the same, but in practise less noil is usually extracted by the rectilinear comb and so the product difference is accentuated.

Not surprisingly, the rectilinear combed product traditionally leads to a fabric with a greater shrinkage and felting potential, and with a softer handle.

Other machine combs were invented mainly for woolcombing and they used rows of vertical pins mounted in a rotating horizontal circle; the pins were heated and oil was added to the fibres to reduce friction and retain fibre straightness.

The Holden comb became obsolete during World War II due to economic rather than technical reasons. The Lister comb was designed, and is still used, for combing the longest of wools and hairs, usually prepared by gilling as an alternative to carding.

The Noble comb, capable of combing all except the very longest and very shortest fibres, was for over a century the most popular woolcombing machine for oil-combed medium length wools, but it has not been possible to obtain significant increases in production; it is no longer manufactured, and generally is being replaced by rectilinear combs.

Fibre feed to the comb

Previous mention has been made of the formation of hooked fibres at the doffer of the card, and that there is a majority in number and in extent of trailing hooked fibres leaving the card doffer, these are subsequently referred to as major hooks.

Neps tend to be near the trailing ends of the long fibres with which they are entangled even though their average fibre length is appreciably shorter than the mean fibre length of the sliver.

Clearly the direction of feed into the comb of such an asymmetrical sliver will influence the amount of noil extracted.

If the sliver in a can supplied by a card is fed without intervening processes into a comb, the major hooks will enter the comb as leading hooks because the last end of sliver into the can will be the first one out. An even number of processes between card and comb will maintain this same direction of feed into the comb provided that reversal takes place at each operation. The direction in which a sliver is fed into a comb has a profound influence on the performance of the comb, but because the influence of feed direction depends on the type of comb this subject will be dealt with separately when each comb is discussed.

For a given material the drafting and doubling used between carding and combing reduces the total number of hooked fibres in either direction so that the improved fibre orientation and fibre extent decreases both the percentage of noil and also the load on the pins of the comb and therefore permits higher rates of production.

The rectilinear cotton comb

Although combing has been of declining importance for the production of fine cotton yarns there has been a compensating increase in the use of combed cotton for blending with man-made fibres. This is likely to continue for the highest quality products, but combing is unpopular from the materials handling point of view. The use of tandem cards prior to combing may permit lower noil percentages without loss of yarn quality.

Preparatory processes

In cotton combing, fibres fed in as trailing hooks generally have a greater chance of being removed as noil than do leading hooks; the reasons for this will be explained at the appropriate stages of the combing cycle. The probability of removal depends on the *extent* of the trailing hook in relation to the length of feed into the comb. Trailing hooks are also likely to cause some other long fibres to be pulled forward by entanglement, causing some long fibres to become noil. Hence feeding with a majority of leading hooks into the comb usually decreases the percentage and mean fibre length of the noil extracted, and increases the mean fibre length of the comb sliver although this is not necessarily true when short detachment settings are used on the comb.

The cotton comb is highly sensitive to the direction in which the fibres are fed to it and also to the total hook content of the fibres fed into the comb. When there is an even number of machines between the card and the comb, the majority of hooks will enter the comb as leading hooks provided that reversal takes place at each operation; there will also be a minimum number of trailing hooks entering the comb. Hence it is usual to employ two machines between cotton card and comb, using draft to improve the fibre orientation.

There is an indirect relationship between noil percentage and pre-comb draft, i.e. the product of the drafts used between carding and combing. In practice pre-comb draft is usually between 10 and 30. Too high a draft increases parallelization which may cause fibre licking i.e. catching on adjacent layers when the laps are unrolled, and with short cottons, drafts higher than 10 may not give any worthwhile reduction of noil.

The improved orientation in itself reduces the number and extent of hooked fibres and thereby contributes to a reduction of noil percentage.

Each head of a cotton comb is fed by a lap produced from card sliver. A comb lap is described on p.85.

One method for making laps of this form is to have a drawframe following the card with about 10 doublings and a total draft of about 8, delivering slivers of about 6 ktex; the drafting unit consists of two consecutive drafting zones to give a gradual breakdown of the entangled fibres. This is followed by a lap forming machine as shown in *Plate 13* with about 12 doublings and a draft from 2 to 5 at each of four heads from which the deliveries are superimposed and passed through an automatic lap former. Such an arrangement may have a total draft product of from 16 to 30, and a total doublings product of about 480, and it ensures that of the fibre hooks present in the lap, the majority will be fed as leading hooks into the comb.

The relatively high draft at the drawframe will give efficient removal of the trailing hook fibres at that process and these will also be trailing hooks when fed into the comb; since combing will straighten out many of the leading hooks, the minimizing of the number of trailing hooks fed into the comb is of considerable importance in lap preparation.

General features of a cotton comb

A cotton comb may have up to 12 combing heads driven from a common main shaft. The slivers delivered by the heads at one side are conveyed along a transverse front table to be fed as doublings into a drawbox at the end of the machine. Two coiler cans of sliver are produced, one from each set of doublings (*Plate 14*). Typical approximate overall dimensions of the complete machine are: length 6 m, width 1.75 m. Air extraction is used to remove dust and fly from various working parts of the machine.

Cotton comb cycle of operations

(1) Feeding

The feed roller A rotates to feed fibres forward through the open nippers B and C as shown in *Figure 7.1(a)*. For a 36 mm staple cotton a feed length of about 6 mm might be used but feed lengths may be altered for different raw materials.

(2) Initial combing

The retreating spring-loaded nippers BC close and direct the projecting fringe of fibres D into the pins of the rotating 150 mm diameter cylinder E as

Plate 13. Pre-comb lap forming machine. This particular machine, which does not incorporate a drafting zone, assembles up to 24 drawframe slivers to form a compact lap ready for the creel of the cotton combing machine. Empty replenishment bobbins are fed in as each full lap is doffed automatically on to the table in the foreground. Courtesy of Platt Saco Lowell (UK) Ltd

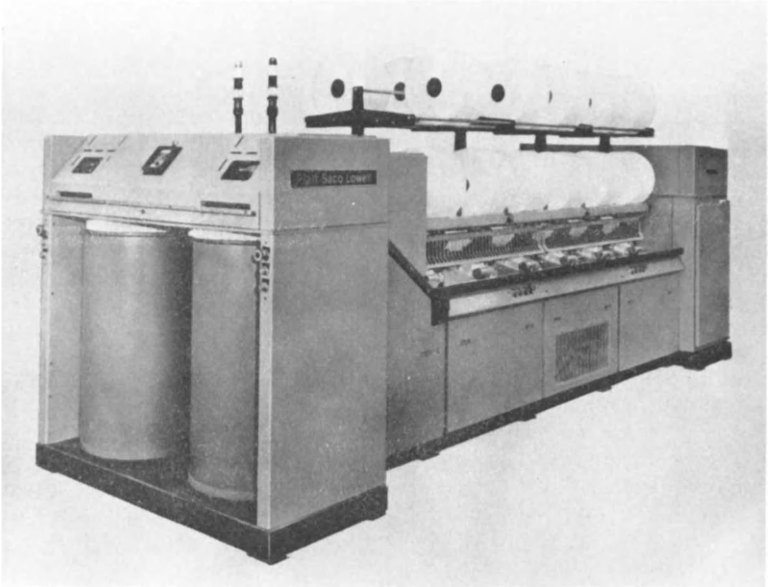


Plate 14. Cotton combing machine. This is a double-sided machine with six heads on each side. Each hand is fed by one lap and it runs at about 240 nips/min; spare laps can be seen on the top platform. The six combed slivers from one side are overlapped to form doublings which are fed into their respective two-zone drafting unit at the drawbox head; drafts from 5 to about 13 may be applied. Each side delivers a sliver from 2.8 to 5.6 ktex, giving a combined total production rate of up to about 55 kg/h in the two cans delivered. Courtesy of Platt Saco Lowell (UK) Ltd

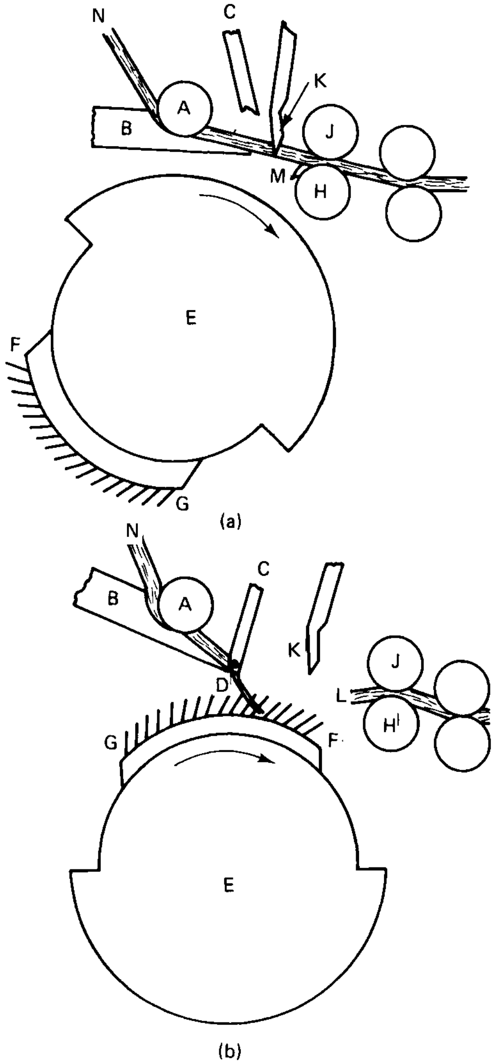


Figure 7.1 Cotton comb cyle of operations (side elevations) (a) feeding, final combing, and drawing-off (b) initial combing. A, feed roller; B, feed plate and lower nipper; C, upper nipper; D, fibre fringe initially combed; E, cylinder; F, first row of pins; G, last row of pins; H, bottom detaching roller; J, top detaching roller; K, top comb pins; L, detached fringe of fibres; M, trailing end of previous fringe; N, continuous lap feed

shown in *Figure 7.1 (b)*. The cylinder pins are graduated from the first row F which holds thicker and more widely-spaced pins, to the last row G which has finer and closer pinning. The closed nippers BC start to move forward and ease the strain on the fibres as the last row of pins passes through the fringe.

It is conceivable that a fibre with a long leading hook could have both limbs of the hook held by the nippers so that the loop could be entered by the cylinder pins, with the high probability that fibre breakage might occur. In practice only a very small percentage of fibres have long enough leading hooks for this to happen, so it can be concluded that breakage of leading hooks during initial combing does not make a major contribution to noil formation at long detachment settings, although this may not be true at short detachment settings.

(3) Final combing and drawing-off

The nippers BC open as they move further forward and the projecting fringe rises level with the detaching roller nip HJ. The surface speed of the detaching rollers is greater than the forward movement of the nippers BC when the fibre fringe is gripped by the rollers HJ. The fringe becomes tensioned and is forced upwards into the top comb pins K as shown in *Figure 7.1 (a)*; the pinning density is usually from 26 to 31 pins/cm. Drafting occurs between the detaching roller HJ and the fibres in the open advancing nippers BC with the pins of the top comb K controlling fibre movement. Neps, impurities, and short fibres are held back by the top comb pins K; they will be near the end of the fringe presented to the cylinder at the next cycle of initial combing. The distance from the nippers BC in their forward position to the nip of the rollers HJ is called the detachment setting; this setting influences the amount of noil extracted — for a 36 mm staple cotton the detachment setting might be about 22 mm. Theoretically the fibres in the comb sliver produced should all be longer than the detachment setting, but in practice a small quantity of shorter fibre is found to be present due to fibre breakage and to inefficiencies arising in initial and final combing.

The top comb K and open nippers BC then move back from the detaching rollers leaving a fringe of finally combed fibre tail ends held in the roller nip as shown at L in *Figure 7.1 (b)*. The nippers BC close during the backward movement ready for the next cycle of initial combing.

The presence of a trailing hook in a fibre fed into the comb will reduce the length of fibre protruding from the nippers and may either make it too short to be gripped by the detaching rollers, in which case it may be removed as noil by the following cycle of initial combing, or alternatively if it is long enough to be gripped by the detaching rollers, it may cause the fibre to be involved in hoop friction with the top comb in which case the likelihood of its breakage may be increased although at short detachment settings one or both parts of the broken fibre may still be long enough to be drawn into the comb sliver.

(4) Sliver formation

The detachment rollers HJ rotate in the reverse direction to cause part of the trailing end of the previously combed fringe to protrude at M as in *Figure 7.1 (a)* before gripping the leading end of the new fringe. This makes an overlap or piecening to form a continuous sliver, the length of overlap being important from the sliver levelness point of view.

(5) Noil removal

Under ideal conditions the comb should remove as noil all fibres shorter than the detachment setting, which may be about 22 mm for a 36 mm staple cotton. Furthermore, because a moving nip is used, the length of fringe presented to the cylinder by the closed nippers during initial combing is equal to the detachment setting *plus* the length of feed. It follows, therefore, that even under ideal conditions the length of the *longest* fibres removed in the noil must be equal to the detachment setting *plus* the length of feed, and *minus* the distance from the nippers to the cylinder pins. In the examples given previously for a 36 mm staple cotton this means that the noil *must* contain some fibres up to about 24 mm long.

The separation of fibres of length L into comb sliver and noil, where detachment setting$<L<$ (detachment setting + length of feed), will be determined by the position of the trailing end in relation to the nip positions before and after feeding.

In practice the noil may contain much longer fibres, and the sliver much shorter fibres, than theory predicts because of fibre disturbance, lack of orientation, fibre breakage, and imperfect initial combing..

It is generally accepted that less noil is extracted when the major hooks are leading when fed into the comb; this is true at high detachment settings, because both parts of a broken leading hook fibre will have a greater chance of becoming noil. However when low detachment settings are used there will be a greater tendency towards some of the broken leading hook fibres being drawn into the comb sliver. Trailing hook fibres have a greater chance of appearing in the comb sliver at low detachment settings, whereas at high detachment settings the likelihood of them becoming noil increases.

The noil contribution from trailing hooks increases more rapidly with increased detachment setting than does the noil contribution from leading hooks, hence the generally accepted view that slivers fed with major hooks leading gives less noil. At low detachment settings the converse may be true.

The fibres and impurities collected by the cylinder pins are removed from the pins as they pass underneath the cylinder by the bristles of a rotating brush (not shown) moving in the same surface direction as the pins but at a higher speed. The noil is released from the brush by centrifugal action and is transferred pneumatically to a large container at the rear of the machine, the air being filtered before being released.

In practice the different parts of the combing cycle take place concurrently; for example, feeding takes place at the same time as final combing and drawing-off. The way in which the actions may be synchronized is indicated in *Figure 7.2*, although the timing details may be varied to cater for different cottons. On modern machines the cycle may be repeated at up to 240 cycles/min, giving an average production rate of about 5 kg/h per head although there may be wide deviations with different cottons.

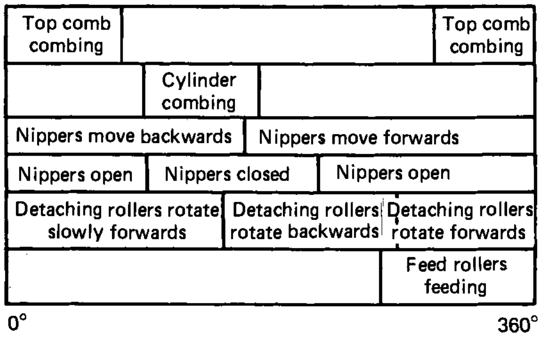


Figure 7.2 Timing diagram of a cotton comb

Sliver delivery of a cotton comb

Each combing head sliver contains a periodic irregularity with a wavelength of about 33 to 46 mm caused by the overlapping of successive tufts of fibre; this irregularity is called a 'piecening wave'.

The combing head slivers are fed into the comb drawbox as doublings and are drafted to form slivers of 3 to 6 ktex delivered into a coiler can up to 0.5 m diameter and 1.2 m high with a capacity for about 50 kg.

During drafting the doublings tend to move in to phase with each other and form a large amplitude periodicity called a 'drawbox wave' with a wavelength in the region of 250 mm in the delivered sliver. By using a sliver condensing funnel off-set to one side, the overlapping tufts can be put in a staggered formation which helps to reduce the periodicity of the product. This arrangement may be applied at each combing head and also at the comb drawbox; a considerable improvement of the piecening wave can be achieved by attention to fibre alignment and distance of tuft overlap.

Consecutive drafting in the same direction must be avoided after combing and hence single-zone drafting with reversal of draft direction at each subsequent process will give the best sliver levelness.

Applications of cotton combing

The noil extraction rate can range from 5% to 30% depending on the end-product requirements and on the raw cotton available. Although there may be many exceptions. Table 7.1 indicates a general classification of products:

Scratch combing, otherwise known as upgrading, may reduce spinning and winding end-breakages compared with carded cotton yarns. Increases from 5% to 30% noil improve yarn strength and appearance and give lower breakage rates. Double combing gives better yarn levelness and a reduction of nep compared with ordinary combing at similar noil removal rates.

Woolcombing

After worsted carding the wool is prepared for the combing process by being passed through a number of gill boxes, using doublings and drafting. It is generally accepted that the conventional gilling sequence in which card sliver is fed into cans before the first gilling operation gives less fibre breakage and therefore less noil than when slivers are fed directly into the first gill box without a reversal of direction.

Gilling the card sliver improves fibre alignment, with each successive gilling process giving a diminishing improvement. An increase in the number of operations up to 3 or 4 gillings gives a significantly improved fibre alignment, and also may be associated with an increased comb sliver nep content. The improvement in fibre orientation is less with short fibre length, and may be associated with the higher fibre breakage in combing which may arise with short wools.

The percentage of noil extracted in woolcombing may vary from about 5% up to about 16%. Because of the length/diameter relationship of wool fibres, the mean fibre diameter of noil may be about 10% finer, and the comb sliver about 1% coarser, than the raw wool from which they have been produced; even large changes in the percentage of noil extracted will have only marginal influence on these relative diameters.

The rectilinear wool comb

Preparatory processes

The rectilinear wool comb is fed with 10 to 24 doublings, giving a total input of about 320 to 360 ktex. An increase of total input sliver thickness will theoretically give an increased rate of production without influencing the noil percentage or the mean fibre length of the comb sliver but in practice an excessive input would cause overloading and inefficient combing.

The feed slivers are usually produced from card sliver by using three processes of gilling. This improves fibre alignment and ensures that the majority of hooks are fed into the comb trailing thereby minimizing fibre breakage and noil extraction, although after three gillings the directional effect is not usually very great.

There is an optimum quantity of fibre lubricant as far as obtaining minimum noil extraction is concerned. Under ideal conditions of woolscouring this may be a residual grease content of about 0.8% for merino wool, but a lower grease content than this would be preferable from the point of view of nep formation in carding. With a low residual grease content, the addition of about 2% fatty matter on the mass of wool for vegetable and mineral oils, or 1% for water-soluble compounds, provides for minimum noil removal in rectilinear woolcombing.

General features of a rectilinear wool comb

As shown in *Plate 15*, the comb is a single-head machine delivering a single sliver of about 20 to 37 ktex into a large coiler can 0.76 m diameter and 1.1 m high with a capacity for about 20kg of sliver. Typical over-all dimensions of the machine including supply cans and noil container are approximately 4.8 m × 1.6 m; the working width may be up to 500

Table 7.1 *Applications of cotton combing*

Yarn description	*Yarn count range (tex)*	*Percentage noil*
Scratch combed	7.5–10.0	up to 5
Semi-combed	7.5–10.0	5–10
Ordinary combed	6.0– 7.5	10–18
Super combed	5.0– 6.0	above 18
Double combed	finer than 5.0	(1) 18 (2) 7

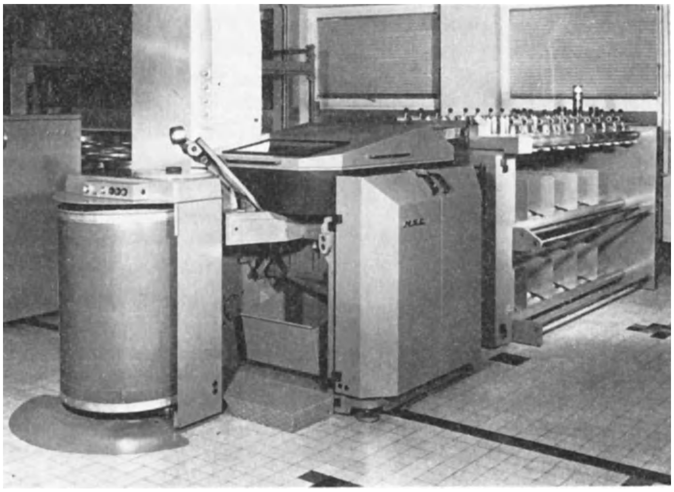


Plate 15. Worsted rectilinear comb. The creel at the far end of the machine has two tiers and is double-sided, with a capacity for 20 balls of feed sliver; alternatively a can creel may be fitted. The machine is fully enclosed, with a perspex observation panel in the top hood. It runs at up to 210 nips/min, with a production rate of up to about 40 kg/h on good length clean wools. Courtesy of N. Schlumberger & Cie

m. Air currents are used to remove dust and fly, and to control fibre movement.

Rectilinear wool comb cycle of operations

A general side elevation diagram of the main working parts is given in *Figure 7.3*. The basic principles involved are very similar to the cotton comb; the main points of difference are mentioned in the following notes.

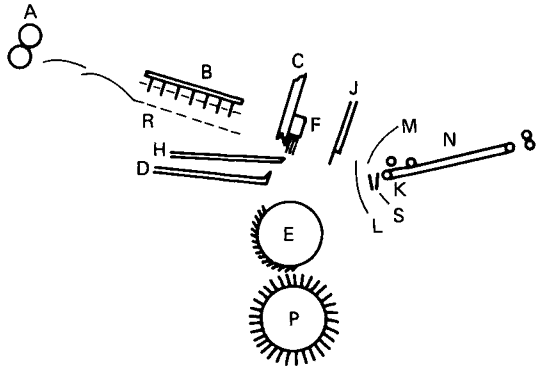


Figure 7.3 Side elevation of a rectilinear wool comb. A feed rollers; B, feed gill; C, upper nipper; D, lower nipper; E, cylinder; F, brush on upper nipper; H, shovel plate; J, top comb; K, detaching rollers; L, counter-sword; M, top sword; N, sliver-supporting apron; P, noil brush; R, feed grid; S, air suction duct (as an alternative to L and M)

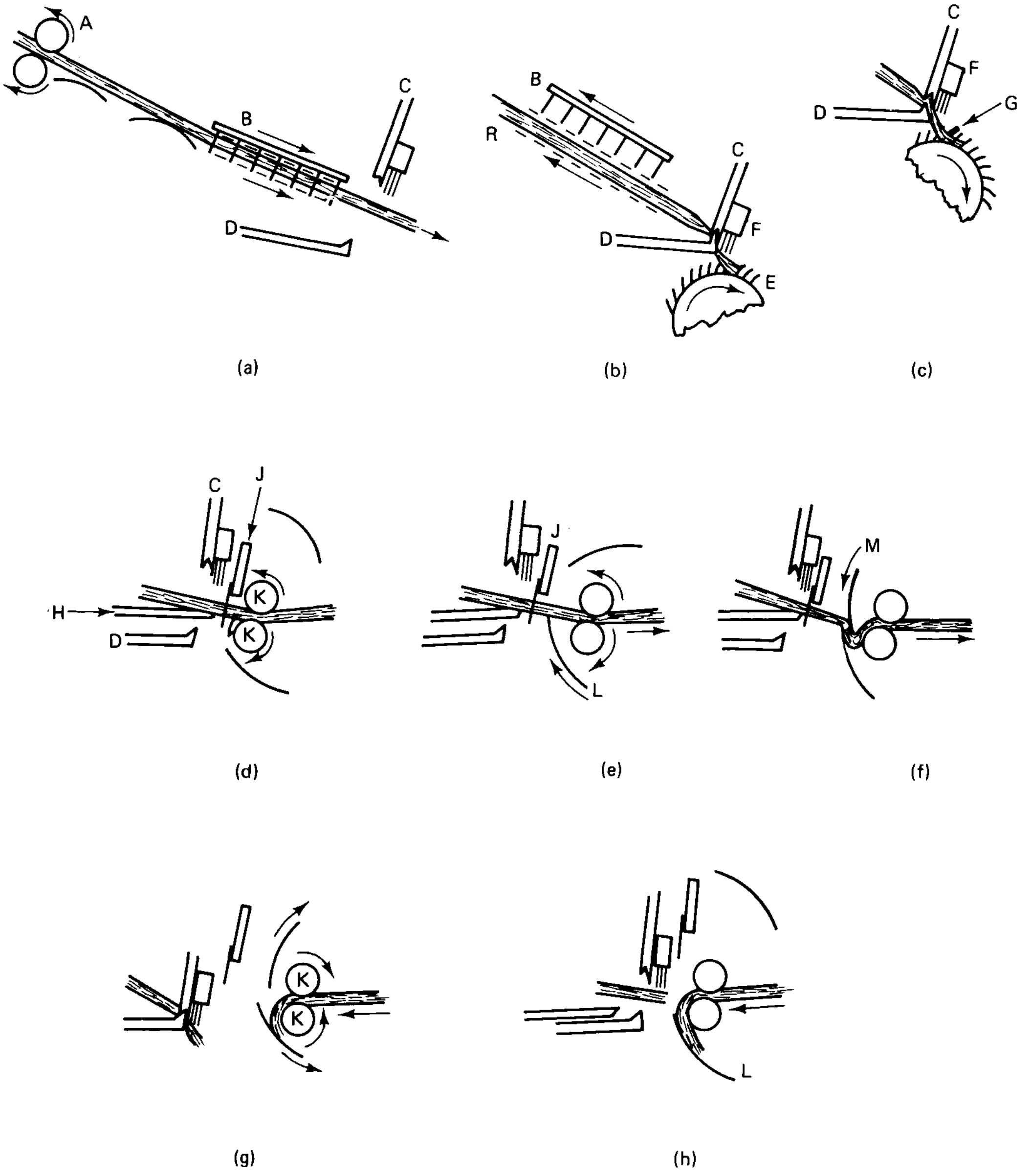
(1) Feeding

The feed roller A and feed gill B feed a fringe of fibres through the open nippers (*Figure 7.4 (a)*). For a medium length burry wool the feed length may be about 6.5 mm depending on the amount of impurity present, a shorter feed being used for more burry material; longer feeds may be used for long wools, and shorter for shorter wools. The length of the feed fringe is determined by the feed rollers in conjunction with the feed gill; this setting, along with the total sliver thickness fed to the comb, determines the production rate.

(2) Initial combing

The nippers CD close and lower the fringe of fibres into the pins of the cylinder E (*Figure 7.4 (b)*) Penetration of the pins is aided by a brush F, and for burry wools a de-burring blade G may momentarily push the fibres down into the last few fine rows of pins (*Figure 7.4 (c)*) The use of a de-burring blade is of little benefit when combing wools containing a low percentage of vegetable matter, and as it may present mechanical difficulties when running at high speed its omission may be preferred; an alternative used on some combs is to draw the fibres into the pins pneumatically.

During this time the feed fill B rises and moves back along with the feed grid R (*Figure 7.4 (b)*) before being lowered ready for the next feeding cycle.



(a) (b) (c)

(d) (e) (f)

(g) (h)

Figure 7.4 Rectilinear wool comb cycle of operations: (a) feeding; (b) initial combing; (c) de-burring blade; (d) final combing and drawing-off; (e) counter-sword raised; (f) top sword lowered (for very long fibres); (g) recoil of detaching rollers; (h) overlapping of tufts about to commence

Under normal conditions the combing efficiency of the cylinder is very good, nevertheless some neps and vegetable particles may remain in the fringe and may then appear in the comb sliver.

The direction of feed into the comb may have an influence on the noil percentage because when fibres are combed with hooks leading, both ends of the hook may be held by the nipper while the loop is broken by the cylinder pins; when the hooks are trailing there is less fibre breakage. This observation is contrary to that which applies to the cotton comb. The reason for this difference is that the mean hook extent in wool fibres is greater in relation to the nipper to cylinder distance than is the case with cotton fibres on a cotton comb.

The cylinder has a diameter of about 150 mm and it carries about 20 comb bars, usually containing thicker and more widely spaced pins on the first bar ranging to thinner and closer pins on the last bar (e.g. first bar 4 pins/cm, 1 mm diameter; last bar 26 pins/cm, 0.38 mm diameter).

(3) Final combing and drawing-off

The nippers CD rise up and open and at the same time the shovel plate H moves forwards between the open nippers to support the fringe as the top comb J descends and the detaching rollers K draw the fringe of fibres away (*Figure 7.4(d)*) Inefficient penetration of the top comb may permit some neps and vegetable particles to be drawn past it and into the comb sliver.

Research indicates that in itself final combing does not account for any appreciable amount of fibre breakage but that the number of pins/cm and the pin thickness of the top comb are of paramount importance as regards removal of neps and vegetable particles.

Frictional contact with the long fibres which are being detached may cause neps, vegetable particles, and short fibres to be accelerated, but with the exception of a few neps which may be attached to fibres which have their leading ends extending into the detaching zone they are held back behind the pins of the top comb J and may interact with other fibres, causing entanglement and thereby contributing to subsequent fibre breakage; they should be removed by the cylinder pins at the next cycle of initial combing.

The top comb may have about 26 pins cm with a rectangular cross-section measuring about 0.3 mm × 0.7 mm for merino wool.

In order to enable long fibre lengths to be drawn away, the detaching rollers K are usually mounted on a carriage which moves away from the nippers at the same time as the detaching rollers rotate to withdraw the fringe.

At this stage on some models of comb, the counter-sword L rises to support the fringe of fibres in the top comb J (*Figure 7.4 (e)*). With very long fibre lengths, drawing-off may be further assisted by the top sword M moving down (*Figure 7.4 (f)*) causing the tail ends of the fibres to be drawn forward over the edge of the counter-sword. On modern machines the mechanical complications of the sword and counter-sword have been replaced by the pneumatic suction duct S shown in Figure 7.3, and mounted on the carriage which moves the detaching rollers back and forth.

(4) Sliver formation

After completing the drawing-off action, the carriage starts to move towards the nippers and the detaching rollers K recoil to start feeding out the tail ends of the previous fringe (*Figure 7.4* (*g*)). As the carriage approaches the nippers, the parallelism of the fibres is controlled on the newer models by the air suction at S, (*Figure 7.3*), which also removes any remaining small particles of dust; on older models the fibres were controlled by the counter-sword L (*Figure 7.4 (h)*). As the carriage approaches close to the nippers the detaching rollers K first stop rotating, then just before the leading end of the initially combed fringe is reached, they start to rotate in the forward direction and grip the new fringe (*Figure 7.4 (d)*) to overlap the new tuft of fibres over the previous one by a chosen amount which determines the thickness of the delivered sliver. The continuous sliver thus formed is supported by an apron N, (*Figure 7.3*), before being condensed through a funnel and delivered into a coiler can.

(5) Noil removal

In the usual arrangement of the rectilinear wool comb where the detaching rollers are mounted on a moving carriage, the length of fringe presented to the cylinder by the closed nippers during initial combing is approximately equal to the noil setting, i.e. the distance between the nip of the detaching rollers K and the nippers CD when the carriage is at its closest position to the nippers. Hence assuming perfect theoretical combing, the noil will include some fibres about as long as the noil setting, along with all the fibres shorter than (noil setting *minus* length of feed), and the comb sliver will contain all fibres greater than the noil setting along with some fibre lengths down to (noil setting *minus* length of feed).

The selection into comb sliver or noil of fibres of length L in the range noil setting>L> (noil setting *minus* length of feed) is determined by the proximity of the leading end of the fibre to the leading end of the fringe immediately prior to detachment.

In practice because fibre breakage in the region of 15% to 30% may arise, the mean fibre length of the comb sliver will be shorter, and the noil percentage greater, than theory would predict.

The least distance possible for the noil setting is about 20 mm, so that provision can be made to produce noil with fibres not longer than about 20 mm. The practical noil settings for 64's quality South African wool usually range from 23 mm for a 6/8 month growth up to 27 mm for a 12 month growth, the shorter wool giving about 8% noil, and the longer one giving about 4% with wools containing a low proportion of vegetable matter; larger amounts of noil would be produced with burry wools.

An increased noil setting for a given wool gives an approximately linear increase of noil percentage containing longer fibres with more nep and vegetable matter removed in the noil. However the accompanying increase of mean fibre length in the comb sliver is limited, even though the percentage number of short fibres in the sliver is reduced, because there is usually an associated increase in fibre breakage with increased noil setting.

An increased length of effective feed fringe (i.e. increased length of feed roller and feed gill forward movement) theoretically should cause a reduction of noil percentage and a decreased mean fibre length of the comb sliver. In practice, up to a point, for a given noil setting an increase of feed length does give a reduced amount of noil, but beyond that point any further increase in feed length may then cause an *increase* of noil percentage; this is due to interaction of fibres behind the top comb during final combing. The length of feed for minimum noil percentage increases linearly with noil setting, and percentage fibre breakage decreases slightly with increased feed length.

The balance between the clarity of the comb sliver and the noil percentage has to be determined according to requirements. If both maximum clarity and minimum noil extraction are required, the length of both feed and noil settings must be reduced thereby giving a lower production rate. Where clarity is of paramount importance it is doubtful whether noil settings greater than 30 mm offer much benefit when combing merino wools because of the attendant increase in noil percentage and fibre breakage.

A minimum percentage of noil is extracted when slivers are fed into the comb without delay after conditioning so that the comb sliver has a regain of about 22%, preferably at 68 to 80% R.H. The actual regain of the noil produced is lower than that of the comb sliver — the difference between the two being greater at higher regains.

The fibres and impurities collected by the cylinder pins are removed by a rotating brush P (*Figure 7.3*), and transferred by a doffing type action to a roller covered in card clothing (not shown); the fibres are removed from the card roller by a reciprocating doffing comb and delivered into a container at floor level. Stray very short fibres, dust, and vegetable particles released by the brush (called comb shoddy) are transferred pneumatically to a large container at the back of the machine.

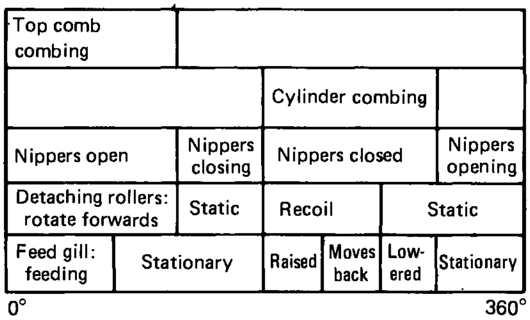


Figure 7.5 Timing diagram of a rectilinear wool comb

In practice some of the parts of the combing cycle which have been described separately, take place simultaneously. The basic way in which the actions may be synchronized is shown in *Figure 7.5*, although variations may arise with differences in models of comb and types of raw material. Modern rectilinear wool combs may repeat the cycle at about 180 times per minute, giving a production rate of about 1 kg/h per micrometre of mean fibre diameter on good length clear merino wools.

Worsted top finishing

In the worsted industry the woolcombing operations (including scouring, drying, carding, combing, and top finishing) are often carried out in a factory which is separated from the spinning factory. Many worsted spinning firms have no woolcombing operations of their own and so they purchase tops from a topmaker.

The product of top finishing is in the form of 20 or 25 ktex top sliver formed into a package, known as a top, which contains up to 22 kg of sliver which is up to about 1100 metres long.

Top finishing usually consists of two gilling operations which combine drafts, doublings, and pin control. The first finisher is usually an autoleveller gill box fed by from 8 to 30 doublings of comb sliver, depending on the comb sliver thickness, and moisture is usually added to the fibres at this stage.

The second finisher gill box may be fed by from 2 to 8 doublings and delivers the required package form. The tops are usually individually wrapped in polythene before being packed in bales ready to be transported to the spinning factories.

Where appropriate, the relative position of combing in processing sequencies is shown in the Appendix.

Further reading

OXTOBY, E., *British Wool Manual (2 Ed)*, Columbine Press, Buxton (1969)

CHARNLEY, F., *Manual of Cotton Spinning Vol 4 Part 2, Drawframes, Combers, and Speedframes*, Textile Institute/Butterworths (1964)

8

PACKAGE FORMATION AND DRAWING PRIOR TO SPINNING

When a series of operations make use of repeated drafting and doubling, with reversal of draft direction, the product of one operation must be transferred to the next operation without disturbance of the fibre arrangement; this necessitates delivering the product into some form of package which will withstand handling. The trend towards faster machine speeds has made the production of larger packages necessary to minimize handling and down time so that increased productivity can be achieved without increased work loads on the operative; a further advantage is that fewer piecenings are made.

Nevertheless other factors such as machine capital cost, taxation policy, floorspace occupied, delivery speed, material in work, and power consumption may impose a maximum limit on package size in certain cases; consideration of the requirements of subsequent operations must also be taken into account. The basic problem is that some costs increase with package size, whilst others remain constant or decrease; the optimum package size for a given process, therefore is not determined solely by technical considerations.

False-twist (self-cancelling twist)

When weak sliver is conveyed over a distance which is long relative to the fibre length, false-twist may be used to provide added strength.

When a stationary strand of fibres held at AC is rotated at B (*Figure 8.1(a)*), then S twist is inserted between AB, and Z twist is inserted between BC. Although the algebraic sum of the twist between AC is zero, when tension is applied to such a strand the inward radial pressures may increase inter-fibre friction to such an extent that fibre slippage can be avoided.

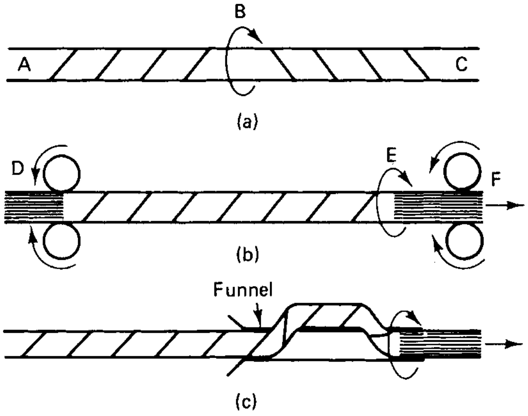


Figure 8.1 False twist insertion (a) stationary strand of fibres (b) strand moving from left to right (c) rotating funnel inserts false twist

Under the dynamic conditions which arise when the sliver is moving, the situation is modified (*Figure 8.1(b)*). At the right-hand side of the point of rotation E, the turns of Z twist initially inserted will be lost from the system because they are free to pass through the nip at F. After this initial loss of twist, the system will settle into an equilibrium state. Assuming a linear sliver speed of 50 m/min and 1000 rev/min of the sliver at E then there will be 20 calculated turns per metre inserted into the sliver between DE (neglecting contraction due to twist insertion). As the strand moves a distance of 50 mm from left to right, the following will occur:

(1) 50 mm of twist-free sliver will enter the system at D,

(2) one turn of S twist will be inserted to the left of E, thereby maintaining the required level of S twist between DE, and
(3) 50 mm of twisted material will pass point E carrying with it one turn of S twist; this will cancel out the turn of Z twist inserted between E and F, leaving the material between E and F twist-free.

In order to provide the necessary fibre cohesion, therefore, it is necessary to place the point of rotation E as close as possible to F, and to improve the efficiency of twist insertion, the sliver may be passed through two holes in a rotating funnel as shown in *Figure 8.1(c)*. Inevitably, because of slippage, the tube must rotate at a higher speed than that required of the sliver.

The false-twist principle has had important applications in the production of textured continuous filament yarns, and in woollen ringframe fibre control; alternating S and Z directions of false-twist are used in self-twist spinning, and in consolidating twist-free rovings in Continental worsted processing and in woollen slubbings (the equivalent of woollen rovings).

There are five main types of delivery which produce packages:

(1) lap (or roll)
(2) can,
(3) balling head,
(4) flyer lead (Bradford drawing box), and
(5) bobbin lead (cone drawing box).

The first three types of delivery are used for twist-free fibre assemblies; laps provide a means of feeding a continuous sheet of fibres from a compact roll, cans provide a large package of low bulk density for thick slivers, and the balling head delivery provides a smaller package suitable for twist-free rovings or worsted tops.

The other two methods provide packages with a high bulk density, for twisted rovings.

A roving may be defined as a fine slubbing intended to be fed into the back rollers of the spinning frame drafting zone. Conventional spinning frames are usually fed by rovings which are finer than about 1.5 ktex, although in semi-worsted and jute spinning it is more usual to omit the roving operation and to spin direct from sliver. Newer spinning methods, such as open-end spinning usually spin from sliver.

Lap or roll delivery

A lap may be described as a sheet of fibres wrapped under pressure round a core to form a compact roll which will fit conveniently into the creel of the following process. This method of delivery is used: at the scutcher, the last operation in a conventional cotton blowroom to provide a supply package for the card; to form the supply package for each head of a cotton comb; and in jute processing.

A cotton scutcher lap is usually approximately 1.1m wide and contains about 100 m of a 400 ktex sheet of fibre compacted by calender rollers with a total force of about 4500 N applied to form a 40 kg package. One lap is sufficient to fill one or two complete card delivery cans so that piecenings are only made at the commencement of a can. The scutcher is fitted with an autolevelling device to promote lap uniformity. An alternative arrangement is to transfer loose fibres from the scutcher to the card pneumatically via a chute fee; this avoids the need for laps and the labour and other costs involved in transferring them to the cards. When chute feeds are used it is essential to have autolevelling either on each card or on the first drawbox after carding.

A cotton comb lap consists of about 340 m of approximately 70 ktex compacted fibre sheet about 260 mm wide, wrapped to form a 14 kg roll as shown in *Plate 13*; a jute roll is shown in *Plate 8*.

Can delivery

This method is used where slivers thicker than about 2.5 ktex are being delivered; if slivers are too thin they are liable to be damaged or broken when being withdrawn from the can at the next operation.

Modern machines use a coiler can delivery as represented in *Figure 8.2 (a)* and shown in *Plates 4, 7, 14* and *15*. This ensures a stable sliver arrangement which will permit easy sliver withdrawal. The coiler tube delivers a continuous spiral of sliver into the slowly rotating can to form coils of sliver in the can as shown in the plan view. This means that one turn of twist is inserted into the sliver per revolution of the can; in practice the amount of twist inserted is negligible. Reciprocating can rotation was first introduced to eliminate the twist insertion but this was superseded by having a stationary can and a coiler head performing a hypocycloid motion as shown in *Plate 7* — this method simplifies the handling of cans.

Sometimes cans are made with a spring-loaded false base which rises as the mass of sliver decreases during emptying of the can thereby ensuring that the top of the sliver pile is accessible near to the top rim of the can. This is particularly useful when proces-

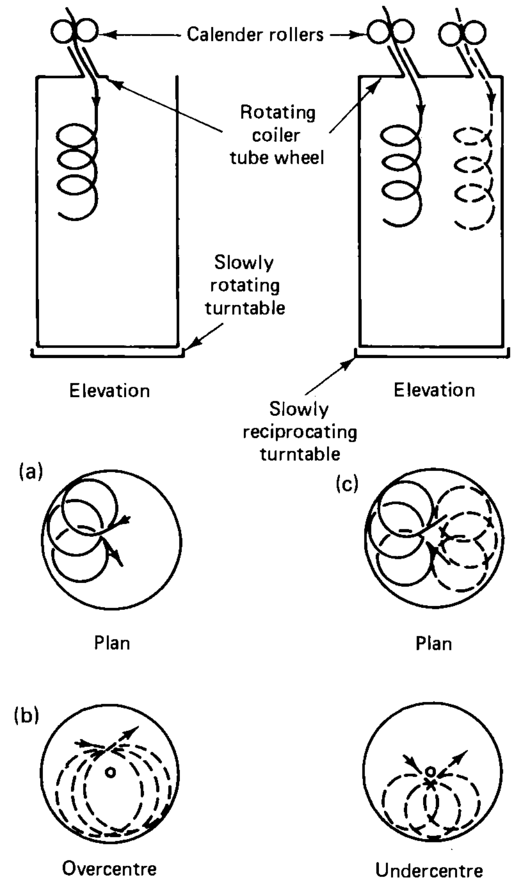


Figure 8.2 Coiler can delivery: (a) single coiler delivery; (b) over centre and undercentre; (c) bicoiler delivery

sing hairs and other fibres which lack cohesion; the following machine may be provided with an inclined feed channel to support the sliver as it leaves the can until it enters the machine.

Can deliveries are popular for use inside the factory because they enable a large package to be formed so that high machine productive efficiency and high labour productivity can be achieved; they are not usually regarded as being suitable for transport outside the factory. However, the contents of a coiler can may be compressed vertically and tied with string to form a compact package for transport; this method is widely used in the worsted industry for top slivers being transported from the combing to the spinning factory — the package is then called a bump top.

The coiler action may be over-centre or under-centre, as illustrated in *Figure 8.2(b)*. Over-centre coiling is often preferred because it enables a greater sliver mass to be accommodated in a given can, but for cans of large diameters exceeding about 760 mm, under-centre coiling may be used because machine construction considerations. Coiler cans are used for cards, combs, gill boxes, and drawframes.

A bicoiler can delivery is based on the same principle but has two coiler tubes each delivering a separate sliver into a single can as shown in *Figure 8.2(c)*. In this case the can has a reciprocating rotation to prevent entanglement of the two separate slivers. Bicoiler delivery may be used where there is limited creel space at the following machine or where the drafting zones can be placed at a close distance. The use of bicoiler delivery enables about twice the length of each individual sliver to be accommodated than would be possible if single coiler delivery into cans of half the diameter were used. The use of a bicoiler delivery may restrict the delivery speed of a machine to about 200 to 250 m/min compared with up to 450 m/min when a single coiler is used.

Many machines are fitted with automatic can change devices which operate when the necessary length of sliver has been delivered. The machine is stopped, the sliver broken, the full can removed and an empty can replaced. The machine then re-starts having taken about 10 seconds to complete the doffing cycle. As machine delivery speeds have been increased, the use of automatic can change has become of greater importance in order to avoid waiting time caused by machine interference.

Balling head delivery

This method, *(Figure 8.3)* is particularly suitable for slivers processed on the worsted system which are finer than about 2 ktex, it is also shown in Plate 9.

The drafted sliver which emerges from the front rollers A has a flat ribbon-like cross-section; if it were wound on to a ball in that state there would be difficulty in unwinding the sliver at the next operation. The rubbing aprons B deliver the sliver forward and at the same time have a sideways reciprocating motion which causes the sliver to be consolidated into a round cross-sectional shape by being rolled about its axis; as a result there is no difficulty in the subsequent unwinding. Because the maximum rubbing speed is about 1000 cycles/min, the aprons impose a limitation on the maximum rate of delivery. Funnel C traverses sideways to distribute the

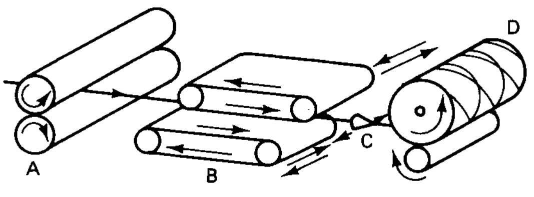


Figure 8.3 Balling head delivery

sliver across the width of the package D. This method is used on Continental worsted roving machines where the delivery is usually about 160 m/min although up to 250 m/min may be possible; the delivered package is usually double mêche (i.e. two rovings wound alongside each other as shown in *Plate 9*) with a total mass of about 2.3 kg.

A similar rubbing principle is used on a woollen card condenser.

Balling head deliveries used to be popular on gill boxes in worsted combing factories for thick slivers up to 50 ktex, and for the production of ball type tops. In this case a sliver funnel with a reciprocating rotary motion was used instead of rubbing aprons to impart the alternating false twist. Badly designed balling heads used to introduce periodicity caused by tension fluctuations associated with the sideways traverse motion; this fault has been eliminated on modern machines. In recent years there has been a general move in favour of using can delivery in preference to balling head delivery for thick slivers in combing factories, and towards the use of bump tops instead of ball tops, although ball tops are used when package dyeing of tops is to follow.

Twist insertion in rovings

Frequently it is preferred to spin from a roving containing twist. At one time in the cotton spinning industry there was a move towards spinning from sliver, but the presence of twist in a roving can improve the final yarn properties provided that the spinning frame is designed for drafting such a roving. In worsted spinning, twisted rovings are often preferred although twist-free rovings are still used in the Continental worsted system.

The amount of twist required has usually been determined by rule-of-thumb methods, and has changed as machine speeds and spinning drafts have altered, particularly in the cotton industry.

In cotton drawing and spinning it has become the common practice to describe the twist in terms of a twist factor. Although all the original work on this subject was carried out using the traditional yarn counting systems, they are here expressed in an equivalent form in the tex system.

Twist factor = twist (t/m) $\sqrt{}$ count(tex)

A theory of this type was advanced by Koechlin in 1828 for cotton yarns. In 1884, probably unaware of Keochlin's work, Ashenhurst propounded a similar relationship for worsted yarns; he was primarily concerned with yarn diameters and setting theories for weaving.

He first established the relationship:

Yarn diameter $\propto \sqrt{}$ count (tex)

which since has been confirmed experimentally. He then went on to state that twist should depend on yarn diameter, meaning that different strand thicknesses should have the same angle of fibre inclination.

This theory intuitively seems to be correct if *Figure 8.4* is considered. It is self-evident that twice as many turns per metre will be required in the thin strand to obtain the same angle of twist (θ) as that shown in the strand which is twice as thick.

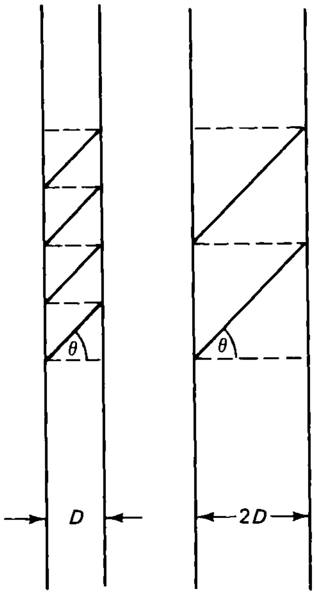


Figure 8.4 Relationship between twist (t/m) and strand diameter for the same angle of twist in each strand

The theory may be explained more formally with reference to *Figure 8.5 (a)* and *(b)* as follows:

The metric length of a strand containing one turn of twist = 1/t, where t = twist (t/m). The angle of fibre inclination on the strand surface = β.In *Figure 8.5(b)*, which represents the strand surface opened out flat: $\tan \beta = \pi Dt$, where D = strand diameter, but $D \propto \sqrt{}$count, therefore $\tan \beta \propto t \sqrt{}$count.

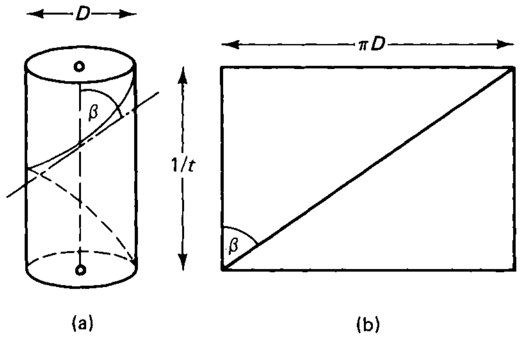


Figure 8.5 Yarn and roving twist geometry
(a) Side view of strand containing one turn of twist
(b) Opened-out surface of strand

Hence to produce a number of different strand thicknesses each with the same angle of twist, i.e. where β is a constant,

$$\text{twist (t/m)} = \frac{c}{\sqrt{\text{count (tex)}}}$$

$$= c[\text{count(tex)}]^{-0.5} \qquad \ldots (1)$$

When twist is allowed to distribute itself along a strand of varying thickness by free rotation of the strand about its axis, the *angle* of twist is found to be constant at the points of different diameter. This fact probably accounts for the widespread use of the so-called twist factor in publications dealing with cotton drawing and spinning, instead of expressing the twist in turns per unit length.

The use of a constant c of the form in equation (1) above *implies* that it may be used for a range of different strand thicknesses. In fact, if the twists which in practice are satisfactory for a wide range of strand thicknesses made from a given fibre are examined, it is found that they do not conform to the relationship indicated in equation (1); the use of the $\sqrt{\text{count}}$ relationship gives too high a twist for thick rovings, and too low a twist for thin rovings.

Hence when widely different strand thicknesses are made from a given fibre supply, in practice it is necessary to use different values of c to obtain satisfactory amounts of twist.

A more satisfactory relationship is given by the empirical formula:

$$t = K\,[\text{count(tex)}]^{-2/3}$$

The accuracy of the relationship between twists used in practice and twists indicated by a formula based on $(\text{count})^{-2/3}$ has been confirmed by the author on the worsted system from a thick slubbing of 15 ktex down to yarn as fine as 6.33 tex, and on cotton yarns ranging from 10 to 60 tex. Compared with twisted slubbings, which must permit subsequent drafting to take place, the value of K for yarns must be increased to eliminate fibre slippage.

The use of a formula based on $(\text{count})^{-2/3}$ can give a useful guide to the necessary twist. It will always be prudent to check the suitability of twist inserted in a roving before proceeding with full-scale production because of differences in factors such as fibre fineness, fibre length, fibre crimp, and fibre frictional properties, which may influence the detailed twist requirements.

For 100% wool worsted flyer-lead produced rovings the recommended formula is:

$$\text{Twist (t/m)} = 3040\,[\text{count(tex)}]^{-2/3}$$

For synthetics or bobbin-lead produced rovings, the constant should be reduced to as low as 2130.

Flyer lead delivery

This method is used where twist insertion is required as well as package formation; the type of package used is a double-flanged bobbin (*Figure 8.6*). The method is only suitable for relatively long fibred materials such as jute, flax, or worsted, because the slubbing produced must be strong enough to pull the bobbin round during winding on. The spindle arrangement is shown in *Figure 8.7*.

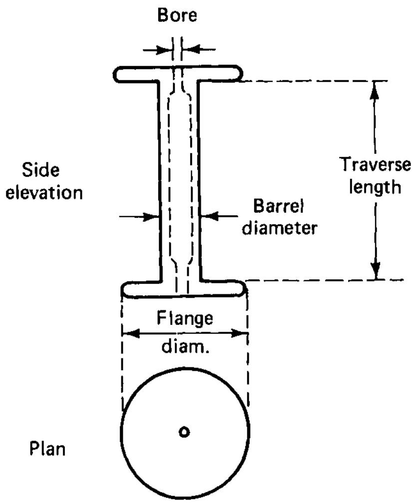


Figure 8.6 Flyer lead delivery double flanged bobbin

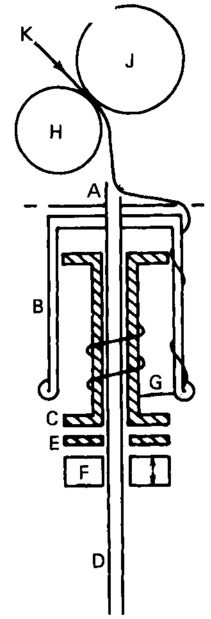


Figure 8.7 Flyer lead delivery side elevation. A, hollow spindle top (bearing not shown); B, flyer leg; C, bobbin; D, spindle (driven from bottom); E, felt drag washer; F, lifter rail (vertical traverse); G, slubbing (pulling bobbin round); H, drafting zone bottom front roller; J, drafting zone top front roller; K, drafted fibres

Twist insertion

Each revolution of the spindle and attached flyer rotates the lower end of the material which extends from the front rollers to the spindle top, thereby inserting one turn of twist into the slubbing. The amount of twist inserted is controlled by the ratio of the spindle speed to the front roller surface speed:

$$\text{Twist (t/m)} = \frac{\text{spindle speed (rev/min)}}{\text{roller delivery (m/min)}}$$

Production

For a given package size there is a maximum safe spindle speed which determines the rate of production. It follows that because

$$\text{Roller delivery (m/min)} = \frac{\text{spindle speed (rev/min)}}{\text{twist (t/m)}}$$

then for a given thickness of delivery,

$$\text{Production} \propto \frac{1}{\text{twist}}$$

Hence if slubbing is produced with increased twist insertion at a given spindle speed, the cost per kilogramme increases.

Winding on

The bobbin fits loosely outside the spindle and therefore can rotate at a different speed and can also slide up and down the spindle.

The spindle is driven by helical gears or some other means, and as it rotates, the slubbing delivered from the drafting zone slides down the flyer leg and passes on to the bobbin. This is made possible by resting the bobbin on a felt drag washer which provides frictional resistance to the rotation of the bobbin. Under normal conditions the bobbin circumference is greater than the length of slubbing delivered from the drafting zone during one revolution of the spindle. It follows, therefore, that each revolution of the flyer around the bobbin will wind the delivered length of slubbing on to the bobbin, and that the bobbin surface will be dragged round a distance equal to the effective bobbin circumference minus the length of slubbing delivered, hence:

bobbin speed (rev/min) = spindle speed (rev/min) – winding-on rev/min, where the winding on speed (rev/min) equals the number of coils wound on to the package per minute = (roller delivery (m/min))/(bobbin circumference (m)). As the bobbin fills and its circumference increases there will be a speed increase of the form indicated in *Figure 8.8*, but at all times the spindle rotational speed is greater than that of the bobbin; this is called 'flyer lead'.

During winding on, the bobbin is traversed up and down by the motion of the lifter rail so that the slubbing is evenly distributed between the flanges.

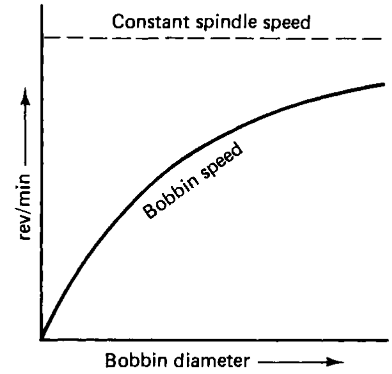


Figure 8.8 Flyer lead delivery bobbin speed

Tension control

Winding tension

This is determined by the dimensions of the drag washer *(Figure 8.9)*. The internal diameter of the washer (W_1) is about 3 mm greater than the spindle diameter, therefore on a given machine, W_1 remains unchanged. A range of washers with different external diameters (W_2) may be used up to a maximum equal to the bobbin flange diameter.

Although Amonton's classical laws of friction indicate that friction is independent of the area of contact, in the case of a drag washer, where the internal and external diameters are considerably different, the frictional resistance can be taken as acting at the mean radius.

Hence:

$$\text{Torque} = \mu R \frac{W_1 + W_2}{4}$$

where μ = coefficient of friction between the bobbin and washer, R = the force normal to the washer/bobbin surfaces, W_1 = the internal washer diameter and W_2 = the external washer diameter.

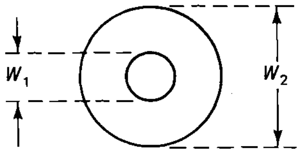


Figure 8.9 Flyer lead delivery drag washer (plan view)

therefore if a bigger diameter (W_2) washer is used, more tension is applied to the slubbing at G in *Figure 8.7*; this is known as the winding tension.

Hence the bulk density of the package can be controlled; a soft, spongy package may cause difficulty in unwinding. Up to a point, a firm package is desirable because the package capacity is increased, giving a longer running time and therefore improved productive efficiency.

Top tension

This is the tension on the slubbing which lies between the delivery rollers and the spindle top. At this point the material is at its weakest because it is almost without twist. To reduce tension at this point, the slubbing is wrapped round the flyer leg: because of the capstan effect, an increased number of wraps reduces the top tension.

Excessive top tension must be avoided as otherwise accidental fibre slippage (sometimes called 'spindle drafting') can occur, giving rise to increased slubbing irregularity.

Tension as the bobbin fills

As the mass of slubbing on the bobbin increases, the force normal to the washer/bobbin interface also increases thereby causing an increase of frictional resistance.

At the same time there is an increase in the effective bobbin radius (r) at the point of winding on as shown in *Figure 8.10*; this is equivalent to an increase in the length of lever used to pull the bobbin round. The result is that the winding tension does not increase as rapidly as might be expected when the increase in total mass is considered in isolation.

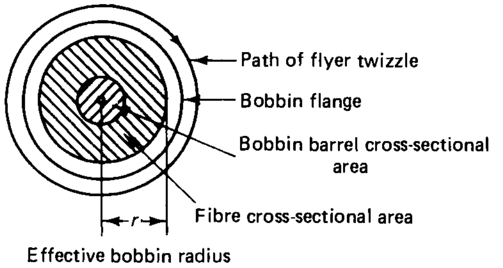


Figure 8.10 Part-full flyer lead delivery bobbin (plan view)

With very large bobbin sizes the winding tension is at a maximum at the commencement of winding on, falls to a minimum when part full, and then rises later. With intermediate bobbin sizes the winding tension falls to a minimum when part fall, but rises to a maximum when full. With small bobbins the winding tension continually increases from empty to full bobbin. Typical winding tensions for a range of common bobbin sizes are shown in *Figure 8.11*. The colloquial bobbin sizes are indicated, e.g. '14 x 9' means traverse length and flange diameter respectively, in inches. The details on which *Figure 8.11* is based are given in *Table 8.1*.

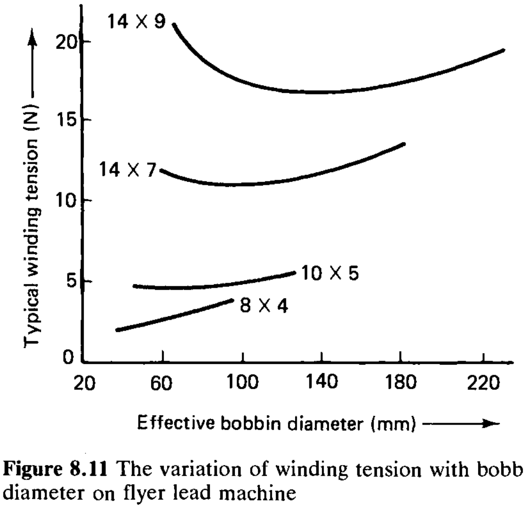


Figure 8.11 The variation of winding tension with bobbin diameter on flyer lead machine

Table 8.1 ***Details used for the construction of Figure 8.11***

Bobbin dimensions (mm)					
traverse length	flange diameter	barrel diameter	empty bobbin mass (kg)	full bobbin fibre mass (kg)	colloquial bobbin size (inches)
356	230	65	1.82	4.09	14 × 9
356	180	60	1.10	2.70	14 × 7
254	125	45	0.49	1.13	10 × 5
203	100	40	0.26	0.57	8 × 4

Distance from twizzle to point of winding on

From the plan view of the winding on geometry given in *Figure 8.12*, the following relationship is apparent:

$$D = \sqrt{(T^2 - r^2)}$$

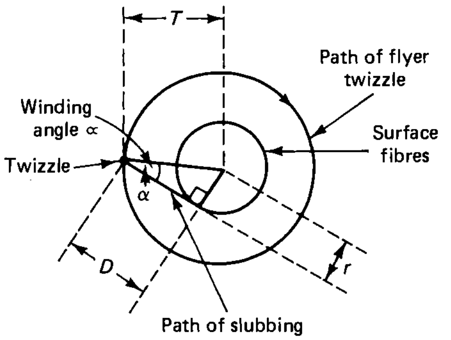


Figure 8.12 Flyer lead delivery winding-on geometry (plan view)

where D = distance from twizzle to point of winding on, T = radius of the path of the twizzle, and r = effective bobbin radius at the tangent-point of winding on.

As the bobbin fills, the winding angle ∝ will increase, and therefore D will decrease; the relationship between D and r is of the form indicated in *Figure 8.13*. It is of interest to compare the distance D with the fibre length; this has been done in *Table 8.2*.

Clearly the effective strength of the length of slubbing between the twizzle and the point of winding on will increase as the bobbin fills and more fibres have a length which exceeds D.

With a large bobbin, when the bobbin is empty, tension is at a maximum, and the effective slubbing strength is almost totally dependent on inter-fibre friction, therefore the amount of twist inserted is most important at that stage of bobbin build.

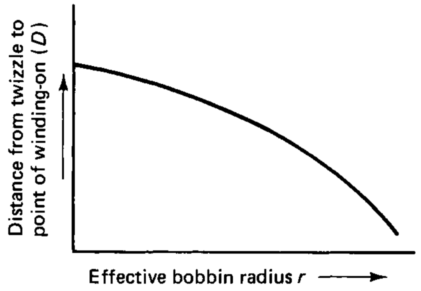


Figure 8.13 Variation of winding distance as the flyer lead delivery bobbin fills

Twist requirements

The twist inserted must lie between certain minimum and maximum limits. The minimum twist limit is determined by the need for the slubbing to be strong enough to pull the bobbin round without inter-fibre slippage. The maximum twist is limited by the need to permit the fibres to slide over each other during subsequent drafting without excessive fibre breakage.

In Bradford worsted drawing, using flyer lead, the approximate amount of twist to satisfy these requirements can be calculated from the empirical formula:

Bradford drawing twist (t/m) = 3040 $[\text{count(tex)}]^{-2/3}$ ± 15%

This formula applies over a wide range of slubbing thicknesses and wool quality numbers. Up to 30% less twist may be necessary for 100% man-made fibres, and intermediate values for blends with wool.

If rovings are to be aged by storing then less twist is required in them than if they are to be spun immediately. Cellaring used to be the normal prac-

Table 8.2 ***Distance from twizzle to point of winding on (D) compared with fibre length distribution of a standard 64's A Bradford quality wool top***

Bobbin dimensions (mm)		*Bobbin empty*		*Bobbin full*		*Colloquial bobbin size (inches)*
Traverse length	*Flange diameter*	*D (mm)*	*%F**	*D (mm)*	*%F**	
356	230	123	4	54	58	14 × 9
356	180	98	17	48	64	14 × 7
254	125	66	45	33	84	10 × 5
203	100	54	59	28	87	8 × 4

*%F = percentage number of fibres which exceed D when processing a 64'sA Bradford quality wool top: Mean fibre length = 70 mm, C.V. fibre length = 50%, Maximum fibre length = 165 mm.

tice, but a similar effect can be obtained more rapidly by steaming. The performance of twisted rovings when spinning near to the fine count limit is substantially improved by cellaring or steaming. On the other hand, the mechanical properties of untwisted Continental type worsted rovings are hardly affected by such treatment.

Testing roving twist

In practice the twist is tested by estimating the tension required to initiate fibre slippage. This is done by running the machine to produce a small quantity of slubbing on to the empty bobbin. A short length of the slubbing is then unwound and gripped firmly between the thumb and index finger of each hand at a distance apart equal to the ratch of the following machine, taking care to avoid rotation of the slubbing about its axis before commencing the test. Tension is gradually increased until the fibres slide over each other. The test is repeated once or twice on lengths of slubbing taken from points about 1 m apart, and the correct tension is estimated subjectively after practice has been gained under the guidance of an experienced person. Although this method may sound crude, it is just as reliable as objective tests and, of course, much cheaper and quicker.

A satisfactory amount of twist insertion must always be confirmed by testing before full-scale production proceeds.

Bobbin lead delivery

In Yorkshire this system is often known as the ‘cone drawing box’, and in Lancashire as the ‘speed frame‘, it was originally designed for processing cotton, a fibre which is too short to pull the bobbin round; it was later adapted for processing short wools on the worsted system where similar conditions apply, but is now also used for longer wools. In cotton processing its use is now restricted to the roving operation when ring spinning is to follow; it is also used as a roving operation in certain worsted drawing systems. A similar principle was also applied in jute processing to permit the use of large bobbin sizes.

The traditional machine is mechanically complicated, usually involving a control mechanism known as the ‘box of tricks’, an opposite-facing pair of cones to provide a variable speed drive to the bobbins and the lifter motion, and a differential gear drive. Incorrect setting-up of these parts of the machine can cause long-term variations in the rovings produced. The use of alternative electronic controls would appear to be a natural development.

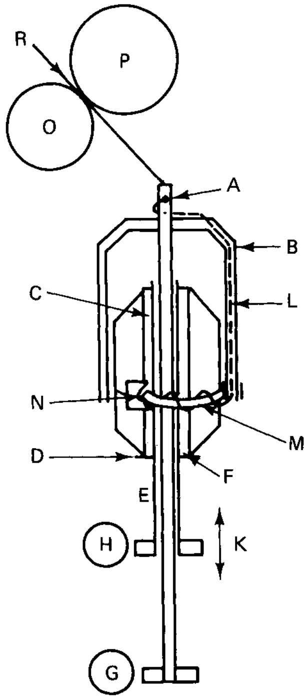


Figure 8.14 Bobbin lead delivery (side elevation). A, hollow spindle top; B, hollow flyer leg; C, bobbin; D, bobbin plate; E, bobbin tube; F, bobbin driving peg; G, constant speed spindle drive; H, variable speed bobbin drive; K, lifter traverse motion; L, slubbing inside flyer leg; M, presser arm; N, presser paddle; O, drafting zone bottom front roller; P, drafting zone top front roller; R drafted fibres

The basic arrangement of the spindle and bobbin drives is shown in *Figure 8.14*; many modern versions of the machine have suspended flyers which do not need removing for doffing, as shown in *Plate 16*.

The principle is similar to that of the flyer lead method, except that the bobbin is positively driven at a variable speed so that throughout the package build it maintains a constant minimal tension on the slubbing as it passes down inside the hollow flyer leg. It is important to maintain a minimum top tension otherwise faulty ‘spindle drafting‘ between the delivery rollers and the spindle top will increase the slubbing irregularity.

By wrapping the slubbing two or three times round the presser arm, the winding tension can be increased without inducing fibre slippage so that the tension at the tip of the presser paddle may be up to twenty times greater than the top tension. The effective bobbin capacity can be significantly increased by this means. Centrifugal acceleration causes the counterbalanced presser paddle to bear

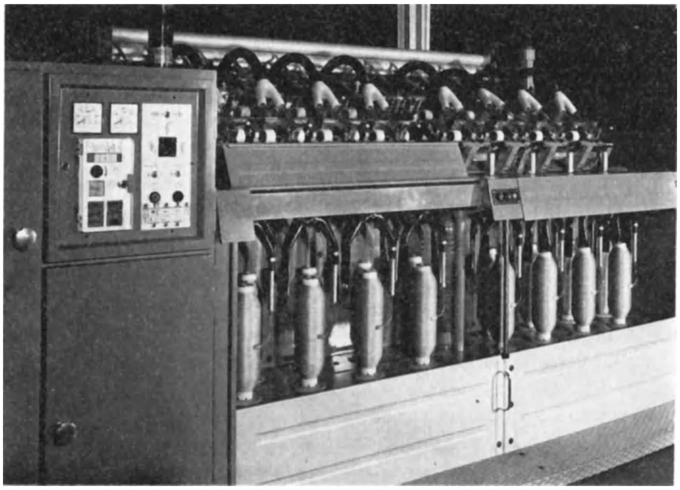


Plate 16. Bobbin lead roving frame. With the safety screens lowered and the top left-hand cover raised, the arrangement of the bobbin and the suspended flyer, with its presser arm, can be seen. Flyer speeds up to 1800 rev/min, and front roller delivery speeds up to 100 m/min are possible. When the bobbins are full, automatically they are lifted off their respective spindles. Note the staggered double row of bobbins and spindles.

Courtesy of N. Schlumberger & Cie

against the bobbin surface to ensure the formation of a firm package.

It is now usual to use a simple bobbin barrel to form a tapered package of the form shown in *Figure 8.14*. It is interesting to note that the bobbin dimensions determined in the past do provide for maximum volume of fibre on a full package. This is important because creel space at the spinning frame is usually limited; for the same reason maximum package bulk density is also desirable.

In the cotton and worsted aplications of this machine, the bobbin runs at a higher rotational speed than the flyer, and this situation is called ‘bobbin lead‘; hence

bobbin speed (rev/min) = spindle speed(rev/min) + winding-on rev/min where

$$\text{Winding-on rev/min} = \frac{\text{roller delivery (m/min)}}{\text{bobbin circumference (m)}}$$

As the bobbin fills and its circumference increases there will be a speed decrease of the form indicated in *Figure 8.15*.

Two advantages are claimed with the use of bobbin lead rather than flyer lead when a positive bobbin drive is used:

Firstly, that as the bobbin fills and its mass increases, the decreased bobbin speed will help to limit the maximum power requirements of the machine.

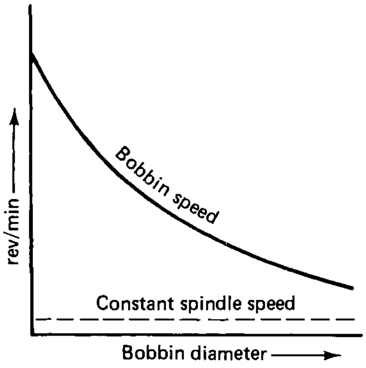


Figure 8.15 Bobbin lead delivery — bobbin speed

Secondly, and more important, if the slubbing breaks, its end on the bobbin will trail behind without causing difficulties, whereas if flyer lead were used with a positive bobbin drive, the slubbing would tend to unwind from the bobbin if a break occurred, damaging adjacent slubbings, and perhaps causing machine breakages.

One disadvantage of bobbin lead is that the higher bobbin speed involves a greater centrifugal acceleration on the slubbing; this is particularly important when the bobbin is full. Because of its increased circumference, the surface velocity of a full bobbin is approximately three times greater than that of an empty bobbin, and as centrifugal acceleration is proportional to the roving count and to the square of the winding surface velocity, this means that the force exerted on the outer layer of slubbing is approximately nine times greater when the bobbin is full than when it is empty. A close-coiled firm package produced with high winding tension is capable of running at higher rotational speeds without coil bursting being caused. Clearly, with a constant spindle speed the danger of coil bursting is most critical as the package approaches full diameter. One method of overcoming this problem is progressively to reduce the machine speed when the package diameter exceeds the point when centrifugal acceleration becomes a limiting factor, and thereafter maintain a constant winding surface velocity. Such an arrangement permits a higher production rate than could be achieved with a constant spindle speed.

Twist requirements

The roving twist must be sufficient to enable subsequent unwinding to take place without fibre slippage; the amount of twist necessary for this purpose is minimized by having minimum creel tensions at the following process. In cotton processing, because of the short fibre length, the twist must be sufficient to enable the slubbing to withstand the centrifugal force generated during winding on. As roving strength is an exponential function of roving twist, a small twist increase may have an appreciable influence on roving strength. Consequently as cotton roving speeds and package sizes have increased there has been a corresponding increase of twist inserted into the rovings. This has also led to increased roller pressures being used during the subsequent drafting at the ringframe; fortunately these changes have led to an improvement in yarn quality.

The optimum roving twist depends on the capacity of the spinning frame drafting zone to break down the high inter-fibre cohesion, and this is reflected in the ultimate yarn properties of count variation and strength and to an even greater extent, in the number of thick and thin places.

In worsted processing the required bobbin lead twist is about 20 to 30% less than that needed for flyer lead delivery; the reduced twist is of advantage if apron drafting is to be used at the following operation.

An approximate guide to the required twist may be calculated from the empirical formula:

Bobbin lead twist (t/m)

$$= K\,\{\text{count (tex)}\}^{-2/3} \pm 15\%$$

Some values of K are as follows:

100% wool 2220		
100% cotton	St. Vincent	1800
	Long Egyptian	2400
	Med. American	3900
	Short Indian	7500
	Montserrat	2100
	Long American	3500
	Med. Indian	6000

In the case of wool fibres, longer wools tend to be coarser, and this has a compensating effect which permits one value of *K* to be used. However; longer cottons are usually also finer cottons, and as finer or longer fibres permit less twist to be used the effect is cumulative; hence the need for the wide range of *K* values for different cottons.

Man-made fibres may require up to 30% less twist, and blends with natural fibres need intermediate amounts.

The actual twist used for the same fibre quality and roving thickness may vary in different factories because of differences in factors such as fibre parallellization, slubbing irregularity, and spindle speed.

It is always necessary to check that the twist provides the necessary roving cohesion and optimum conditions for spinning before full-scale production is commenced.

General advantages of this type of delivery over the flyer lead system for worsted processing include:

(1) Larger bobbin sizes can be used.
(2) Fewer operatives are required for a given output.
(3) Less floorspace is required because two rows of staggered spindles can be accommodated at the front of the machine as a result of the low slubbing tensions involved.
(4) Very fine rovings can be made. This advantage is now of no practical importance because the use of higher spinning drafts has eliminated the need for fine rovings.

Because of the increased complexity and capital cost there is no advantage in using bobbin lead delivery for slubbings thicker than about 2 ktex in worsted processing.

Spindle speed is the factor which limits the production of this type of machine — speeds are generally 1200 to 1400 rev/min although speeds up to 1800 rev/min have been used commercially. Consequently the maximum delivery speed is usually from 30 to 50 m/min compared with 160 m/min or more on a Continental worsted rover with balling head delivery. On the other hand the presence of twist in the roving ensures better unwinding at the following process, and larger roving packages may be used, which reduces labour requirements at the spinning process. A package 356 mm long, and 178 mm diameter may contain about 2.7 to 3.2 kg of roving. This compares with a 2.3 kg double mêche balling head delivery package, which contains only 1.15 kg of each separate worsted roving.

Drawing

In this context the word 'drawing' refers to a series of operations using drafting and doubling; it should not be used loosely to mean 'drafting', and it should not be confused with 'continuous filament drawing' The machines which work together for this purpose are usually called a 'drawing set'.

The objective of a drawing set is to convert the supply sliver into a fault-free roving from which a yarn can be spun in a single operation, using a suitable spinning draft.

The supply may be card sliver, comb sliver, worsted top sliver, or converter sliver, depending on the system of yarn manufacture being considered.

Normally a drawing set will be installed to produce a specific roving count or a narrow range of roving counts. The wide range of drafts and doublings which have been combined into a single table in each of the examples given on the following pages represent the range of possibilities which exist for different individual drawing sets. They have been called composite drawing sets to emphasise the point that such a wide range of roving counts normally would not be produced by a single drawing set actually in use in industry. Even so they do not necessarily represent the full range of drawing sets in use because there may be a larger or smaller number of operations employed in some arrangements as well as differences in the applications of drafts and doublings.

Worsted drawing

Although in the past there were considerable differences between the English and Continental systems of processing, these differences have been reduced to such an extent that now the most commonly used arrangement consists of four operations.

The first two operations are gill boxes, the third operation may be either a gill box or a Schlumberger ET11 drafter (with apron and pressure pads), and the fourth operation is roving. Alternatively instead of gill boxes at the first three operations, a pinned cylinder fibre control may be used in place of screw-driven fallers. The roving operation may have either a bobbin lead delivery producing twisted rovings, or a balling head delivery producing twistless rovings. *Table 8.3* indicates a commonly used sequence of machines for a modern worsted drawing set.

Semi-worsted drawing

The usual arrangement is to have a drawing set consisting of three gill box operations so that a majority of trailing-hook fibres enter the spinning frame (note that there is no roving operation). The importance of hook direction during drafting was discussed in detail in Chapter 5.

A typical sequence of machines is indicated in *Table 8.4*.

Carded cotton drawing

The findings regarding direction of drafting of hooked fibres described in Chapter 5 are important in the production of carded cotton yarns. The principles to be followed may be summarised as:

(1) a majority of trailing hooks should be fed into the drafting zone of the spinning frame, and

Table 8.3 ***Composite worsted drawing set to convert 20 ktex top sliver to roving***

Machine	*Doublings*	*Draft*	*Delivery (ktex)*
(1) Single delivery autoleveller gill box	7–10	7–8	17.5–28.6
(2) Double delivery gill box	3–4	7–8	6.6–16.3
(3) Four delivery gill box or ET11 drafter	3	7–8	2.5–7.0
(4) Roving, either bobbin lead or balling head	2	10–16	0.3–1.4

Followed by ring spinning using drafts from 15 to 25, a range of yarn counts from about 12 to 93 tex could be spun.

Table 8.4 ***Composite semi-worsted drawing set to convert 20 ktex card sliver to gilled sliver***

Machine	*Doublings*	*Draft*	*Delivery (ktex)*
(1) Single delivery autoleveller gill box	6–9	7–8	15.0–25.7
(2) Double delivery gill box	3–6	7–8	5.6–14.7
(3) Four delivery gill box	2–3	7–8	1.4–6.3

Using spinning drafts from 15 to 25, a range of yarn counts from about 56 tex to 420 tex could be spun direct from sliver.

Table 8.5 ***Composite carded cotton drawing set to convert 5 ktex card sliver to roving***

Machine	*Doublings*	*Draft*	*Delivery (ktex)*
(1) First drawframe	6–8	6–7	4.3–6.7
(2) Second drawframe	8–10	8–9	3.8–8.3
(3) Bobbin lead roving	1	9–11	0.345–0.922

Followed by ring spinning with drafts from 15 to 25, this would produce yarn counts from about 14 to 62 tex.

(2) higher drafts should be applied at operations in which a majority of trailing hooks are being drafted.

A typical sequence of machines in which these principles are applied is indicated in *Table 8.5*.

A drawing set for rotor spinning may consist of two drawframe passages to produce a feed sliver of about 4 ktex for the spinning machine, although alternative arrangements are possible, a drawframe is shown in *Plate 17*.

Combed cotton drawing

Usually two passages of drawframe are used, followed by bobbin lead roving. The fibres are already parallel and so the technique differs from that used for drawing prior to carded yarn spinning.

Cotton comb slivers contain periodicities caused by the overlapping of the combed fibre tufts to form a comb sliver. If multi-zone drafting is used on such slivers, the periodicities tend to be accentuated, consequently single-zone drafting is preferable, with a lower total frame draft.

A typical arrangement is to have six doublings and a draft of six at each of the two drawframes, followed by roving.

When blended yarns are to be produced an additional drawframe passage is usually introduced. For example, in the production of polyester/cotton blends, carded polyester sliver is blended with combed cotton in a drawing set with three drawframe passages, followed by roving.

Flax drawing

The traditional machines used in flax drawing provide fibre control in drafting by using upward-pointing faller pins in the drafting zone. It is usual for the fallers to have a higher surface speed than the back rollers; this is known as 'lead' or 'back draft'. Back draft is necessary to ensure adequate pin penetration, but it is normally kept as low as possible. It may be up to 1.02 in line processing, and up to 1.05 in tow processing.

One of the problems which arises when processing the relatively short tow fibres on such machines is a periodic irregularity in the delivered sliver — called 'faller-bar marking' as described in Chapter 5; this problem does not usually occur when the longer line fibres are processed.

To help to minimise this effect a front doubling plate is fitted to combine the slivers from each drafting head into a single composite delivered sliver; this arrangement is represented in *Figure 8.16*. By using this method, the load in the pins at each head is reduced (one single composite sliver is fed in to each drafting zone at the following

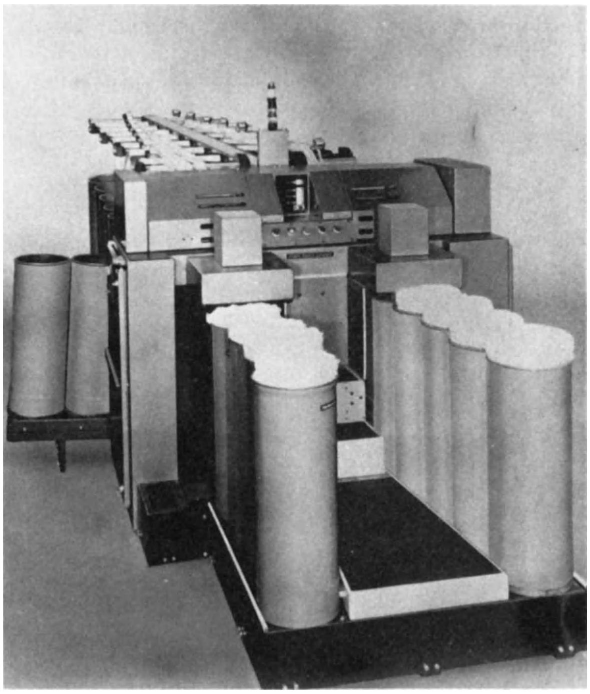


Plate 17. Drawframe for cotton or for short-staple man-made fibres and blends. This is a single-head two-delivery drawframe delivering into small cans for creeling on rotor spinning machines which have an upward fibre flow-path; the quantity of sliver in the cans is maximised by pneumatically operated compactors. Autolevelling controls medium- and long-term count variation. Delivery speeds up to 400 m/min, automatic can changing, and a power-driven creel are provided. Courtesy of Platt Saco Lowell (UK) Ltd

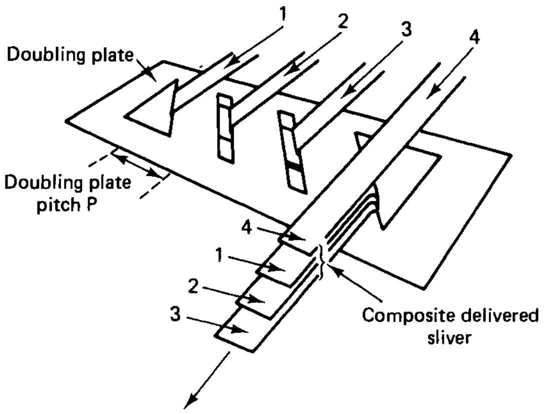


Figure 8.16 Flax or jute drawing front doubling plate

machine) and yet a thick enough composite sliver is produced to provide adequate cohesion for can delivery. At the same time, by using a 'good' front draft between the fallers and the front rollers of the drafting zone, the faller-bar marks from each head can be displaced longitudinally relative to each other to reduce their effect in the composite delivered sliver.

$$\text{'Good' front draft} = \frac{P}{\left(n + \dfrac{1}{d}\right)f}$$

where P = doubling plate slot pitch, n = any positive integer, d = number of heads, and f = pitch of fallers.

With a four-head delivery a 'good' front draft will put each head sliver out of phase with respect to the adjacent head sliver/s by one quarter of a wavelength.

The composite sliver is usually delivered into a circular can with about 320° reciprocating rotation and automatic tramping motion to push the sliver down in the can to maximise the can capacity and minimise breakages when the sliver is withdrawn at the following operation.

(1) Line processing

The bundles of line fibre from the hackling process are automatically fed to the spreadboard and delivered after drafting and front doubling as a continuous sliver into a can. This sliver is then fed into a heavy doubler machine with a ratch (the word 'reach' is often used in the flax industry instead of ratch) of about 0.6 m and six heads of fallers, with each head drafting four adjacent slivers to be doubled into one composite sliver; thus there is one can for each set of fallers, making six cans for the full machine.

The heavy doubler is usually followed by four drawing operations, each with can delivery and ratch decreasing at each subsequent operation, and then a gill roving process with a ratch of about 0.5 m and flyer lead delivery. A flax drawing frame is shown in *Plate 18*.

An example of a drawing set is given in *Table 8.6*.

Wet spinning involves passing the roving through hot water immediately prior to drafting. The gums holding the ultimates together are softened sufficiently to allow most of them to be separated by drafting, although many ultimates will still remain grouped in twos, threes, or even more.

The degree of retting previously carried out is very important in wet spinning; insufficiently retted flax ultimates may fail to separate during drafting, thereby impairing the yarn quality, whereas over-retting will cause a reduction of yarn strength.

A more recent alternative is to process scutched unhackled flax into a sliver using pin control, and then a heavy doubler is followed by three passages of intersecting gill boxes as used in the semi-worsted system, followed by a roving process and then spinning. Such an arrangement has a much lower labour requirement than the traditional drawing system described above.

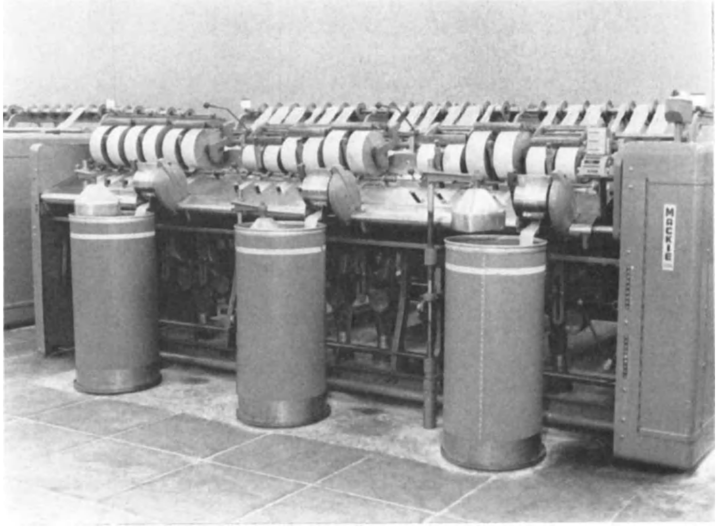


Plate 18. Flax line first drawing frame. Multi-head open screw gill faller pin fibre control is used in the drafting zone of this machine. Each head has six slivers drafted alongside each other; they are then combined together at the front doubling plate, which is clearly visible between the cans and the front rollers of the drafting zone. Each sliver is delivered into a reciprocating can and is compacted by the tramping motion which can be seen in its lowered position in the centre can. The delivery speed is up to 20 m/min, giving an output of about 50 kg/h. Courtesy of James Mackie & Sons Ltd

Table 8.6 ***Flax line drawing set to process input slivers of 6 to 12 ktex***

Machine	*Draft*	*Doublings*	*Composite Sliver Delivery (ktex)*
(1) First drawing frame	10	8	4.8–9.6
(2) Second drawing frame	8	6	3.6–7.2
(3) Third drawing frame	6	4	2.4–4.8
(4) Fourth drawing frame	5	4	1.92–3.84
(5) Roving	10	–	0.192–0.384

Wet ring spinning with a ratch (reach) of about 50 to 85 mm and a draft from 6 to 8 may be used to deliver yarn counts from 24 to 64 tex.

(2) Tow processing

It is possible to produce either carded or combed quality yarns from flax tow.

For the carded quality, drawing consists of a machine arrangement similar to that shown in *Table 8.6*, but with shorter ratches, and producing a thicker roving.

For combed quality, there are two drawing frames prior to the rectilinear comb, which is followed by two further drawing frames and then roving. Usually only re-scutched tows and coarse hackled tows are processed by the combing route.

Wet spinning may be used for tow yarns in the count range of approximately 30 to 80 tex.

For thicker counts from about 80 to 200 tex, dry spinning would normally be used. The process involves using a ratch of 250 – 370 mm and an apron and tumblers to control the 'fibres' composed of intermeshing strands. Dry spinning may sometimes be used for some line yarns.

Jute drawing

The sliver from the finisher card is passed through a drawing set usually consisting of three drawing frames which are similar to those used in flax processing with pin control during drafting, and on the first two operations a front doubling plate arrangement at the delivery as shown in *Figure 8.16*, and in *Plate 19*.

For yarns finer than about 200 tex an additional roving operation may be used with flyer twist insertion and bobbin delivery.

Jute card sliver contains a large number of short fibres; about 60% of the fibres may be shorter than the front ratch, which is usually about 50 mm. Consequently the front doubling plate (described in the flax drawing section and shown in *Figure 8.16*) and a 'good' front draft are essential features in jute drawing. A back draft of about 1.05 helps to ensure suitable pin penetration of the single set of upward pointing faller pins. An example of a jute drawing set is given in *Table 8.7*.

Table 8.7 ***Jute drawing set to process 65 to 90 ktex finisher card sliver***

Machine	*Draft*	*Doublings*	*Delivery (ktex)*
(1) First drawing frame	4.5–5	2	36–40
(2) Second drawing frame	6–7	4	20–27
(3) Third drawing frame	8–10	2	4.0–6.7

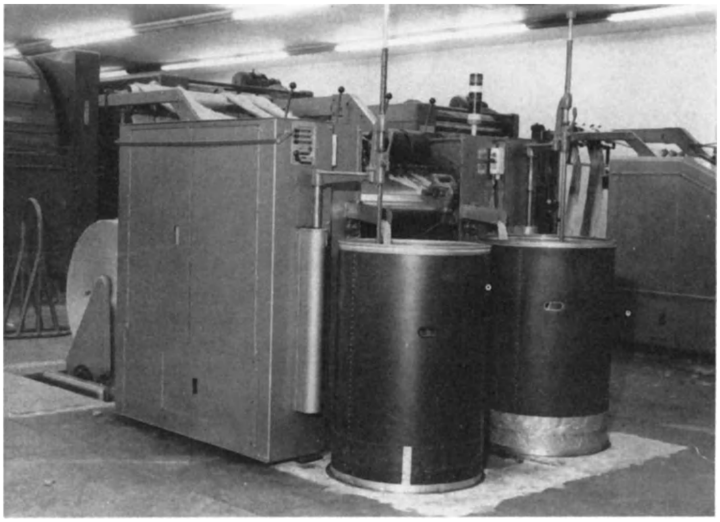


Plate 19. Jute first drawing frame. The creel at the back of the machine feeds four rolls of finisher card sliver into separate drafting zones using faller pin control. Two lots of two slivers each are front-doubled by a sliver plate and crimped before delivery into the two reciprocating cans, each fitted with a tramping motion to pack as much as 57 kg of sliver in each full can. The fallers run at up to 1200 drops/min, with a front roller delivery speed of 56 m/min giving a production rate of up to 230 kg/h. The machine, including creel and cans, is about 3.7 m long and 2.0 m wide overall. Courtesy of James Mackie & Sons Ltd

Spun silk drawing

The longer fibre lengths selected at the dressing process, or the shorter fibre lengths which have also been carded, gilled, and rectilinear combed, provide the fibres to be fed into the processes preparatory to spinning. Pin control is used throughout on finely pinned gill boxes.

The first process, called a spreader, delivers the material in the form of a lap wound around a cylinder of approximately 0.9 m diameter. When a given mass of fibre has been processed, each lap is removed and fed to form a continuous feed of doublings to the second machine, called the sett frame, which delivers continuous sliver into a can.

Three or four drawboxes follow with can feed and can delivery, using drafts and doublings to promote regularity and parallelization.

Gill roving follows using pin control in the drafting zone and a bobbin delivery with twist insertion.

The last operation is a finisher rover with twist fibre control and bobbin delivery with twist insertion.

An example of such an arrangement is shown in *Table 8.8*.

This would be followed by ring spinning usually to produce yarn counts in the region of about 5 tex.

In recent years some firms have processed spun silk on worsted drawing sets.

Table 8.8 *Spun silk drawing and preparatory processes*

Machine	*Doublings*	*Draft*	*Delivery (ktex)*
(1) Spreader		6–12	lap
(2) Sett frame	lap	10–12	1.9–2.4
(3) First drawbox	10–12	10–12	1.9–2.4
(4) Second drawbox	10–12	10–12	1.9–2.4
(5) Third drawbox	10–12	10–12	1.9–2.4
(6) Fourth drawbox	10–12	10–12	1.9–2.4
(7) Gill rover	1	10–12	0.16–0.24
(8) Finisher rover	2–3	8–12	0.04–0.06

Man-made fibre processing

Man-made fibres are made in dimensions which approximate to those of the various natural fibres. The processing of man-made fibres in blends or 100% may be carried out on the same types of machines used for the natural fibres. Details of drafts and doublings may be modified, and when twist control is used, the amount of twist is usually less than that used for 100% natural fibre.

The position occupied by drawing is indicated, where appropriate, in the Appendix.

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9

THE SPINNING PROCESS

Although spinning is only one single process in the sequence of operations required to produce a staple fibre yarn, it is an expensive one; it requires much more floorspace, power, and labour than all the drawing operations combined.

The reason for this is the relatively low rate of production caused by the fineness of the strand of fibres being delivered, and the relatively slow speed of delivery.

The spinning process basically consists of three stages:

(1) Reduction of strand thickness from the supply roving (or sliver) to the required yarn count. This is usually done by roller drafting with some means of fibre control such as double apron, but a different arrangement is used in open-end spinning and in mule spinning. It is important that the correct yarn count is produced because there is no subsequent opportunity for correcting any mistakes in this respect.

(2) The prevention of further fibre slippage — usually by twist insertion, although there are other methods.

(3) Winding on to a package which is convenient for handling and which protects the yarn.

The position of spinning in the sequence of operations is indicated in the Appendix.

Classification of spinning machines

Spinning machines may be broadly divided into two main groups:

(1) Intermittent

These machines can only carry out stage 3 of the spinning process, i.e. winding-on, while stages 1 and 2 are interrupted. Mule and centrifugal spinning machines are both of this type.

(2) Continuous

Machines of this type perform the three stages of the spinning process simultaneously on consecutive lengths of the material.

Sub-divisions of this group include:

(i) Conventional frame spinning machines

These machines were invented during the late 18th and early 19th centuries:

(a) Flyer spinning,
(b) Ring spinning, and
(c) Cap spinning.

(ii) Modern commercial machines

These machines became available during the 1960s and 1970s as the result of intensive research effort:

(a) Open-end spinning, and
(b) Repco self-twist spinning

(iii) Other spinning machine developments

This group includes machines which have not yet been adopted widely for the commercial stage of application:

(a) Twistless spinning,
(b) Spin-folding, and wrapped yarn spinning,

(c) Front folding
(d) Jet spinning,
(e) Bobtex A.B.S. (aerodynamic brake spinning), and
(f) Bobtex I.C.S. (integral composite spinning).

General features of conventional spinning machines

Creels

A creel is the structure which supports the supply packages or fibre supply into a machine.

The umbrella creel is the most commonly used type for a spinning frame which is supplied from roving bobbins and may be seen in *Plates 21* and *29*. The vertical roving bobbins are suspended from a peg which permits rotation with a minimum of tension. To remove the bobbins an upward push releases the support catches with an umbrella-like action. Can creels may be used when direct spinning (i.e. from sliver) is used; there may be rotating assisting rollers which feed the slivers towards the back rollers of the drafting zone.

Roving traverse motion

The roving is usually fed through a guide which traverses sideways so that wear is evenly distributed across the face of the rollers and other moving parts of the drafting zone, such as aprons.

Top roller covering and pressure

The top front roller is usually covered with a synthetic cot mounted on the roller boss which rotates on needle bearings. Roller concentricity is achieved by turning the roller and grinding the surface; re-grinding restores the concentricity of worn rollers to an accuracy of about 12 μm maximum eccentricity.

Coverings are made with different degrees of hardness and there is some evidence to suggest that soft coverings and low pressures may improve spinning performance; methods of applying loads to rollers were described on page 49.

Underclearers

Modern machines are fitted with suction tubes mounted beneath the front roller nip to collect stray fibres and broken ends. This keeps the spinning frame clean, prevents material from lapping round the front rollers, keeps the waste clean, and makes it easier to piecen a broken end. The suction tubes are clearly visible in *Plate 22*. Felt covered rollers or pads may run in contact with the top front rollers and underneath the bottom drafting apron, where fitted.

Spindle drives

Ideally all the spindles should run at the same speed; methods of driving the spindles include the following:

(1) The oldest machines used self-tensioning band drive to the spindles, but this gave rise to large variations between spindle speeds.
(2) Tape drive, tensioned with a jockey pulley, and usually driving two or four spindles per tape; this gives less variation between spindle speeds. Mean tape slippage may be up to 10%, but spindle speed variation does not usually exceed 1% C.V. If a spindle is stopped by knee brake, the tape usually slips around the stationary spindle whorle, and this may cause a substantial speed reduction of the other spindles driven by the same tape. When the lifter traverse motion involves an upward and downward movement of the spindle whorle, as on a cap spinning frame, this may introduce a periodic variation of the bobbin speed.
(3) Helical gear drives can be arranged to eliminate slippage and permit narrow frame construction, but this method has a higher capital and a higher running cost.
(4) Direct electric motor drive is a method which was tried for flax spinning in the 1920s and for a worsted frame in the 1950s, but it has never been adopted widely, probably because of cost factors, and difficulties in spindle braking.
(5) Tangential belt drive consists of a long laminated belt which passes each spindle in turn along the whole length of the machine. Removal of the spindle whorle from the belt or vice-versa easily can be arranged in conjunction with a spindle brake. This type of drive permits very narrow frame construction and eliminates the need for a long main driving shaft, thereby reducing power consumption and air turbulence. By adjusting the pressure at each belt/spindle whorle contact, variations between spindle speeds can be eliminated.

Change speed devices

Most frames have a vee belt drive from the electric motor which drives the whole frame. The speed of a spinning frame is frequently described in terms of spindle speed, and normally if the spindle speed of a frame is increased by a certain amount, then the speed of all its moving parts is also increased in the same ratio. A change of mean spindle speed may be made by changing a vee belt pulley, or by changing a chain sprocket wheel in the change speed device, or by some other means.

Maximum speed limitation

The maximum spindle speed of a frame is limited either by engineering considerations, as in conventional flyer spinning, or by limits imposed by the yarn itself, i.e. technological limits. Spindle rotation accounts for a high proportion of the power consumed in yarn production, hence roller-bearing design and lubrication is an important economic factor. Spindle speed is the dominant factor which limits the rate of production of the conventional spinning processes by restricting the speed of delivery from the drafting zone for a given yarn construction. For example, if a yarn is to be spun with 500 t/m, then with a spindle speed of 8000 rev/min the delivery roller surface speed = 8000/500 = 16 m/min; an increase to 10 000 rev/min would permit a delivery of 20 m/min.

There is also a limitation imposed by operative dexterity because of the maximum delivery speed at which an operative can make a piecening; this is usually taken to be a maximum of about 20 m/min with ring spinning in the absence of underclearers and up to 40 m/min with underclearers, or up to 90 m/min in open-end spinning. This limitation does not apply if automatic piecening is used.

Excessive spindle speed usually causes an increased end breakage rate and may lead to increased yarn hairiness.

Variable speed spinning

As the package diameter and balloon length change their contribution to tension applied to the yarn also changes; when they impose less tension it is possible to increase the spindle speed to maintain constant tensions conditions. Variable speed spinning therefore permits higher average spindle speeds and increases production by 10 to 15% with a lower end-breakage rate; it also provides a more uniform yarn by maintaining constant spinning tension. Variable speed spinning has been widely used on ring spinning machines.

An alternative arrangement is to have a dual speed system which provides a high uniform speed throughout the middle of the spinning cycle. Increased production of about 14% has been claimed for this arrangment.

Spindle pitch

The distance between the centres of two adjacent spindles is called the pitch of a spinning frame. A smaller pitch means that an increased number of spindles can be accommodated in a given area of floorspace, which is clearly desirable, and is usually associated with higher spindle speeds and finer yarn counts; an increased pitch is generally required for a thicker yarn to permit larger package sizes which allow for a suitably long spinning cycle.

Lifter traverse motion

When the twisted yarn passes down on to the package it is necessary to wind the yarn on in an orderly manner so that it forms a package which can withstand handling and which will unwind without becoming entangled.

The upward and downward movement is provided by the lifter traverse motion which usually involves a combination of cam and ratchet mechanisms. The drive is conveyed to the lifter rail which extends along the full length of the spinning frame.

Some of the different forms of traverse used in spinning and in yarn folding are shown in *Figure 9.1*, along with the package shapes which they produce; in the shaded part of the diagrams the vertical movement of the lifter (h) is plotted against time (t) on the horizontal axis.

The provision of bobbins at the spinning process is expensive because of the large number of spindles involved, and there is a general preference towards simple tapered tubes made of compressed paper or plastic, and used for cop build which is unwound over-end at the following operation.

With cop build, the yarn moves down slowly, and up quickly to provide locking coils and to avoid sloughing-off when the yarn is subsequently unwound. The balloon rotates faster when unwinding from the nose than from the shoulder. The rate of acceleration of angular velocity of the unwinding balloon is kept low by having more coils to unwind on the upward unwinding traverse; this avoids a sudden change in balloon speed which could lead to snatching of the yarn at the nose thereby pulling off a number of yarn coils simultaneously.

Spool build was widely used when it was common to put the spun package direct into the weaving shuttle; it is still used for some mohair weft yarns.

Parallel build on double-flanged bobbins was widely used in cap, ring, and flyer spinning, but unwinding imposed speed limitations because the sideways withdrawal of the yarn during unwinding caused rotation of the package. The other variations of parallel build may be used in yarn folding.

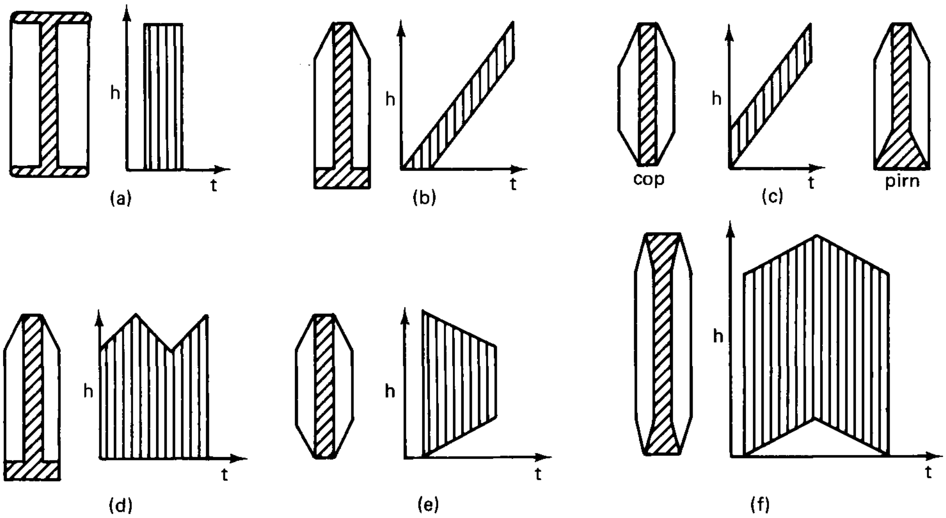

Figure 9.1 Types of yarn traverse and package shapes: (a) parallel build; (b) spool build; (c) cop build or pirn build; (d) tapered parallel build; (e) parallel 'roving' build; (f) differential parallel build

Productive efficiency

$$\text{Productive efficiency} = \frac{\text{Actual production} \times 100}{\text{Theoretical non-stop production}}$$

This is a measure of the actual time during which yarn is being produced by a given number of spindles, expressed as a percentage of the total spindle-time available. Spinning production is usually measured in kilogrammes; the following are the main factors involved in the loss of production:

(1) Doffing

When the spinning packages are full the machines must be stopped while they are removed and replaced by empty packages. This is usually a manual operation which may take about 10 minutes depending on labour arrangements. For a given yarn count larger packages will give longer running time and only take the same time to doff, hence they enable a higher productive efficiency to be achieved. On the other hand they usually require a lower spindle speed and entail a higher power consumption.

(2) Spinning end-breakages

Every time a thread breaks, the actual production of yarn is reduced and in addition waste may be produced.

(3) Changing lots

When the production of a given lot of yarn nears completion it is necessary to 'run-out' the rovings in such a way as to keep most spindles in use for as long as possible; inevitably some spindles are left empty near the end of a run-out. The machine will then need cleaning and setting up for the new lot, samples must then be checked for count before production can be resumed.

(4) Mechanical failures

There are numerous possible mechanical causes for stoppages of which the most common is probably the breakage of spindle driving tapes.

(5) Interference

An operative may be required to attend to two or more machines at the same time — clearly one or more of the machines must wait.

Yarn piecening

Piecening is necessary every time an end breaks; it involves locating the yarn end on the bobbin, withdrawing and re-threading it, and bringing it into close proximity with the strand of fibres being delivered from the drafting zone so that the twist binds the two ends of yarn together where they overlap. Manual piecening may take 10 seconds or more, with an average of about 36 seconds on a woollen ringframe, or from 5 to 17 seconds or more on worsted or cotton ringframes.

Various devices have been designed to eliminate the need for operative piecening when an end breaks; this may be done with or without removing the bobbin, or it may involve the use of a separate length of yarn; automatic piecening will be used increasingly in the future. An automatic piecener is shown in *Plate 21*.

Automatic doffing

Manual doffing involves preparation, removal of full bobbins and replacing them with empty bobbins, transporting the bobbins and re-starting the frame; this may take about 10 minutes per frame.

Manually operated mechanically assisted doffing devices were developed for flyer and cap frames many years ago although they were never used widely on the latter type of frame.

As ring spinning became more widely used, interest focussed on developing fully automatic doffing devices. Traversing doffers which have a lower capital cost may prove better for fine counts where there is a longer running time between doffs, but it may necessitate having a large number of identical spinning frames suitably spaced. There are two different systems of traversing doffers: continuously operating machines with individual cop doffing; or step-wise operating, where a group of spindles are doffed simultaneously.

For thick counts where doffing occurs frequently a full frame doffer is likely to be preffered. Some machines of this type convey full and empty bobbins to and from the headstock, respectively, and have a maximum doffing time of about 3 minutes. Such a device is shown in *Plate 21*. The economic aspects of autodoffing are complex.

The economics of spinning

The determination of the most economic spinning conditions such as package size and spindle speed are influenced by many cost factors, including capital, power, doffing, rewinding, floorspace, and overheads. The two yarn parameters of count and twist have a most important influence.

The economy of the process is also influenced by factors such as deployment of labour, handling costs, end-breakages, waste percentages, and package density.

The factors can vary considerably in different sections of the industry. For example, a typical approximate yarn package density is 0.4 g/cm^3 for a 100% wool yarn, and 0.5 g/cm^3 for 100% viscose; the power required to rotate a package of given size and mass of smooth yarn may be only one third of that needed for a fibrous woollen yarn.

The way in which some of these factors may combine is shown in general terms in *Figure 9.2*. from which the optimum economic spindle speed may be determined; this may be not necessarily the best speed from the technological point of view. In a similar way the optimum package dimensions may be determined.

It is important to appreciate that such an exercise should not be carried out in isolation — the effect of changes at the spinning process itself may influence costs at both preparatory and subsequent processes.

Even with the application of complete automation, conventional spinning would still account for about 50% of the cost of processing a cotton yarn.

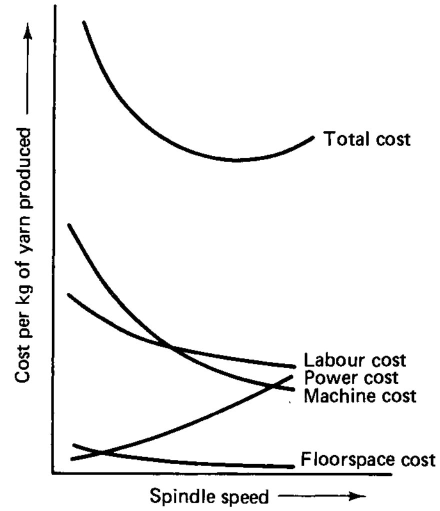

Figure 9.2 Factors influencing yarn cost

General features of the spinning process

Yarn twist has a most important influence on yarn properties and on the spinning process itself.

Yarn strength

The strength of most spun yarns depends on two principal factors: the fibre strength, and the frictional resistance to slippage. A third factor, the effect of the fibres themselves being twisted about their own individual axes — which might conceivably cause them to shear — can have little influence on yarn strength or extension for most yarns, although it probably does have an influence in very high twist yarns.

The source of fibre strength lies in its molecular structure; the long chain molecules tend to be orientated in the direction of the fibre axis.

As yarn twist is increased the angle of fibre inclination (β in *Figure 8.5*) increases and therefore the component of fibre strength in the direction of the yarn axis decreases; this is represented in *Figure.9.3.* Hence theoretically, fibre strength makes its maximum contribution to yarn strength when the fibres lie parallel to the yarn axis, i.e. when the yarn contains no twist. This effect is most easily demonstrated with continuous filament yarns but is also true of the fabric strength contribution of the twistless staple fibre yarns described later. Hence the relationship between the fibre strength contribution to yarn strength is of the form indicated by the broken line in *Figure 9.3.* An increase of twist increases the angle of fibre inclination from β_1 to β_2 and decreases the fibre strength contribution to the yarn strength from S_1 to S_2.

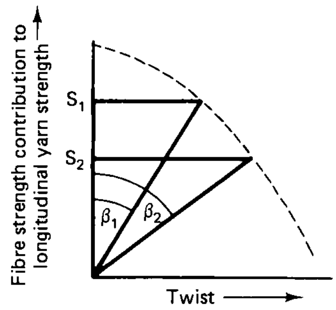

Figure 9.3 The influence of twist on the fibre strength/yarn strength relationship

As yarn twist is increased the frictional resistance between the fibres gradually increases until a point is reached at which fibre slippage is virtually eliminated as shown in *Figure 9.4.*

In most single spun yarns the effect of twist on total yarn strength is determined by a combination of the two effects described above, and the resulting relationship is of the form shown by the solid line in *Figure 9.5.*

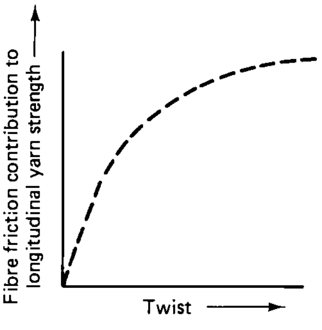

Figure 9.4 The influence of twist on the fibre friction/yarn strength relationship

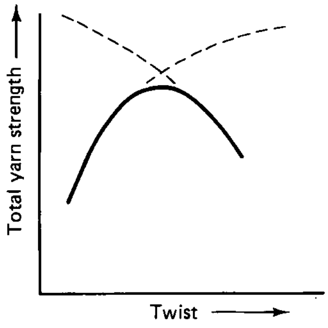

Figure 9.5. The influence of twist on total yarn strength

The amount of twist required to produce maximum yarn strength will depend on the detailed fibre properties. For example, as illustrated in *Figure 9.6*, for a given fibre strength, a higher frictional property will enable a higher maximum yarn strength S_3 to be obtained with a lower amount of twist T_3 than would be possible if the same strength of fibre had lower frictional properties (S_4, T_4), but the effect of reduced twist on the ultimate fabric must also be considered.

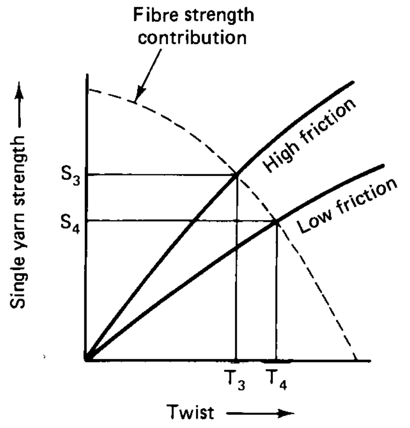

Figure 9.6 The influence of fibre friction on the twist/yarn strength relationship

The use of finer fibres in a yarn has a similar effect to increased friction, enabling stronger yarns to be made with less twist than could be made with coarser fibres which are otherwise alike; also less twist may be used with longer fibres.

Similarly, for fibres with equal frictional properties, but different fibre strengths, as shown in *Figure 9.7*, a weaker fibre requires less Twist T_5 to develop its maximum yarn strength S_5 compared with the stronger fibre (T_6, S_6), although the maximum strength of the yarn made from the stronger fibre will be greater than that of the weaker fibre.

In practice, of course, there may be simultaneous variations of frictional, strength, and other properties to influence the strength/twist relationship.

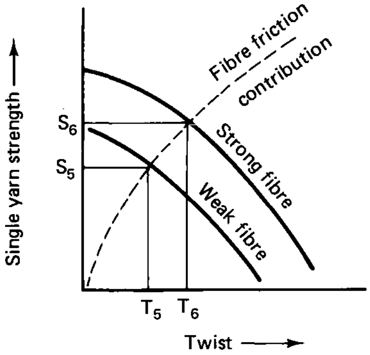

Figure 9.7 The influence of fibre strength on the twist/yarn strength relationship

In cotton spinning it is common to use the twist for maximum strength in single warp yarns, and less twist in weft yarns.

The amount of twist for maximum strength is largely influenced by the mean fibre fineness and is virtually uninfluenced by fineness variation.

Because strength is not usually a problem in worsted yarns, normally twist about 60 to 70% of that required for maximum strength is used.

Lower twists may be used in yarns which are to be folded, and very high twists may be used to produce special effects such as crêpe.

Twist variation and yarn appearance

Because under free conditions, twist distribution depends on strand thickness, there is a tendency for twist variation to be caused by local yarn count variation, depending on the length of yarn over which freedom to rotate extends. The relationship between twist in a yarn and local yarn count is of the form shown in *Figure 9.8*; at longer test lengths the correlation between count variation and twist variation decreases.

The result of more twist in the thin places is to increase the bulk density at those places, while thicker places remain with less twist; therefore at certain levels of twist the differences in bulk density accentuate the appearance of thickness variations. If further twist is added, eventually the thin places become saturated with twist and then additional twist flows into the thick places causing a reduction in the differences between the visual appearance of thick and thin places, and a reduction of twist variation.

It is also possible for twist variation to be caused by mechanical defects, but in this case it is usually a longer-term variation; such causes of variation can be avoided by a suitable programme of preventive maintenance.

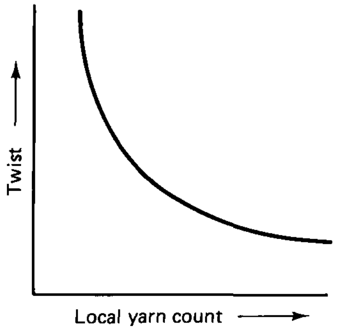

Figure 9.8 The influence of local yarn count on twist

Differences of mean twist influence the light reflection of a yarn, and this is readily observed in fabric form. A difference of about 40 t/m is sufficient to cause a weft bar in a woven fabric; when viewed from one selvedge the bar may appear lighter and when viewed from the other selvedge it may appear darker than the surrounding cloth. This simple observation is an almost infallible guide to the identification of a weft bar caused by a difference between mean twists; a similar change in appearance of individual warp threads can arise when viewed from different angles.

The coincidence of twist angle and twill angle may enhance the light reflection of a woven fabric, and untwisted cotton yarns were produced at great expense many years ago to obtain maximum lustre.

Yarn thickness, compressibility, and twist

In general, twist difference have a considerable influence on these yarn characteristics.

If yarn thickness is measured by mechanical compression between parallel plates, an increased amount of twist is found to cause:

(1) greater yarn thickness when measured under a high load,
(2) under a low load: (a) a decrease of yarn thickness with high crimp fibres, (b) an increase of yarn thickness with low crimp fibres, and
(3) a lower rate of yarn compression.

Spinning production

Spinning frames normally are run at maximum spindle speed for a given material and yarn count. Consequently delivery rate is inversely proportional to twist, and therefore it costs more to insert increased twist; as a result there is a strong motive towards spinning with minimum twist.

The increased twist requirements of finer yarn counts accentuate the reduction in production rates for fine yarns; for example, when changing from 18 tex to 36 tex, the production rate will not merely be doubled, as might commonly be expected, but may increase by a factor of 2.5 to 3.0 because of the lower twist requirements of the thicker yarn and the consequently increased delivery speed.

If a high twist yarn is required for effect purposes it may be more economic to spin the yarn with a normal amount of twist and then insert the additional twist at a higher speed on a subsequent machine. Such a procedure may also increase the yarn strength and elongation at break as compared with a single process yarn.

Spinning end-breakages

When large scale production is undertaken it is inevitable that some threads will break when the yarn tension exceeds the yarn strength for a long enough instant of time. Either (a) the yarn strength is too low to enable it to withstand the normal tension, or (b) the tension is too great for the normal strength of the yarn. Apart from ends down caused by gross yarn faults, the most critical factor is yarn irregularity, followed by mean yarn strength, and mean spinning tension. In conventional spinning the minimum angle of lead (θ in *Figure 12.2*(*a*)) has a marked effect only when there is a low end-breakage rate; other factors have little influence on end-breakage rates. Clearly the frequency of end-breakages will influence the number of spindles which can be allocated to an operative and the amount of waste produced.

When discussing end-breakage rates it it usual to normalize the results obtained and express them as the number of end-breaks per 100 spindle-hours. It is important to appreciate that end breaks per 100 spindle-hours are not strictly comparable when different spindle speeds are involved. For example, a rate of 6 end breaks per 100 spindle-hours at a spindle speed of 10 000 rev/min would have the same number of ends down *per kg of yarn produced* as 9 end breaks per 100 spindle-hours spun at 15 000 rev/min.

In ring spinning the majority of end-breaks occur between the front rollers and the yarn guide where twist penetration is not complete, and particularly when there is a thin place in the yarn at the point of delivery. In worsted yarns finer than about 20 tex a break usually occurs as the result of fibre slippage.

Occasionally one broken end may lead to multiple end-breaks on adjacent spindles although the use of balloon separators helps to minimize this occurrence.

A sizeable minority of end-breaks (about 23%) may be due to systematic faults; computerized monitoring and data collection provides a means of isolating such faults.

Because yarn strength is influenced by spinning twist, there is a sensitive relationship between twist and the spinning end-breakage rate of the form indicated in *Figure 9.9*, hence the amount of twist can be used as a means of controlling the end-breakage rate; an excessive increase of twist (which is unlikely to arise in practice) would cause a rise of end-breaks as indicated by the broken line in *Figure 9.9*.

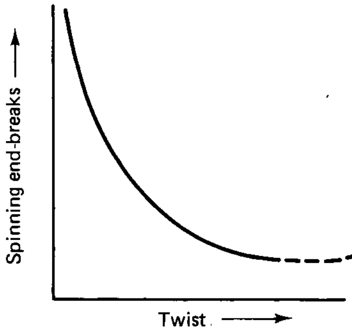

Figure 9.9 The influence of spinning twist on end-breaks

Spinning tension is approximately proportional to (spindle speed)^2 and so for a given material, end-breakages increase disproportionately with increased spindle speed, the relationship usually being of the form shown in *Figure 9.10*. Hence end-breakage rates can be controlled by alterations of spindle speed.

The end-breakage rate is very sensitive to small changes in yarn count, the relationship being of the form shown in *Figure 9.11*; this is because of the yarn count/tenacity relationship shown in *Figure 19.7*.

Besides the influence of spinning twist, spindle speed, and yarn count, various other factors influence the number of end-breakages arising in practice. These include the details of the spinning

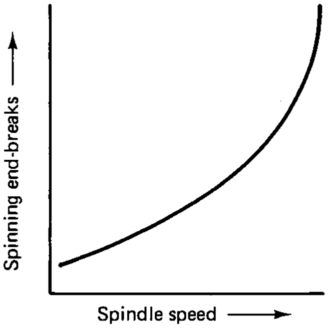

Figure 9.10 The influence of spindle speed on end-breaks

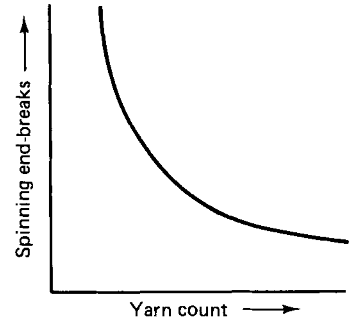

Figure 9.11 The influence of yarn count on end-breaks

machine, roving twist, atmospheric conditions, fibre additives, uniformity of fibre composition, average number of fibres in the yarn cross-section, fibre frictional properties, fibre length and distribution, and fibre strength. In conventional spinning machines there is a tendency for a decrease in the end-breakage rate near the middle of the spinning cycle.

A tolerable end-breakage rate in one factory may be regarded as unacceptable in another, and there is no universally accepted standard for end-breakage rates. Nevertheless for conventional spinning the following is given as a general guide to end-breaks per 100 spindle-hours, although breakages may be higher for fine counts:

worsted spinning	up to 5
cotton spinning	up to 3
woollen spinning	24 to 30.

In general, the amount of twist used in spinning is the minimum required to give a 'good spin' (i.e. to give an acceptable end-breakage rate) provided that yarn strength is adequate for subsequent processes; an exception to this rule is when spinning yarns containing synthetic fibre in which case additional twist may be inserted to minimize pilling, although it may be preferable to use low-pill synthetic fibre instead.

The estimation of end-breakage rates from observation of a limited number of spindle-hours must be treated with caution because of the variability which arises and it is important to record end-breaks over one or more *complete* spinning cycles.

Spinning twist formulae

Various theories and empirical formulae have been advanced from time to time to enable the calculation of a satisfactory spinning twist. Most of them were originally introduced using the traditional yarn counting systems, but they have been re-written here in the equivalent tex system form. For convenience they may be classified in the following groups:

Group 1

$$\text{twist (t/m)} = \left[\frac{a}{\text{count (tex)}}\right] + b$$

where constants a and b are specified. Formulae of this type give a straight line graph when 1/count is plotted against twist, but it is well known that in industrial practice a linear relationship does not exist when a range of counts is spun from a given fibre supply. Formulae of this type may be useful over a narrow range of yarn counts, e.g. (12 000/tex) + 25 = twist (t/m) gives an approximate guide for worsted yarns from 18.5 to 37 tex, but it tends to indicate too much twist for fine yarns and insufficient twist for thick yarns.

Group 2

$$\text{twist (t/m)} = \frac{C}{\sqrt{\text{count (tex)}}}$$

$$= C[\text{count (tex)}]^{-1/2}$$

where C is a constant.

A formula of this type was stated for cotton yarns by Koechlin in 1828. Ashenhurst, probably unaware of Koechlin's work, proposed a similar formula for worsted yarns in 1884.

Theoretically the use of such a formula should produce the same angle of fibre inclination to the yarn axis when a range of yarn counts is produced from a given material.

This theory was discussed on page 87 with reference to roving twist; when a formula of this type is used for a wide range of yarn counts spun from a given material, it gives insufficient twist for fine yarns and too much twist for thick yarns.

The explanation of this is that the proportion of fibres forming the 'ineffective outer layer' is greater in fine yarns than it is in thick yarns and consequently to compensate for this factor higher values of twist constant C have to be used for finer yarns in order to obtain satisfactory amounts of twist when widely different counts are spun from the same fibre supply; the influence of the 'ineffective outer layer' of fibres on yarn tenacity is discussed on page 209.

This is the reason why formulae of this type have never found wide favour with worsted spinners although 2600 $\{\text{count (tex)}\}^{-1/2}$ = t/m gives a fairly good guide for worsted yarns within the limits of 18.5 to 37 tex.

However this type of formula appears to be regarded generally as being satisfactory for cotton, woollen, jute, and flax yarns.

It has become common to describe the twist in a cotton yarn in terms of the twist constant C instead of in turns per metre, and the Aronson agreement on wages and conditions, 1947, quoted the equivalent of 3800 as the constant for normal twist. The satisfactory general guide obtained by using 3800 $\{\text{count (tex)}\}^{-1/2}$ = t/m for cotton spinning may be accounted for by the practice of cotton spinners usually selecting the fibre grade according to the count to be spun, whereas in worsted spinning a wide range of yarn counts may be spun from the same raw material.

In jute processing the twist constant C for maximum yarn strength is about 2500 over a count range from 70 to 480 tex made from good, medium, and poor quality fibre.

In flax spinning the use of the $\sqrt{\text{(count)}}$ relationship has been standard practice for many years, and the twist for maximum yarn strength is when $C = 2560$.

On the woollen system where a widely varying range of raw materials is used, analysis of the published twists used in practice shows that a good approximation is 4000 $\{\text{count (tex)}\}^{-1/2} \pm 30\%$ equals turns per metre. The latitude of ± 30% is necessary because of the wide range of hard and soft twists which are used for both thick and thin yarns, and because of the variety of raw materials used in woollen yarns.

Group 3

Twist (t/m) = $K \{\text{count (tex)}\}^{-2/3}$

The formula 4400 $\{\text{count (tex)}\}^{-2/3}$ is applicable to many yarns spun on the worsted system and it gives satisfactory twist for yarns from 6.33 tex to 110 tex.

In fact this is basically the same formula given previously for flyer lead roving twist on page 88, but multiplied by a factor of 1.447 to eliminate fibre slippage. Hence the $(\text{count})^{-2/3}$ relationship has been shown to be valid on the worsted system from 6.33 tex up to 15 ktex, with an adjustment made to the constant used to permit or eliminate fibre slippage as appropriate for slubbings or for yarn. For man-made fibres and blends, up to 30% less twist may required than is indicated by the above formula.

The fact that a longer wool is also usually a coarser wool permits one value of K to be used for worsted yarns although more twist may be required for short wools of less than 12 months growth, and for slippery fibres such as mohair.

Because longer cottons are also finer cottons, it is not possible to have a single value of K for widely different cottons. Nevertheless for a given cotton processed to a wide range of yarn counts, a single value of K is valid: e.g. a combed cotton blend with a mean staple length of 27.8 mm ($1\frac{1}{32}$ inches) and a micronaire value of 4.3 was spun to counts ranging from 10 tex to 60 tex using a K value of 4400 to obtain a yarn tenacity of 142.5 mN/tex. Longer and finer cottons require a smaller K value, and vice-versa.

To summarise: the $(\text{count})^{-2/3}$ relationship is valid with one value of K *for a given stock of fibre processed on a given set of machinery*; in general, within limits, a higher value of K may be used to obtain increased yarn tenacity.

Yarn length contraction

An increased amount of spinning twist causes greater yarn length contraction. For example, yarns spun from the same roving with the same spinning draft, but with different spinning twist, produced the results indicated in *Table 9.1*.

For a given absolute increase of twist, the yarn contraction increases at a faster rate at higher levels of twist than at low levels, the relationship between twist and contraction being of the form indicated in *Figure 9.12*.

This factor must be allowed for in determining the draft required to produce the correct spun count.

Table 9.1 ***Changes of count produced by altering only the spinning twist of yarns spun from the same roving***

Spinning twist (t/m)	*Yarn count (tex)*
645	19.9
724	20.1
803	20.4
882	20.8

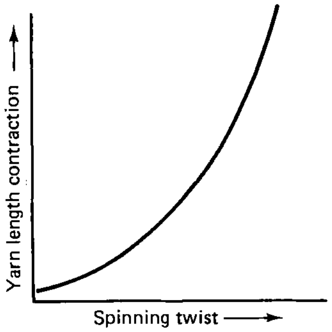

Figure 9.12 The influence of spinning twist on yarn length contraction

Fine count limit

The fine count limit of a fibre is the finest yarn which can be spun satisfactorily under commercial conditions from that fibre supply; it is hard to define because it depends on many factors such as the type of spinning machinery, package size, spindle speed, twist insertion, and on the tolerable end-breakage

Table 9.2 ***Mean fibre diameter and approximate spinning count limits for Bradford wool tops***

Quality number	70	66	64	60	58	56
Mean fibre diameter (μm)	20.5	21.5	22.5	24.0	26.5	28.5
Lower tex limit	15	18	18.5	22	28	30.5

rate. The quality number of a given wool is closely related to the mean fibre diameter, consequently it is also related to the finest yarn which can be spun from a given wool quality.

Clearly a certain minimum number of fibres must be present in a yarn cross-section in order to provide sufficient fibre contacts to prevent fibre slippage. In worsted yarns the minimum number of fibres required in the yarn cross-section for commercially successful spinning is about 30 to 40 for any quality of wool from 40's to 80's.

When spinning near to the fine count limit, because of the yarn count/tenacity relationship shown in *Figure 19.7,* a small change in count can cause a large change in the end-breakage rate as indicated in *Figure 9.11*, and as labour becomes more expensive, spinning to the count limit becomes less economic in the absence of automatic piecening.

The practical count limits used by many worsted spinners for Bradford type tops is shown in *Table 9.2*.

A similar relationship between mean fibre fineness and spinning count limit applies to all fibres.

An almost linear relationship applies between count limit and blend short fibre component percentage, and up to a point an increased mean fibre length permits finer yarns to be spun; excessive fibre crimp can impose limitations on the finest count which can be spun.

The introduction of an increasing percentage of strong fibres permits a finer spinning count limit as well as having an appreciable effect on yarn strength, and one of the benefits of blending man-made fibres with natural fibres is the finer spinning count limit which can be obtained.

It must be emphasised that the limit count is the *fine* count limit to which a fibre may be spun, but it does not necessarily follow that it must be spun to that count; on the contrary, many fibres are spun into yarns considerably thicker than the limit count.

Fly waste

In conventional spinning it is impossible to collect all fibres emerging from the front rollers into the forming yarn. Some fibres may escape as they emerge from the front rollers, while others may be thrown out later by centrifugal acceleration.

In worsted spinning the author has shown that fly waste is primarily composed of short fine fibres and coarse, but longer fibres which lie near to the yarn surface. Alkali damage in wool causes an increased percentage of fly waste which may account for the high proportion of fibre tips in fly waste.

Microbiologically damaged cotton also causes an increase of fly waste and more fly waste is formed when more short fibres are present in the roving.

The quantity of fly waste can be minimized by ensuring that the fibres emerge from the delivery rollers in as narrow a ribbon as possible, and spinning with higher drafts from thicker rovings tends to increase the amount of fly waste.

Amounts of fly waste are also increased by a reduction of relative humidity, increased spindle speed, or reduced roving twist.

Fly waste is a potential cause of yarn faults such as slubs if it is allowed to accumulate on machine parts. Underclearers and other suction/blowing devices help to remove it before faults can be caused; a travelling cleaner for this purpose is shown in *Plate 21*.

10

FIBRE MIGRATION AND DISPLACEMENT

It is often intuitively, but wrongly, assumed that a yarn is built up of concentric layers of helically disposed fibres in which the helix angle is zero at the core and increases with increasing helix radius up to a maximum at the surface, depending on the amount of twist inserted.

In such a structure, the length of fibre 1 corresponding to a length of yarn L is given by $l = L/\cos\theta$ where θ is the helix angle of inclination to the yarn axis. Hence $L = l$ at the yarn core and $l/L > 1$ at other points, rising to a maximum at the yarn surface.

For such a yarn to be produced, either each fibre would have to be delivered at a speed corresponding to its helix radius, or else the leading end of each individual fibre would have to retract by an appropriate amount before being gathered into the forming yarn. In practice when twist is inserted into a ribbon-like strand of fibres immediately after drafting in order to convert it into a twisted assembly, neither of these requirements is possible; the former because the roller delivery is constant for all fibres, and the latter because the frictional grip provided by twist insertion prevents such movement.

It follows, therefore, that during twist insertion the fibres must be subjected to different tensions — ranging from a minimum at the core to a maximum at the surface of the yarn. This results in the tendency for inner fibres to buckle out of their planes of motion and outer fibres to interchange positions with inner fibres in order to equalize tensions. Tension differences also arise in drafting.

The short-term migration arising from tension differences in spun yarns is superimposed on a long-term migration arising from a geometric mechanism related to roving twist × draft, the short-term migration being predominant.

This phenomenon of individual fibres exhibiting variable helix radii at different points along their length is called fibre migration; it can be characterized by:

(1) mean fibre radial position;
(2) the amplitude of migration; and
(3) mean migration intensity, i.e. rate of change of radial position.

A high degree of migration from core to outer layers contributes to increased yarn strength. It is rare for a fibre to traverse from core to surface and back again in one cycle of migration; the frequency of reversal from outward to inward short-term migration (and vice-versa) is directly related to the amount of twist insertion in spinning.

In the case of staple fibre spinning on cap, ring, or flyer frames, as each fibre leaves the delivery roller nip, the tension in its trailing end must decrease, permitting it to move outwards, if not already on the surface, to form a projecting hair. The length of fibre affected in this way, expressed as a percentage of total fibre length, is greater for short fibres and so they have less tendency to interchange positions than would longer fibres.

Cotton fibres are unique in that they taper in thickness from the heavier root end to the finer tip end; the root tends to migrate outwards and the tip inwards towards the yarn core.

Fibre displacement in drawn-and-spun yarns

Blending of fibres differing in length, diameter, and mechanical properties can be expected to lead to a preferential distribution of the components relative to the yarn axis.

This tendency towards preferential radial distribution is here called fibre displacement in order to distinguish it from the general term fibre migration, although it is a particular form of migration and has been called migration in other publications.

Fibre displacement might be exploited deliberately in certain circumstances, such as, for example, where a cheaper fibre may be required to migrate to the yarn core; alternatively a uniform radial distribution of fibres may be desirable where surface shade variations are to be avoided.

Three groups of factors influence displacement:

(1) fibre factors;
(2) yarn factors; and
(3) process factors.

Fibre factors

These include the physical properties of length, fineness, cross-sectional shape, frictional properties, fibre substance, and the mechanical properties of tensile modulus, bending modulus, torsional rigidity, elastic recovery, and extensibility.

Finer fibres tend to move to the yarn core, whereas coarser fibres tend to move to outer zones and tend to protrude more frequently and further from the body of the yarn. This effect may be caused by the greater strain imposed on finer fibres, aided by the greater rigidity of the thicker fibres resisting being gathered into the yarn by twist insertion; it has been exploited deliberately to produce an imitation kemp surface effect.

Shorter fibres tend to move outward and increase yarn hairiness because they are subjected to lower tensions; blended cotton yarns with this characteristic are called 'oozy'.

Relatively small differences in length and fineness are sufficient to produce a significant degree of fibre displacement.

Fibres with a higher modulus are associated with inward displacement as are fibres with higher frictional properties.

Relaxation of a high shrinkage fibre causes it to move inwards.

Displacement also appears to be influenced by the fibre substance but this is a complicated matter to codify, and its effect on displacement is small compared with the other factors.

Yarn factors

This group includes yarn count, roving twist, spinning twist, blend proportions, and fibre entanglement; they appear to influence the degree of fibre displacement, rather than the direction.

Fibre displacement can occur both in long staple and in short staple rovings, and the effect may be further emphasised in the spinning process.

Up to a point fibre displacement in appropriate two-component blends increases as spinning twist increases; further increase of spinning twist eventually reduces displacement, presumably because of the increased radial forces impeding fibre interchange.

The migrational behaviour of a fibre is influenced by its mean radial position in the yarn; surface fibres show the least tendency to migrate, while core fibres exhibit a short-term but low amplitude migration. Fibres in intermediate layers tend to a more complete cycle of migration.

Lower spinning twist and thicker yarn count are both associated with reduced migration.

Process factors

This includes machine geometry and setting, drafting system, amount of draft, spinning tension, and the position of the fibres emerging from the delivery rollers.

Most of these factors are pre-determined on a given system and do not have a major influence on fibre displacement, although spindle speed and spinning tension influence migration to some extent.

Increased strand width emerging from the delivery rollers accentuates the tendency for long fibres to be displaced towards the yarn core and for the fibres near the edges of the emerging fibre ribbon to be displaced towards the yarn surface.

In most woollen yarns displacement is negligible, and even under favourable conditions where long fine and short coarse fibres are blended together displacement is only slight because of the high degree of fibre entanglement. However, in woollen-spun yarns containing man-made fibres there is some displacement, and also fibre migration.

The degree of fibre migration in open-end yarns is much lower than that of ring-spun yarns, because the fibres do not form a flat ribbon immediately before twist is inserted.

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11

INTERMITTENT SPINNING MACHINES

Mule spinning

The mule was invented by Samuel Crompton in 1774; it was so named because it combined the principles of roller drafting and spindle drafting for cotton spinning. Later the same ideas were applied to worsted spinning; the use of ring spinning has since rendered mule spinning obsolete in both the cotton and worsted industries.

The principles of mule drafting (i.e. spindle drafting) was also applied to woollen and condenser cotton spinning, but without roller drafting. This method of spinning is still used in the woollen industry and has become known as the woollen mule; gradually it has been losing ground to the ringframe and might be displaced further by open-end spinning. A modern woollen mule is shown in *Plate 20.*

The woollen mule is fed by an untwisted slubbing which consists of a narrow strip of card web which has been consolidated by the reciprocating rubbing aprons of the woollen card condenser; almost all the fibres are tangled or hooked therefore roller drafting can not be used to bring about a major re-

Plate 20. Mule spinning machine. This make of mule is still currently manufactured. It is made in lengths up to 60 m, with approximately 800 spindles, depending on the spindle pitch, which ranges from 60 to 70 mm. Spindle speeds up to 9500 rev/min may be employed because the spindle rail is stationary; the carriage, shown on the right, traverses to carry the condenser bobbins back and forth. Mule spinning is still in use for spinning some fine woollen yarns, hosiery, cashmere, and lambswool. Courtesy of S. Bigagli & C.S.p.A. (Italy)

distribution of the fibres as in cotton or worsted spinning.

There are four main objectives of the woollen mule:

(1) to reduce the slubbing to the required yarn count,
(2) to minimize the short-term irregularity of the spun yarn,
(3) to improve fibre alignment, and
(4) to insert twist in order to obtain satisfactory yarn strength (which is also influenced by items 2 and 3 above).

The woollen mule cycle of operations

This description refers to the conventional machine as represented in *Figure 11.1* in which the spindles, winding faller and counter faller are mounted on a carriage which can move to and fro in relation to the delivery rollers which are mounted on fixed centres. The percentages in parenthesis indicate the approximate amount of time spent on each part of the cycle, but these may vary depending on draft and twist requirements.

Delivery (20%)

The surface drum rotates the condenser bobbin to feed twistless slubbing through the delivery roller nip under slight tension. The carriage recedes from the rollers, and the spindles slowly rotate to insert a moderate amount of twist (usually in the S direction) into the undrafted slubbing. Each revolution of the spindles, inclined at about 12½° from vertical, allows one coil of yarn to slip off the spindle tip and thereby insert one turn of twist per revolution; there is nothing to prevent the twist from running up to the roller nip, therefore the material becomes twisted as it emerges from the rollers. *Figure 11.1 (a)* shows delivery just commencing, and *Figure 11.1 (b)* shows delivery almost completed.

Drafting (30%)

The condenser bobbin and delivery rollers stop rotating but the carriage continues to recede from them, gradually decelerating towards the end of the draw while the spindles rotate at a constant moderate speed, hence drafting takes place against an increasing angle of twist in the material which reaches from the spindles to the stationary rollers; this arrangement promotes the formation of a uniform yarn.

The actual amount of twist found in a mule-spun yarn is usually 15 to 20% less than that calculated from the known spindle revolutions and the yarn length; this arises by fibres moving relative to each other radially as well as longitudinally during the drafting part of the cycle.

As each coil slips off the spindle there is a 'plucking' action which induces a high speed longitudinal vibration in the thread which facilitates fibre adjustment to the strains imposed by the moving carriage.

During the drafting stage, the correct balance between draft and twist must be maintained as the thread becomes thinner so that the twist, which continually re-distributes itself in order to maintain equal torque at all cross-sections, may limit drafting of the thin places, but permit drafting of the thicker places. *Figure 11.1 (b)* shows the position just before drafting commences and *Figure 11.1 (c)* shows drafting just being completed.

Mule drafting may take place in two phases. The first phase mainly consists of a straightening out of the fibres in the softly twisted material with substantial elongation of the slubbing taking place and although there is no general relative fibre movement there must be some minor relative individual fibre movement to enable the fibres to be straightened — this straightening phase applies up to a draft maximum of about 1.25 to 1.50, depending on the conditions. The thread has a minimum irregularity just at the end of the straightening phase and it appears that mule drafting is usually accomplished almost entirely by simple straightening. If drafting is continued beyond the point at which the first phase is completed then the second phase which consists of fibre slippage — sometimes of a violent nature — gives rise to a slip-stick sort of fibre motion which leads to large changes in the relative positions of groups of fibres, and the yarn irregularity increases rapidly; the onset of the second phase is not simultaneous at all points along the yarn length.

Before drafting almost all the fibres in the slubbing are tangled or hooked, and after drafting there is a small change in the fibre configuration, but more than two thirds of the total fibre length is still in a tangled state; therefore, the fibres are not set at a longitudinal strain in woollen yarns as a consequence of the spinning process, but there is a significant increase in fibre extent.

Given a suitable combination of draft and twist the short-term yarn irregularity between lengths l is less than that between slubbing lengths of l/D where D is the draft, the degree of reduction of irregularity being significantly influenced by the amount of draft and by the original slubbing irregularity; a relatively irregular slubbing has a greater chance of improving, whereas a perfectly uniform slubbing could not be improved. As draft is increased, a point is reached when yarn and slubbing irregularities are equal. Further increases in draft lead to a rapid increase in yarn irregularity and this is accompanied by the appearance of 'twits'.

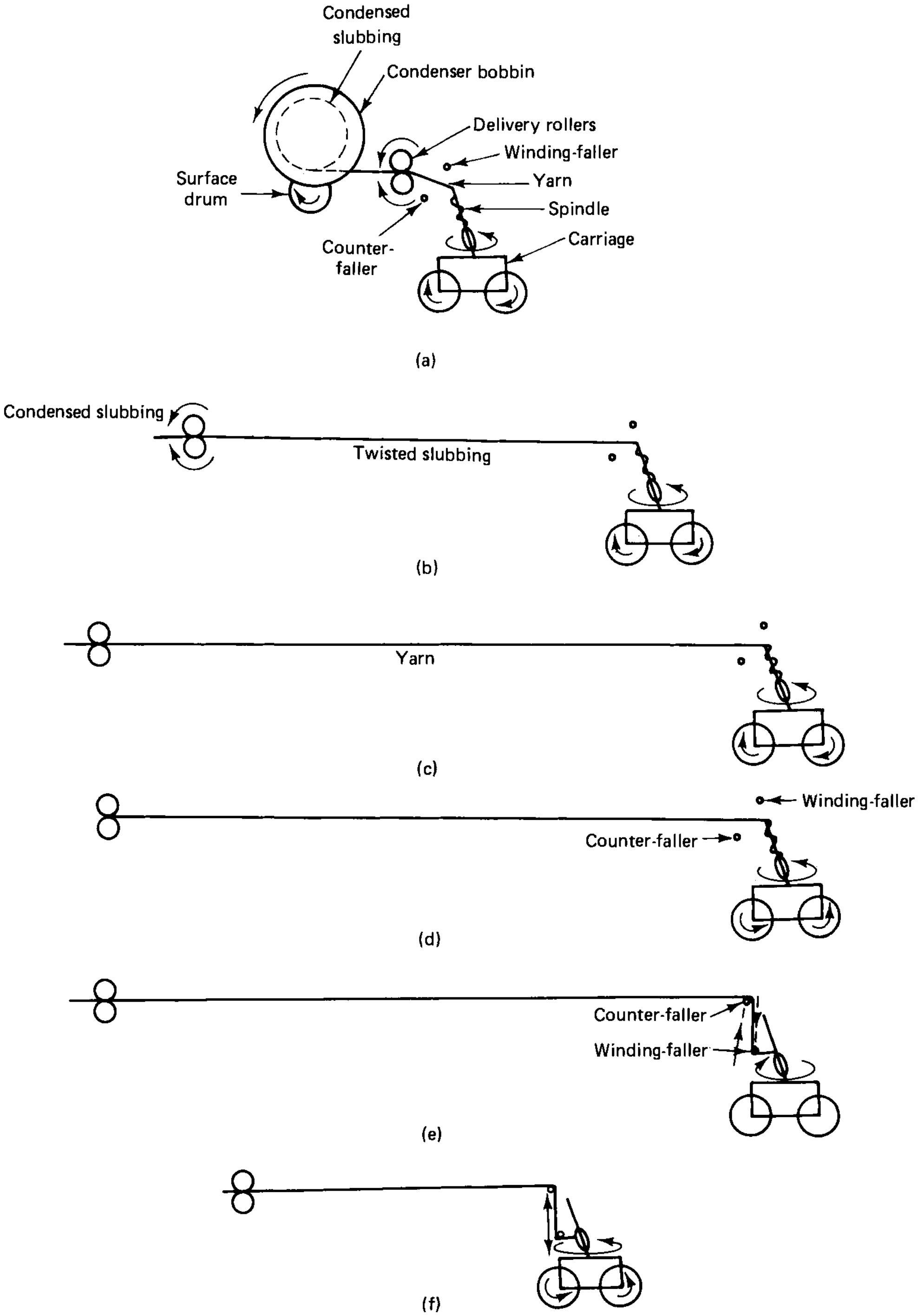

Figure 11.1 The mule spinning cycle: (a) delivery commencing; (b) delivery almost completed; (c) drafting almost completed; (d) twisting almost completed; (e) backing-off; (f) winding-on

A typical twit is a short thick place which is bounded by two abnormally thin places. A twit contains some 'through' fibres which extend through the thick place from one thin place to the other so that they prevent further drafting of the thick place. A twitty yarn has an unacceptably ragged appearance. Twits tend to form around some defect such as a burr or a nep; when the thickness of the drafted strand approaches that of the impurity, the strand diameter at that point is then prevented from becoming thinner so that twist concentrates in the thinner parts of the strand at each side until the through fibres become locked in place by the higher twist at the thin places.

Twisting (30%)

The spindles rotate at a maximum speed of about 5500 rev/min on older machines or up to about 9500 rev/min on modern machines to insert the necessary amount of twist into the previously drafted yarn. The carriage usually moves slightly towards the delivery rollers (about 25 to 50 mm) to allow for contraction of yarn length due to the twist insertion; this is called 'jacking-in' or 'jacking-up'. *Figure 11.1 (d)* shows twisting almost completed. During twisting the thread tension should be limited to a level lower than that reached at the end of drafting by jacking-in sufficiently.

In general the properties upon which most emphasis is laid in mule-spun yarns are strength, extensibility, and levelness; many yarns are used to make fabrics which will have a milled finish, in which case the minimum amount of twist is preferable.

Backing-off (5%)

The spindles revolve a few revolutions in the reverse direction to unwind the coils of yarn which extend to the spindle tip, causing a rapid drop in thread tension; the number of revolutions required for backing-off decreases as the package fills. Simultaneously the winding-faller and counter-faller take up positions ready for winding-on as shown in *Figure 11.1 (e)*, restoring tension almost to its previous level.

Winding-on (15%)

The carriage runs in towards the delivery rollers and the spindles rotate in the original direction at a slow variable speed while the winding-faller guides the yarn on to the package; the counter-faller is gradually pulled lower and the tension on the yarn reaches its highest level. *Figure 11.1 (f)* shows winding-on taking place.

The ideal requirement for successful winding-on is that at any instant during the inward run of the carriage, the rate at which yarn is being wound on to the cop must be equal to the inward carriage speed. The variations in spindle speed required actually to achieve this are complex because the spindles have to take into account not only the varying carriage speed, but also the varying cop diameter as the winding-faller traverses the yarn first rapidly from nose to shoulder, then slowly back to the nose again. The quadrant mechanism is only partially successful in meeting this varying spindle speed requirement and therefore the counter-faller is used to control a loop of surplus yarn which can be increased or decreased to accommodate the discrepancy between the actual and the ideal carriage speed/spindle speed relationship.

The load applied to the counter-faller controls the package density. In general there is little difference between yarn properties from hard and soft crops except that there may be a lower extension at break for hard (i.e. denser) cops; as mentioned previously, increased package density gives a longer running time between doffs and therefore increases the productive efficiency.

As winding is completed the winding-faller and counter-faller are locked out of action ready for the next delivery as shown in *Figure 11.1 (a)*, and tension falls to its lowest level.

The woollen mule cycle is repeated about 3 to 4 times per minute, with a total draw of about 1.8 m on a typical conventional mule with 320 spindles, each producing a package of 180 to 210 g. With a spindle gauge of 63 mm such a machine would have a length of about 22 m.

The draft is usually about 1.5 up to a maximum of 2 for 100% wool, and it may be as low as 1.2 for very short fibre blends; the maximum draft for acceptable yarn levelness is critically dependent on the slubbing twist content after delivery.

The approximate length required to be fed during delivery can be calculated from the relationship:

$$\begin{pmatrix}\text{total draw}\\ \text{length}\end{pmatrix} - \begin{pmatrix}\text{jacking-in}\\ \text{length}\end{pmatrix} = \begin{pmatrix}\text{condenser bobbin}\\ \text{delivery length}\end{pmatrix} \times \begin{pmatrix}\text{total}\\ \text{draft}\end{pmatrix}$$

although in practice there is usually a discrepancy between the calculated and actual draft.

Up to a point the use of a higher spinning draft produces a stronger yarn of a given count because of the improved fibre alignment; beyond that point an increased yarn irregularity and an excessive end-breakage rate may arise.

An interesting feature of the mule is that unlike other methods of spinning it tends to draft out a piecening until it is no longer visible; furthermore there are no drafting waves in a woollen yarn.

In the woollen system, the spinning machine has a relatively minor role in that it applies a small draft and inserts twist to convert the slubbing into a yarn.

In general the irregularities in the slubbing are passed on to the yarn and so it is true to say that the card largely determines the irregularity of a woollen yarn. Nevertheless short-term slubbing irregularities may be slightly reduced by the spinning process before being passed on to the yarn, and care should be exercised to minimize the introduction of additional irregularities by the spinning process.

At distances apart equal to the length of the mule draw, thick places may occur and periodic twist variation may arise over the same repeat length, with a coefficient of variation of twist between 250 mm yarn lengths rarely less than 15%.

When the cop of yarn is nearly full several coils of yarn may be unwound unintentionally (called 'sloughing-off') while the carriage is still withdrawing, causing an increase in the yarn count at the end of the full cop compared with the beginning. Once sloughing-off has started it tends to be self perpetuating and it is best avoided by not filling the package higher than about 38 mm from the spindle tip, and by ensuring that the counter-faller is below the height of the delivery roller nip after the carriage run-in is completed so that the yarn between the roller nip and the package is as straight as possible; this ensures that the minimum length of yarn is left unwound at the end of running-in.

The yarn from a mule cop is unwound by withdrawal over-end. Each turn of yarn round the spindle forms one additional turn of twist in the yarn as it is withdrawn. The effect of this extra twist is more noticeable at the base of the cop where the yarn was wound on to the smallest diameter of the package. The result is a few metres of yarn at the end of the mule cop which may contain up to 50 t/m of additional twist; in low twist yarns this may be an appreciable percentage increase of twist which could conceivably cause fabric faults.

A few alternatives to the conventional mule have been attempted, these include an electronic mule, a hydraulic mule, and an electric mule, but these developments have not been widely adopted.

The Bigagli mule, shown in *Plate 20*, is a machine which operates at about 3 to 3.5 draws per minute with a draw length of 3.0 m. The delivery rollers and condenser bobbins are mounted on a moving carriage which approaches and withdraws from the fixed rail on which the spindles are mounted; this arrangement permits the use of spindle speeds up to 9500 rev/min because of the more rigid mounting. This machine can produce yarn at more than twice the speed of a conventional mule, but the floorspace is increased to almost twice as much per spindle.

Centrifugal spinning

The centrifugal spinning pot was invented by C.F. Topham in 1900 to insert twist into wet-spun continuous filament viscose.

The basic principle of centrifugal spinning can be explained with reference to *Figure 15.8 (a)*. Instead of twist being inserted by a rotating package mounted on a spindle, the strand of fibres from the front rollers is passed to the inside of a rotating container into which the yarn is collected with the aid of centrifugal force. One turn of twist is inserted for each revolution of the point at which the yarn contacts the rotating surface inside the container.

Siemens-Schuckert of Berlin experimented with centrifugal flax spinning prior to 1937. Prince-Smith & Stells of Keighley investigated centrifugal spinning in 1935, and launched a commercial worsted spinning machine, the P.S.C. (Prince-Smith Centrifugal) in 1949. Production of these machines was discontinued in the mid 1950s.

During the 1950s the Japanese firm Mitsubishi introduced a machine based on similar principles, but designed to spin finer yarns; production was discontinued during the 1960s.

When the centrifugal system is used for wet spinning of yarns such as viscose, the material gathered in the rotating container forms a stable package, or 'cake' which can be removed when rotation stops. With dry staple fibres, the whole mass of torque-lively yarn would collapse to form a tangled mass of hard waste if the container were stopped; over-coming this difficulty was the key to the development of the P.S.C. machines. There is no problem while the yarn is under the influence of centrifugal acceleration inside the high speed rotating container, but the yarn must be transferred to a suitable bobbin without stopping the rotating container.

Among the advantages claimed for P.S.C. spinning over the conventional machines *in use at that time* were: high spindle speeds; larger packages; fewer end-breakages; less labour; high speed semi-automatic power-driven doffing; less tension on the yarn; and about 30% less floorspace per kilogramme of yarn produced. The subsequent development of large package ring spinning nullified the latter claim.

The disadvantages which account for the lack of general acceptance of staple fibre centrifugal spinning include: high power consumption and heat generation; the wide pitch between the rotating containers; it was not possible to make a piecening; the high noise level; yarn loss in the event of a power failure; yarn hairiness; and the package sizes were not competitive with the large package ring frames introduced in the 1950s.

Although the centrifugal spinning system outlined above is no longer used, a similar principle is applied in the 'Axifugal' system which combines the spinning and folding processes; the system is described in Chapter 15.

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12

CONVENTIONAL FRAME SPINNING MACHINES

The general features of spinning machines, the spinning process, and the factors influencing spinning costs have been described in Chapter 9. The main opposing cost relationships are:

(1) Power costs can be reduced by decreasing package size and by decreasing spindle speed.
(2) Capital costs per kilogramme of yarn produced can be reduced by increasing the running speed.
(3) Package handling costs can be reduced by increasing the package size.

Of the conventional frame spinning machines, ring spinning has proved to be the most amenable to improvements in speed and package size, but it has now been developed to such an extent that further extensive research effort would be uneconomic because any improvements would be marginal. This realization has led to the channelling of research effort into the newer methods of spinning; nevertheless all three conventional frame spinning methods of twist insertion and winding-on are still in use.

Flyer spinning

The principle of flyer spinning is similar to that of the flyer lead drawing box described in Chapter 8 although there are differences in the details of construction, such as spindle pitch and package size; on some flax and jute spinning machines the bobbin was retarded by a tensioned cord, a method which gave rise to greater tension variations than when a washer is used.

Because the flyer method uses the yarn to pull the bobbin round, it is only suitable for thick counts, and because of the relatively low spindle speed, flyer spinning has been replaced by ring spinning where possible. Nevertheless flyer spinning is still used for spinning single mohair weft yarns direct on to pirns in the 37 tex to 50 tex count range with spindle speeds of 3000 to 3500 rev/min and a maximum bobbin capacity of about 70 g. It is also used for spinning flax, hemp, and jute yarns thicker than about 240 tex at spindle speeds up to about 4750 rev/min with a bobbin capacity of about 570 g.

A few types of mechanically assisted doffing frames have been produced which enable one person to doff one side of a frame in about 30 seconds to 1 minute; this development was never applied to the cord-tensioned type of frame.

Ring spinning

Ring spinning using a traveller to guide the yarn on to the package was invented in USA by Messrs. Addison and Stevens in 1829, a year after John Thorp had invented a form of ring spinning without a traveller.

The ring method developed into the most successful form of spinning and is widely used for processing cotton, worsted, woollen, flax, spun silk, and man-made fibres. It can not be used for wool qualities coarser than about 50's when spinning relatively fine counts (e.g. 37 to 50 tex) because of the difficulties caused by fibre rigidity when relatively light-weight travellers would have to be used.

During the period from 1945 to 1960, ring spinning was subjected to intensive research and development until it was realized that any further improvements would be only minimal.

The ring frame is versatile and can produce yarn which is good enough for almost any end-use, but the need to strike a balance between the three major costs, i.e. capital, labour, and power, limits the maximum profitable spindle speed.

At least 85% of the total power requirement of a ringframe is consumed in driving the spindles, depending on details such as yarn count, pcakage size, and spindle speed — the remainder is consumed by the drafting and lifter mechanisms.

The general spindle arrangement of a modern ring spinning frame is shown in *Figure 12.1*, and a full ring frame is shown in *Plate 21*.

The self-balancing spindle is driven by tape or belt thereby making the yarn tube, which is mounted on it, rotate. Spindle speeds range from about 3000 rev/min for large package woollen carpet yarn spinning up to about 17 000 rev/min for fine count spinning of polyester/cotton blends.

The trend towards narrower spinning frames has led to the drafting zone being almost vertical, permitting the twist to run into the delivery roller nip. Combined with a high level of fibre control in the drafting zone this leads to the formation of a lean yarn, i.e. a yarn which is not bulky.

The yarn is threaded as shown in *Figure 12.1*, and the plan view of the arrangement is shown in *Figure 12.2 (a)*.

Concentricity of the ring and spindle is important in order to minimize tension fluctuations and end-breakages. The tension T_w in the yarn (called the winding tension) causes the traveller to slide around the spinning ring which surrounds the bobbin, and centripetal acceleration enables the yarn to form a balloon between the traveller and the yarn lappet guide.

The traveller mass is selected to control the winding tension which in turn produces the tension in the lower balloon at the other side of the traveller. Because of yarn/traveller friction, the balloon tension is rather less than half the winding tension. The balloon tension in turn gives rise to the spinning tension between the lappet and the front roller nip; this depends on the winding tension, and on the centrifugal force and the air drag on the balloon. Within practical limits the coefficient of traveller/ring friction varies inversely with traveller mass, directly with ring diameter, and increases to a maximum at a particular rotational speed.

In general heavier travellers are used for thicker counts, and usually the maximum traveller mass is used which is consistent with a good spin, i.e. an acceptable end-breakage rate. As a last resort it may

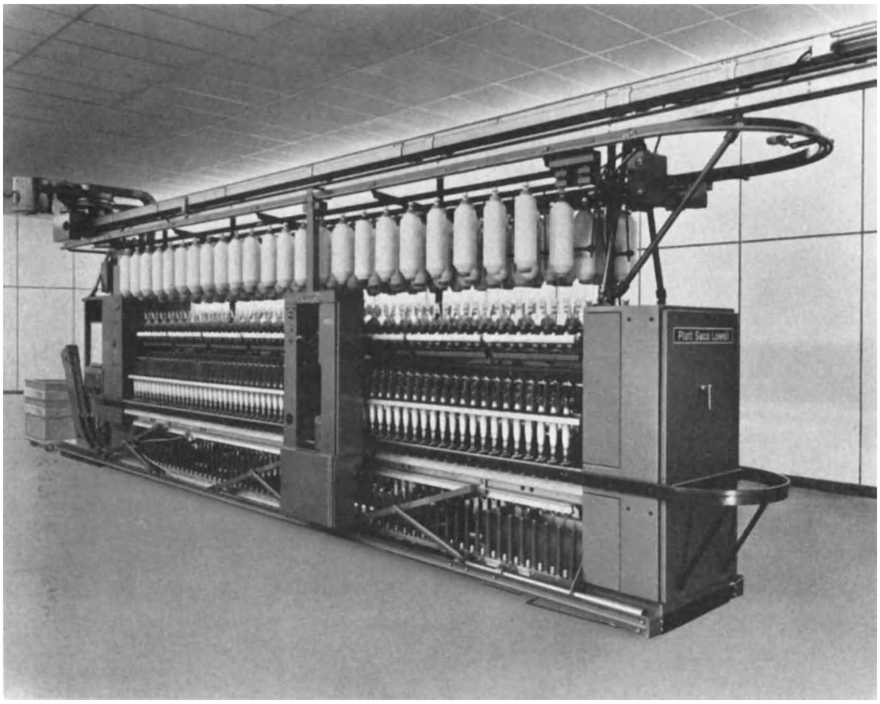

Plate 21. Ring spinning frame. The machine shown has 64 spindles on each side although there can be up to 324 spindles per side with 70 mm spindle pitch. A fully automatic frame doffer is shown with the empty tubes ready at the lower level. Also shown is an automatic traversing yarn piecener. The 14 × 7 bobbin lead rovings are suspended on the umbrella creel. The underclearer suction holes are mounted in units, which serve eight spindles each, just below the front rollers. The overhead monorail supports the travelling cleaner which can be seen at the far end of the machine, with its nozzles attending to the spindles and drafting zones at the far side of the machine. Courtesy of Platt Saco Lowell (UK) Ltd

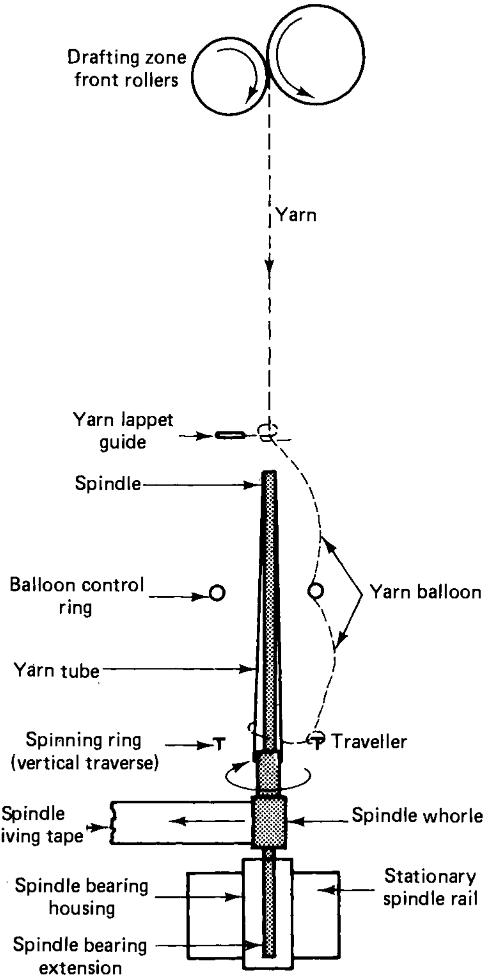

Figure 12.1 Ring spinning frame (side elevation/section)

be necessary to reduce the spindle speed in order to control the end-breakage rate.

On many modern high speed machines a balloon control ring is used as shown in *Figure 12.1*, and separators are placed between spindles to prevent adjacent balloons from contacting each other.

Each revolution of the traveller inserts one turn of twist into the yarn:

$$\text{Twist (t/m)} = \frac{\text{traveller speed (rev/min)}}{\text{roller delivery (m/min)}}$$

At all practical spinning speeds the traveller is pressed firmly against the inner surface of the ring by centrifugal force.

Compared with general machine parts, the ring and traveller are subjected to severe working conditions; for example, a steel traveller running at 12 000 rev/min on a 50 mm diameter ring has a surface speed of about 31 m/s (110 km/h) and this can be maintained for a total of about 250 h, giving a total distance travelled of about 27 500 km under the influence of a centripetal acceleration about 4000 times greater than gravity, without lubrication.

If a temperature of about 260 °C is exceeded at any point on the traveller, 'steeling' of the ring occurs, i.e. the ring picks up particles of steel from the traveller and rapidly becomes unusable. Under un-lubricated conditions the traveller temperature is high at the point of contact (i.e. the 'hot spot'), but during steady running heat is lost largely by conduction to the ring, partly by conduction along the traveller, and partly by direct transfer to the atmosphere. The actual point of contact alters with variation in the traveller inclination so that the contact region as a whole is subjected to a lower steady temperature which should not exceed 100 °C if rapid wear is to be avoided. With lubrication the traveller temperature is similar to room temperature even at traveller linear speeds of 105 m/s, but traveller wear becomes a major factor at such speeds. Longer running times are possible with suitably surface-treated travellers.

The spindle rotates at a constant speed, and because of the winding-on revolutions the traveller rotates at a lower speed:

$$\begin{array}{c}\text{Traveller speed}\\ \text{(rev/min)}\end{array} = \left[\begin{array}{c}\text{spindle speed}\\ \text{(rev/min)}\end{array}\right] - \left[\begin{array}{c}\text{winding-on}\\ \text{rev/min}\end{array}\right]$$

$$= \left[\begin{array}{c}\text{spindle speed}\\ \text{(rev/min)}\end{array}\right] - \left[\frac{\begin{array}{c}\text{roller delivery}\\ \text{(m/min)}\end{array}}{\begin{array}{c}\text{bobbin}\\ \text{circ. (m)}\end{array}}\right]$$

On most ringframes the ring rail is traversed vertically, usually with a slow upward and a fast downward motion to produce a cop build; other arrangements such as a traversing spindle rail have been tried, but have not been adopted widely. The ring rail movement in itself may cause end-breakages by influencing the traveller speed, traveller inclination, yarn tension, and twist flow, particularly as lifter reversal takes place.

The traverse speed is chosen according to the yarn count to obtain a firm package which will unwind satisfactorily at the following process. Too slow a traverse speed may lead to sloughing-off (i.e. simultaneous unwinding of adjacent coils) in subsequent unwinding, but too high a speed increases machine wear and may increase the end-breakage rate.

With a cop build it follows that the bobbin circumference varies from a minimum at the top of each lifter stroke to a maximum at the bottom, causing the traveller speed to vary. A consequence of the alterations in the traveller speed is that the rate of twist insertion varies as illustrated by the following example based on the assumption of a spindle speed of 12 000 rev/min, a delivery of 18 m/min, a package circumference of 60 mm at the top of the traverse, and 120mm at the bottom.

For a 60 mm package circumference

$$\text{Traveller speed} = 12\ 000 - \frac{18}{0.06}$$

$$= 11\ 700 \text{ rev/min.}$$

$$\text{Twist} = \frac{11\ 700}{18} = 650 \text{ t/m.}$$

For a 120 mm package circumference

$$\text{Traveller speed} = 12\ 000 - \frac{18}{0.12}$$

$$= 11\ 850 \text{ rev/min.}$$

$$\text{Twist} = \frac{11\ 850}{18} = 658 \text{ t/m.}$$

The difference in twist due to this cause is so slight that it is of no practical importance and in any case, if the yarn is unwound over-end from the package, as is usual with a cop build, the unwinding revolutions will cancel out the winding-on revolutions. Therefore it is customary to determine the calculated twist:

$$\text{Calculated twist (t/m)} = \frac{\text{spindle speed (rev/min)}}{\text{roller delivery (m/min)}}$$

For the previous example, calculated twist

$$= \frac{12\ 000}{18} = 666.7 \text{ t/m.}$$

The tension on the yarn depends largely on the frictional resistance of the traveller against the ring. For a given type of ring and traveller this is determined by the rotational speed which, as mentioned previously, is practically constant. Referring to *Figure 12.2 (a)*, traveller B is caused to move by the winding tension T_w in the yarn. C is the spindle centre, F is the tangential force required to cause traveller movement, and θ is the angle of lead from the traveller to the tangential point of winding on at A. The force T_w may be resolved into two components:

(1) The force I acting in the direction BC; this force tends to reduce the ring/traveller pressure, and
(2) The force F, that is the frictional resistance of the traveller.

From the triangle of forces XYZ shown in *Figure 12.2 (b)* the relationship between T_w and F is given by T_w = F/sin θ, but XYZ and ABC are similar triangles in which the angles θ are equal, therefore T_w = F ×BC)/AC. But throughout the filling of the package the ring radius BC is constant, hence for any force F required to move the traveller, $T_w \propto 1/$(package radius). Also $T_w \propto$ ring radius, therefore ring frames are fitted with larger diameter rings when a range of thicker counts is to be spun; the yarn is strong enough to withstand the increased tension, and a larger package size is desirable when thicker counts are spun.

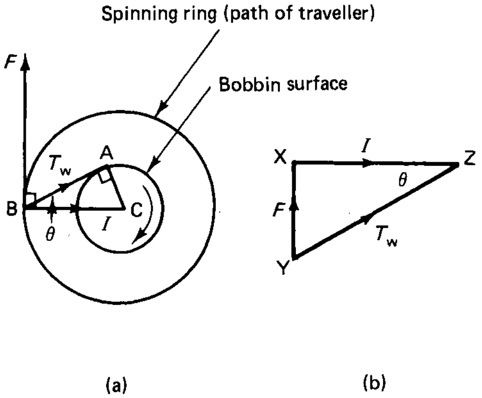

Figure 12.2 Ring spinning tension: (a) plan view of ring and package; (b) triangle of forces

As a general rule the angle of lead θ is usually not less than about 28 ° which is equivalent to a minimum ratio of (tube diameter)/(ring diameter) = 0.47.

Variable speed spinning can be used to provide virtually constant tension conditions by compensating for variations in the package diameter and thereby produce a more uniform yarn.

As the lifter rises, more yarn is wound on to the package than is supplied by the delivery rollers because the balloon length is shortened, and the opposite applies on the downward stroke. It follows therefore that the traveller rotational speed must be less on the up stroke than on the down. However, the twist originates in the balloon and it must flow past the traveller to pass on to the package, and past the lappet to penetrate into the front roller nip. Because of the change in direction of the yarn path and also the frictional resistance at the traveller, the balloon twist is higher than the twist in the yarn on the package. This twist differential across the traveller is determined by the angle of yarn wrap, the yarn/traveller contact pressure, and the yarn/traveller coefficient of friction.

With a cop build the change in balloon length is accompanied by significant changes in tension as winding-on moves from the nose to the shoulder of the package and so the twist variation on the package and in the front roller nip depend on the relative magnitudes of the changes in twist differential and traveller speed. In practice the twist is least near the top of the chase and greatest near the bottom.

The effect is different with a parallel lifter motion because the tension changes during one traverse of the lifter are relatively small compared with the alteration of the balloon length. Hence when the lifter rises, besides the reduction of traveller speed mentioned above, there is also a transfer of yarn from the balloon to the package and as this has a higher twist level it cancels out the effect of traveller speed reduction. Consequently on the up traverse there is more twist than average in the yarn wound on to the package, and the converse is true of the down stroke.

This effect may be illustrated by an example based on the following assumptions:

> Spindle speed 8000 rev/min, roller delivery 20 m/min, change of yarn length in the balloon 200 mm per lifter stroke, package circumference 80 mm, the balloon contains 25% more twist than the mean package twist, and the lifter takes 15 seconds per up or down stroke.

$$\text{Calculated twist} = \frac{8000}{20} = 400 \text{ t/m}$$

$$\text{Approximate balloon twist} = 400 \times \frac{125}{100} = 500 \text{ t/m}$$

Twist in 200 mm length of balloon =
$500 \times 0.2 = 100$ turns*

Spindle revolutions per up or down stroke =

$$\frac{8000}{4} = 2000 \text{ rev}$$

$$\text{yarn delivery per up or down stroke} = \frac{20}{4} = 5 \text{ m}$$

This effect produces a periodic twist variation with a repeat which corresponds to the length of yarn delivered per complete lifter traverse cycle. On a folding machine this phenomenon has been known to cause weft bars with two-fold yarn, but the occurrence of such a fault is extremely rare and can be corrected by the selection of a suitable lifter traverse speed; a slower traverse speed reduces the amplitude of the twist difference produced on the up and down strokes of the lifter and increases the repeat length.

	Effect during upward stroke or lifter	*Effect during down stroke of lifter*
Yarn wound on (m)	5.2	4.8
Winding-on revolutions	$\frac{5.2}{0.08} = 65$	$\frac{4.8}{0.08} = 60$
Traveller speed (rev/$\frac{1}{4}$ min)	$2000 - 65 = 1935$	$2000 - 60 = 1940$
Twist on package (t/$\frac{1}{4}$ min)	$1935 + 100^* = 2035$	$1940 - 100^* = 1840$
Package twist (t/m)	$\frac{2035}{5.2} = 391$	$\frac{1840}{4.8} = 383$

Balloon theory

Ballooning occurs when a length of yarn is rotated about the central yarn axis along a path external to itself; the yarn balloons outwards so that the tension in the yarn just provides the centripetal force on each element of yarn that is required to keep it in rotation. Because of the persistence of vision, when this is done at a high speed the yarn outline apparently forms a transparent balloon which in spinning seems to envelop the rotating package; the shape of the spinning balloon is mainly determined by centripetal force, tension, and air drag.

The behaviour is broadly similar in ring and cap spinning, in up-twisting, and in withdrawing yarn over-end from a stationary package.

In ring spinning the yarn tension can be controlled by the traveller. In up-twisting the supply package rotates at a high speed and the tension is almost completely due to air resistance, in withdrawal from a stationary package the tension is partly due to air drag and partly due to yarn/package friction.

A basic balloon formed by rotating one end of a length of string while the other end is fixed is shown in *Figure 12.3 (a)* where l is the distance measured from the top node to the imaginary node below the path of rotation, and H is the vertical height from the top node to the path of rotation. The balloon profile is similar to a sine curve of wavelength λ and half-wavelength l. $\omega = 2\pi f$, where ω = angular velocity (rad/s), and f = frequency (Hz). In the absence of air,

$$l = \frac{\lambda}{2} = \frac{1}{2f}\sqrt{\frac{T_0}{m}} = \frac{\pi}{\omega}\sqrt{\frac{T_0}{\mathrm{m}}} = \pi P$$

where T_0 is the yarn tension at the lappet guide (dynes), and m is the yarn mass (g/cm).

$$P = \sqrt{\frac{T_0}{m\omega^2}} \text{ (cm)}$$

P has the dimension of a length and forms a natural unit which enables results to be expressed in a non-dimensional form.

The height H of the balloon cannot exceed l without the formation of an intermediate node as shown, for example, by the solid outline of *Figure 12.3 (b)*. If H were increased considerably then a multiple series of nodes could be formed.

In ring spinning the balloon does not behave exactly like a tensioned string because of the relatively large balloon radius, and the influence of other factors which include air drag, the yarn/traveller and the ring/traveller friction. Consequently in ring spinning a stable balloon system can be formed for many combinations of balloon height (H), ring radius (R), package radius (R_1), spindle speed, yarn count, and yarn tension. This is because the length of *yarn* forming the balloon is not fixed even though the axial balloon height H is fixed; the yarn length is self-adjusting so that the balloon shape permits the nett horizontal force on each element in the yarn just to provide the necessary centripetal force on that element.

For given values of R and H there is a limiting value of P for which a balloon without a node can be formed. The limiting value of P decreases as the ratio R/H or R_1/H increases; the maximum theoretical value of H/P is π for a ring of infinitely small radius.

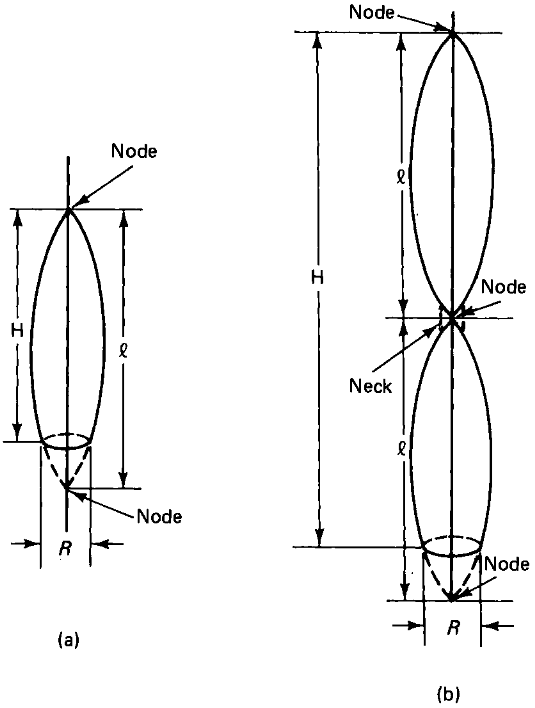

Figure 12.3 Balloon node formation: (a) basic balloon; (b) balloon with intermediate node or neck

Air drag is relatively more important with fine yarns than with coarse yarns; it allows fine yarns to be spun at higher spindle speeds or lower specific tensions than can be used with coarse counts and it limits the maximum balloon diameter; the finer the yarn count and the smaller is the maximum balloon diameter.

The shape of the balloon is influenced by air resistance, particularly in fine count spinning. Work must be done to rotate each yarn element and therefore the yarn must lie along the direction of the necessary tension in the yarn. Consequently the yarn is inclined to the axial plane in the manner shown in *Figure 12.4 (a)* so that each element leads the one above it; an increased traveller mass reduces the angle of inclination of the yarn to the axial plane. At the traveller the tension × circumference = total work done per revolution in rotating the balloon when the yarn linear velocity is small.

Air resistance helps to stabilize the balloon shape and the yarn tension against changes such, for example, as yarn count variations. If m decreases slightly it causes P to increase hence R/P and H/P decrease, causing a reduced maximum balloon radius which would mean less air drag and less tension. Reduced tension T_0 involves a reduction of P and tends to cancel the effect of the original reduction of m. Thus a slight change of count, for example, has a much smaller effect on balloon shape than it would have in the absence of air drag.

In practice an envelope of rotating air forms around the spindle thereby slightly reducing the yarn/air relative velocity but this effect is not very great. The effective diameter of spun yarn decreases

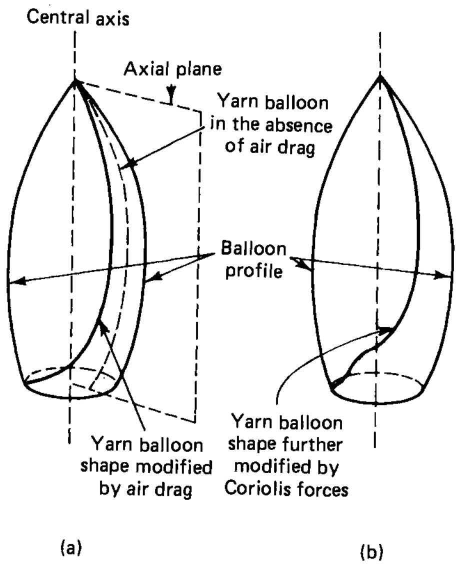

Figure 12.4 Balloon shape: (a) influence of air drag; (b) further influence of Coriolis forces

at higher speeds due to the behaviour of the projecting fibres.

Coriolis forces also influence the shape of a yarn balloon because the kinetic energy of rotation of each yarn element increases as it moves down to the maximum balloon radius, and it decreases as it moves back inwards in the lower part of the balloon. The overall effect on balloon inclination is similar to air drag except that whereas air drag forces are cumulative down to the traveller, the tangential Coriolis force is reversed below the point of maximum balloon radius, modifying the balloon shape to the form indicated in *Figure 12.4 (b)*.

Coriolis forces are proportional to the linear yarn velocity, therefore in spinning where the linear yarn velocity is small compared with its rotational velocity the Coriolis forces are much smaller than the air drag forces. Coriolis forces have a significant influence on balloon shape only when the linear yarn velocity is high as in high speed winding or at low rates of twist insertion in spinning.

Balloon collapse

In the presence of air a true node as shown by the solid outline in *Figure 12.3 (b)* cannot be formed because the radius of rotation must remain finite in order to provide the work to rotate the higher balloon; hence a 'neck' of finite radius is formed as indicated by the broken line in *Figure 12.3 (b)*, rather than a true node.

To avoid neck formation R/P and H/P must be small: i.e. P must be large. Thus for a given yarn count this means that either T_0 must be large or ω must be small, either of which is undesirable.

The formation of a neck in the balloon occurs gradually if unfavourable conditions arise, such as an increase of H, or a reduction of traveller mass. Balloon collapse arises when the neck contacts the package significantly thereby causing a breakdown in the spinning process. Collapse would be most likely to occur when the yarn is winding on to the maximum package diameter with the longest balloon length,i.e. when H is at a maximum and P is at a minimum.

Balloon control rings

By restricting the maximum balloon radius and thereby reducing air drag on the balloon, control rings provide the means whereby a longer total balloon can be formed without a neck and with a much lower yarn tension than otherwise would be possible. Each section of the total balloon then has a smaller value of H thereby effectively reducing H/P and avoiding the likelihood of balloon collapse even though the overall balloon length is increased. By stabilizing and avoiding an increase of tension T_0, the benefits arising from the use of control rings permit larger package lengths, higher spindle speeds, and reduced power consumption.

The use of control rings was first empirically developed by Gwaltney in USA prior to 1950.

In practice the use of two control rings is more difficult and more expensive than a single control ring because ideally it would require separate movement of the lappet, the two control rings, and the spinning ring in order to avoid a long initial length of balloon. Consequently many modern ringframes with lifts of 230 mm or longer use a single control ring actuated by the lappet mechanism and situated at approximately half the balloon height when spinning at the bottom shoulder of the cop. Single control rings can be seen in *Plate 22*. Balloon control rings can cause filamentation (i.e. rupturing of man-made fibres) during high speed spinning of polyester/cotton blends; this is best avoided by having a suitably shaped control ring profile with its diameter slightly larger than the spinning ring, and by yarn lubrication.

With finer yarn counts the maximum balloon diameter is reduced and it may be less than the spinning ring diameter. Since it is impracticable to fit control rings which are smaller than the spinning ring diameter, their effectiveness ceases under such conditions.

Moving lappets

A further factor in the development of large package spinning was the realization that an increase in the distance from the front rollers to the yarn lappet guide (such as is shown in *Figure 12.1*) has negligible influence on yarn tension provided that ballooning does not occur above the lappet. In ring spinning this makes it possible to increase the distance from the top of the package to the front rollers so that doffing of a longer package can take place. As the package fills, the lappet can be gradually raised in sympathy with the spinning ring so that almost constant balloon conditions can be maintained from an empty to a full package.

Large package spinning

In the early 1950s there was considerable pressure on machinery makers to develop large package spinning frames. The consequent technical and economic research gave a much better understanding of the process and led to higher spindle speeds because of improvements in the design of machine parts such as spindles, rings, and travellers. It also led to the appreciation that in general large package spinning was only economic for coarse yarns, particularly since automatic winding came into general use.

Rings and travellers

A bewildering variety of both rings and travellers have been under constant development ever since ring spinning was invented. In 1932 it was widely acknowledged that for practical purposes the maximum permissible traveller speed was about 23 m/s, although there were some exceptions. Now traveller speeds up to 40 m/s or more may be achieved under favourable conditions; speeds in excess of 50 m/s are used in continuous filament processing.

Flange rings and travellers

The flange ring was the original type of spinning ring to be widely used for cotton spinning and it is still used for that purpose. The basic cross-sectional shape is shown in *Figure 12.5 (a)*. Flange widths range from flange 0 = 2.3 mm to flange 5 = 6.3 mm, but the most commonly used ones in short staple spinning are flange 1 = 3.2 mm for yarn counts finer than about 30 tex, and flange 2 = 4.0 mm for yarns thicker than about 30 tex.

the flange is the traveller bearing and it must be adequate to withstand the load of the rotating traveller and to dissipate the heat developed. In cotton spinning, flange rings are run without added lubricant to avoid the excessive adhesion of dust and lint on the ring and traveller. However, particles of fibre and wax form a fine layer which acts as a lubricant, preventing metal-to-metal contact which otherwise would cause overheating. Progressive accumulation of fly waste on the traveller can alter the effective traveller mass and may cause a change in yarn hairiness; stationary traveller clearers can be set close to the passing traveller to prevent the collection of fly, but too close a setting must be avoided as it can cause travellers to jump and to wear an indentation on the ring.

The requirements of a traveller include good heat dissipation, sufficient thread space, the matching of traveller size and shape to the ring flange, and good sliding properties. Travellers are made from a variety of wire cross-sectional shapes, some of which are shown in *Figure 12.5 (b)*. Types 1 and 2 give a greater bearing area and so permit higher speeds, but 3 or 4 may give better yarn appearance, particularly with hard synthetic fibres and with wool, but they are restricted to a maximum linear traveller speed of about 26 m/s. The cross-sectional shape of a traveller may also influence yarn irregularity and tenacity.

Travellers for flange rings are made in various shapes, some of which are shown in *Figure 12.5 (c)*.

The C shaped traveller (*Figure 12.5 (d)*) is satisfactory when speed is restricted by factors other than traveller speed, its advantage being the lower end-breakage rate because of the large space available for the yarn which makes it suitable for bulky and knoppy yarns. The angle of yarn tension applied to the traveller continually changes from the shoulder to the nose of the cop and is also different on the up and down strokes of the lifter; this causes the traveller to tilt, twist, and pitch, and therefore introduces tension variations.

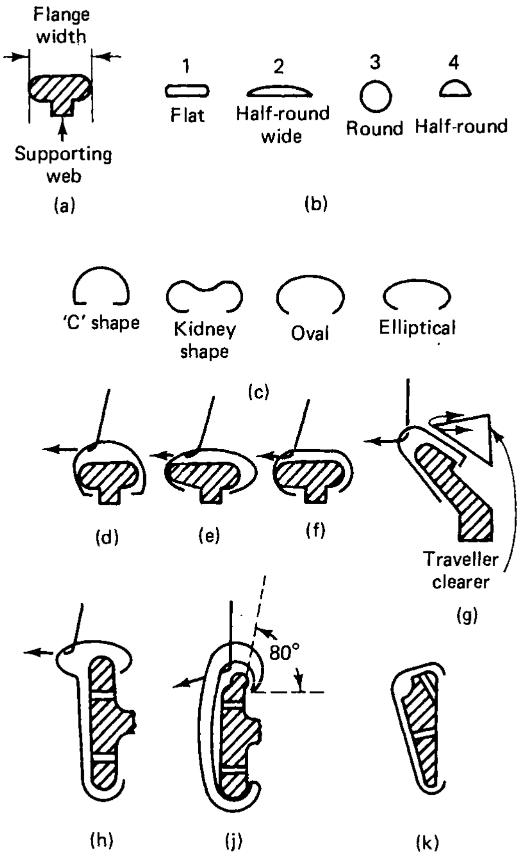

Figure 12.5 Rings and travellers: (a) basic flange ring cross-section; (b) traveller wire cross-section shapes; (c) traveller shapes for flange rings; (d) 'C' shape on ordinary flange; (e) elliptical shape on anti-wedge ring; (f) flat-top shape on anti-wedge ring; (g) SU ring and traveller (h) ear-shaped traveller on vertical ring; (j) nylon traveller on back-slope ring; (k) conical ring

Because the area of contact with the ring is small the pressure causes local high temperatures and traveller wear. The kidney-shaped traveller has been popular in mainland Europe because it combines sufficient yarn clearance for medium and fine counts with the greater stability obtained with a lower centre of gravity. When winding tension is decreased the pip in the back of the traveller contacts the top of the ring and increases the drag to compensate.

The oval traveller has a lower centre of gravity than the C shaped, but still provides adequate yarn clearance for common yarn counts, while the elliptical traveller has a very low centre of gravity which ensures very stable running conditions when used on a suitably shaped ring flange, but because the thread clearance is limited, the elliptical traveller is most suitable for fine count yarns.

Figure 12.5 (e) shows an elliptical traveller on an anti-wedge ring. The offset web and built-up inside flange of the anti-wedge ring is designed to give more contact with the elliptical traveller, giving a better spread of load and better heat dissipation; it also eliminates the tilting and turning of the traveller on the flange and so avoids a wedging action between the traveller toe and the ring web so that traveller life is increased and ring wear is decreased. Alternative traveller shapes other than elliptical, such as the flat-top traveller (*Figure 12.5 (f)*) are made for use on shallow flange anti-wedge rings for high speed spinning of yarns containing man-made fibres such as polyester on the short staple system. These have an even lower centre of gravity than ellipitical travellers and retain the large contact area but at the same time provide adequate yarn clearance.

In general the minimum yarn clearance consistent with yarn appearance is preferred, but insufficient clearance can cause fibre melting and fusing of synthetic fibres when spinning at high speeds; shallow flange anti-wedge rings combined with flat-topped travellers made from half-round wire cross-section are recommended for polyester and blended yarns.

At one time it was the standard practice to polish rings in the final stages of manufacture. It has now become more common to produce suitably case-hardened rings in the unpolished state because better control of the metal boundary layers and dimensional accuracy is possible.

When new rings are fitted it is usual to have a running-in period to polish the rings during which minute particles of metallic debris are liberated. This may involve running at a reduced speed and perhaps using lighter travellers for a number of frequent traveller changes between each of which the rings are cleaned. It is important that burnt travellers are not allowed to run on a ring for prolonged periods otherwise oxidized metal from the traveller is deposited on the ring flange and the bearing surface deteriorates. Rings should always be run-in with plain steel travellers so that if heat discolouration occurs it can be seen easily. Different tracks will be worn on a ring with variations of traveller speeds, traveller mass, and traveller curvature. For maximum performance, therefore, rings should be run-in for a given set of conditions which should then be adhered to if possible.

S.U. rings and travellers

This, another non-lubricated type (*Figure 12.5 (g)*), was invented in USSR and is manufactured under license in the UK.

The running position of the traveller is along the line of the resultant forces involved giving stable running conditions. The long inside leg of the traveller gives reduced pressure and permits higher traveller speeds and longer traveller life than flange ring travellers. Round wire S.U. travellers can be run as fast as flat C shaped travellers and give better yarn quality. S.U. rings are widely used for short staple polyester and polyester/cotton blends when traveller speeds up to 40 m/s may be used at a spindle speed of about 15 000 rev/min with a 50 mm diameter ring; they are also used for acrylics on the worsted system where the omission of ring lubrication is an advantage. A traveller clearer is essential; it consists of an adjustable stationary plate which can be set close to the traveller path to remove stray fibres. Investigations at Wira showed that S.U. rings and travellers were not considered suitable for normal worsted spinning because they were associated with an increased end-breakage rate.

Vertical rings and ear-shaped travellers

These were originally introduced for the folding of cotton yarns thicker than about R10 tex/2 where unlubricated rings would provide excessively severe conditions because of the greater traveller mass required. Grooves were introduced on the inside face for grease lubrication; rings needed re-greasing manually after every doff on thick counts. Spindle speeds about 15% higher than plain rings are possible, but excessive grease application can cause yarn staining. The basic arrangement is shown in *Figure 12.5 (h)*.

Self-lubricating rings

Oil is much less influenced by changes of temperature and humidity than is grease and can be fed automatically to the bearing surface. One method is to pass a wick in a groove inside the ring and connect it to an outside reservoir through a hole in the ring wall. The reservoir may serve a group of spindles and only needs replenishing at infrequent intervals; alternatively the oil may be conveyed from a central lubrication system. Self-lubricating rings are used for woollen spinning, thick cotton yarn folding, worsted yarn spinning and folding, and man-made fibre twisting. Lubricated rings are particularly useful for the wet folding of cotton yarns where the natural gums otherwise tend to accumulate on the rings and cause end-breakages.

Back-slope rings

These are designed for use with nylon travellers to improve their performance (*Figure 12.5 (j)*), they give a better grip to the traveller head and provide the yarn clearance in the ring so that a simplified traveller shape can be used.

Conical rings

This type of lubricated ring (*Figure 12.5 (k)*) is used in worsted spinning and can be used for folding yarns finer than about R50 tex/2, but it is not satisfactory for very high speeds or heavy work.

The sloping faces of the ring are designed to provide an increased bearing surface and the angle is such that the yarn balloon tension and the winding tension on the traveller respectively just provide the components of centripetal force required to maintain the rotation of the traveller in a stable position on the ring. The friction between the bottom of the ring and the traveller is kept low compared with an ear-shaped traveller on a vertical ring, but at the same time the traveller can move up and down to cater with balloon tension fluctuations induced, for example, by count variation, so that the winding tension variations are minimized. Yarn clearance is provided in the ring so that for a given ring diameter a larger package diameter can be accommodated.

Porous sintered metal (P.S.M.) rings

These are made by welding metal particles together so that about 20% by volume is a porous space which is then filled with a non-oxidizing oil. A fine oil film on the bearing surface is drawn up by the action of the traveller giving less friction than is obtained by spreading lubricant on an ordinary ring. The lubricant lasts about 5000 running hours before the rings need cleaning and re-impregnating. Alternatively, automatic lubrication can be employed with either intermittent high oil pressure at intervals of from 10 to 20 minutes, or by continuous low pressure.

This type of metal is used for plain vertical rings, back slope rings, and conical rings.

P.S.M. rings give the advantages of lubrication while avoiding the danger of yarn staining and therefore are popular on the worsted system for the spinning and folding of pastel shades and hand knitting yarns. They are also used for fine cotton yarn folding and the spinning and folding of continuous filament yarns.

Their main disadvantage is that they are easily damaged and have a shorter working life than solid steel rings; it is preferable to use nylon travellers when possible. They are not suitable for wet processing or for use with heavy steel travellers.

Travellers

Travellers are made from a variety of materials and with various surface finishes. A summary of the more important ones is given here in ascending price order:

(1) Steel

These are widely used for flange rings, vertical rings, and conical rings. They are the cheapest type of traveller and for fine count spinning they retain sufficient rigidity even when made in very small sizes.

(2) Brass alloy

These are used for wet folding of cotton yarns on lubricated rings. Without lubrication, brass would be transferred to the ring surface thereby increasing the traveller/ring friction which is normally lower than that of nylon travellers. Any accumulation of gum and dirt increases the traveller/ring mean friction and variation of friction to a much greater extent than is the case with nylon travellers.

(3) Molybdenum disulphide treated

Travellers of this type may be used on non-lubricated rings and are recommended for high speed spinning, particularly to compensate for the absence of cotton wax lubrication when processing short staple 100% man-made fibres.

(4) Nylon

These permit speeds up to 30% faster than steel, with reduced ring and traveller wear and reduced lubrication, more uniform tension, and with a wider count range covered by a given traveller size. They are widely used for cotton, worsted, woollen, man-made fibres, jute, and glass. Nylon has its limitations in that travellers for flange rings in cotton spinning, and lightweight travellers for fine count worsted spinning cannot be used because of the lack of rigidity. At the other end of the range, nylon travellers greater than a certain mass are so bulky that they restrict the space available for yarn on the package — even with medium travellers the yarn space is provided for on the ring. Lubrication of nylon travellers on steel rings is essential. There has been a trend towards using a shallower depth of vertical ring to permit the use of shorter and therefore stiffer nylon travellers. They are popular for use on P.S.M. rings because of the reduced likelihood of damage to the ring.

Because nylon travellers have a higher coefficient of friction, to produce the same yarn tension they are rather less than half the mass of steel or brass travellers.

(5) Nylon traveller with metal insert

These reduce yarn/traveller wear when yarn abrasion would be a problem with plain nylon travellers, such as in high speed man-made fibre processing, and with animal fibres. They have similar ring/traveller frictional properties to plain nylon travellers but are more expensive; however the reduction of machine down time and operative work load compensate for this.

(6) Nickel-plated steel

These are used to obtain longer traveller life under high speed running conditions; they are expensive and therefore are only used for long runs.

(7) Chrome-plated-head steel traveller

These provide a harder wearing yarn path on the traveller and are used for synthetic drawtwisting where traveller wear can be a factor limiting the maximum package size. They cost about twenty times more than plain steel, but last about ten times longer when used with matt synthetic yarns.

Factors influencing spinning conditions

The factors of ring diameter, balloon height, spindle speed, and traveller mass have a most important influence on spinning conditions; The main considerations relating to these factors are briefly summarized here:

(1) Ring diameter

Because package capacity is approximately proportional to (ring diameter.)^2, a large diameter ring is desirable, but in practice the maximum ring diameter is restricted by the considerations of yarn tension previously described, and also by:

(i) Traveller wear limitations

Maximum linear traveller speed $\propto \sqrt{}$(ring diameter), therefore maximum spindle speed $\propto \sqrt{}$1/(ring diameter). Hence although higher linear traveller speeds may be achieved with an increased ring diameter, this leads to a reduction of spindle rotational speed. On the other hand bigger rings dissipate heat better.

One method of increasing the maximum spindle speed, as far as this factor is concerned, is by positive rotation of the ring in the same direction as the traveller movement, more recently by using an air-bearing ring; it has not yet been adopted widely. Although the linear traveller speed relative to the ring is reduced, other causes of yarn tension in the balloon such as centripetal force and air drag remain unchanged.

(ii) Power consumption

The spinning power (i.e. the power required for twist insertion and winding-on) per kilogramme of yarn produced, increases at a greater rate than a given increase of ring diameter.

(iii) Capital cost and floorspace

Both capital cost and floorspace are approximately proportional to the ring diameter.

(iv) Doffing costs

This mainly depends on package capacity, therefore doffing cost $\propto$ 1/(package capacity) $\propto$ 1/(ring diameter)^2.

Hence the optimum ring diameter is highly dependent on yarn count; in general larger ring diameters are economic for thicker yarns, the count range for a given ring size being approximately proportional to (ring diameter)^2.

(2) Balloon height

(i) Power consumption

Spinning power increases more rapidly than balloon height per kilogramme of yarn produced.

(ii) Capital cost and floorspace

Capital cost does not increase as rapidly as balloon height increase, and floorspace is uninfluenced by balloon height.

(iii) Doffing costs

Doffing costs are approximately inversely proportional to balloon height.

(iv) Balloon collapse

An undue increase of balloon height increases the ratio H/P and leads to balloon collapse. The use of balloon control rings permits increased package length without balloon collapse, therefore the longest balloon height which will safely avoid balloon collapse is the most economic.

(3) Spindle speed

(i) Power consumption

This is the major additional expense when spinning at higher speed.

As a convenient approximation it may be said that power consumption is approximately proportional to (spindle speed)^2.

(ii) Production

Production is approximately proportional to spindle speed, therefore standing charges per kilogramme of yarn are reduced at higher spindle speeds.

A balance between reduced standing charges and increased power costs per kilogramme of yarn can be found, but in practice lower speeds may be used to minimize traveller wear, end-breakages, and difficulty in piecening.

(4) Traveller mass

The minimum mass is determined by the need to avoid balloon collapse when winding on to the maximum package diameter at maximum balloon length. The maximum mass is limited by the need to avoid excessive tension which would cause a high end-breakage rate. Thus for a given set of conditions, there is a range of traveller masses which can be employed and this range becomes narrower as spindle speed is increased.

The minimum tension required to avoid balloon collapse is proportional to (spindle speed)^2 and the tension produced by a given traveller is proportional to f(spindle speed)^2 where f is a coefficient which depends on the ring/traveller coefficient of friction, yarn/traveller coefficient of friction, and the angle of wrap of yarn round the traveller. The minimum traveller mass would be independent of spindle speed if f remained constant, but in practice although f is constant at low spindle speeds, it decreases at higher speeds. Consequently a slightly heavier traveller mass is required at a higher spindle speed.

Minimum traveller mass is proportional to the yarn count and to (balloon height)^2, but is inversely proportional to ring diameter. Too light a traveller permits an excessive balloon diameter, causing beating of the yarn against the separators; also it may permit traveller 'flutter' or 'chatter' (i.e. a vibration with audible impacts between the traveller and the ring) which induces higher peak tensions and increases end-breakages as well as traveller wear, and ring wear which may resemble the milled edge on a coin.

In practice a traveller mass greater than the minimum may be used to produce a firmer package of increased capacity and to increase the twist differential across the traveller. This may increase yarn strength by parallelizing the fibres as they are gathered from the delivery roller nip and also may reduce the end-breakage rate, but a heavier traveller will increase the power consumption.

It is generally assumed that in cotton spinning the tension ratio (mean individual thread breaking load)/(mean spinning tension) must not be less than 14 in order to obtain an acceptable end-breakage rate. Higher tensions with ratios of 4 or 5 are acceptable for polyester/cotton blends, and a ratio of 12 for worsted spinning. In fact the yarn emerging from the front roller nip is only partially twisted and its strength may be about only one third of the ultimate individual thread breaking load.

Ring spindle attachments (Suppressed balloon spinning)

Although various spindle attachments have been introduced to enable reduced balloon spinning to take place, they can be classified into two basic types as represented in *Figure 12.6* (*a*) spool top, and (*b*) fixed top.

These methods are generally referred to as suppressed balloon spinning, and a single balloon control ring may be used in conjunction with the spindle attachment, as shown in *Plate 22*.

With the spool top method the yarn passes direct from the front roller nip to the spool top. Under the influence of the ballooning yarn the spool rotates freely at the speed of the traveller; this method has not been used widely. In the case of the fixed top method, the yarn from the front roller nip passes through a vertically adjustable lappet. The fixed top is firmly attached to the spindle and rotates at the same speed, but the balloon, which rotates at traveller speed, slips from notch to notch in the fixed top attachment. This causes the yarn to spiral round the spindle before forming only a small balloon immediately above the traveller. The number of coils around the spindle is influenced by traveller mass, package diameter, and the design of the fixed top; the number of coils is controlled by adjusting the height of the lappet.

In either method the balloon size is reduced and some of the work required to rotate the balloon and traveller is provided via the spindle top, thereby reducing the winding tension and hence also reducing the balloon tension. The angle at which balloon tension is applied tends to reduce the friction of the traveller against the ring as compared with free balloon spinning. In addition the torsion in the yarn emerging from the front rollers is increased and the tension at that point may be only 2 to 3% of the winding tension (compared with about 60 to 80% on a similar frame without suppressed balloon spinning). This permits higher spindle speeds and/or

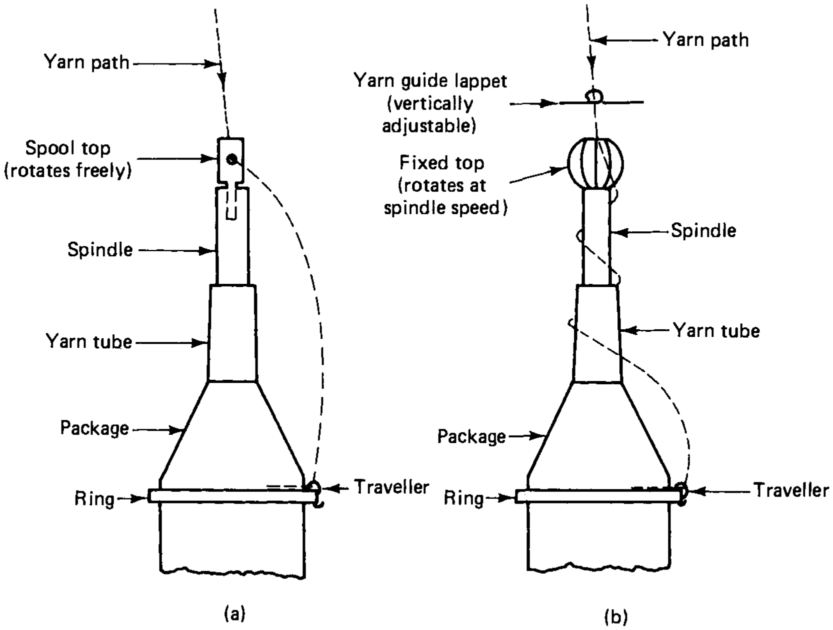

Figure 12.6 Suppressed balloon spinning ring spindle attachments: (a) spool top; (b) fixed top

larger packages with fewer spinning end-breakages.

This principle has been widely applied to the spinning of woollen yarns particularly for carpets and blankets where a large package size is desirable to enable long knot-free lengths of yarn to be spun with a minimum of doffing time; it has been applied to condenser cotton spinning, and also to fine count worsted spinning where the benefits of package size and spindle speed can be obtained when spinning near to the fine-count limit. Suppressed balloon spinning is not often used in carded or combed cotton spinning where very fine yarns are frequently produced.

Ringframe drafting for condenser spun yarns

The woollen ringframe provides a continuous method of spinning as an alternative to the intermittent mule.

Drafting takes place between back rollers and front rollers, but placed close to the front rollers is a false-twist device which inserts about 80 to 160 t/m into the upstream slubbing to provide the sole method of fibre control during drafting. The ratch of the drafting zone is usually considerably longer than the maximum fibre length, and the false-twist inserted in the drafting zone is virtually self-cancelling.

With this arrangement most of the drafting takes place in the region of minimum twist near the drafting zone back rollers, but some drafting takes place close to the front rollers. As in mule spinning, drafting consists mainly of fibre straightening and drafts usually in the region of about 1.5 with a maximum of about 2 are used to produce a yarn which has no drafting waves. Within the limits of satisfactory yarn levelness, the use of a higher draft on a thicker slubbing produces a stronger yarn for a given count spun.

Almost invariably piecenings made on a woollen ringframe are inferior to those made on the mule but this is no great detriment if automatic winding and clearing of the single yarn is used.

The woollen ringframe has been gradually displacing the mule, particularly for thick counts used in end-products such as carpets and blankets, although the mule is still used for some apparel yarns.

The ringframe produces about $2\frac{1}{2}$ times as much per spindle and only occupies about one third of the floorspace per spindle compared with the mule. The ringframe is simple to adjust and operate, permitting lower labour and maintenance costs, and larger packages than the mule. The mule can spin softer yarn and more difficult blends than can be spun on the ringframe.

Woollen ringframes are produced with a range of different ring diameters and package lengths to make them suitable for spinning different count ranges; a close-up view is shown in *Plate 22*.

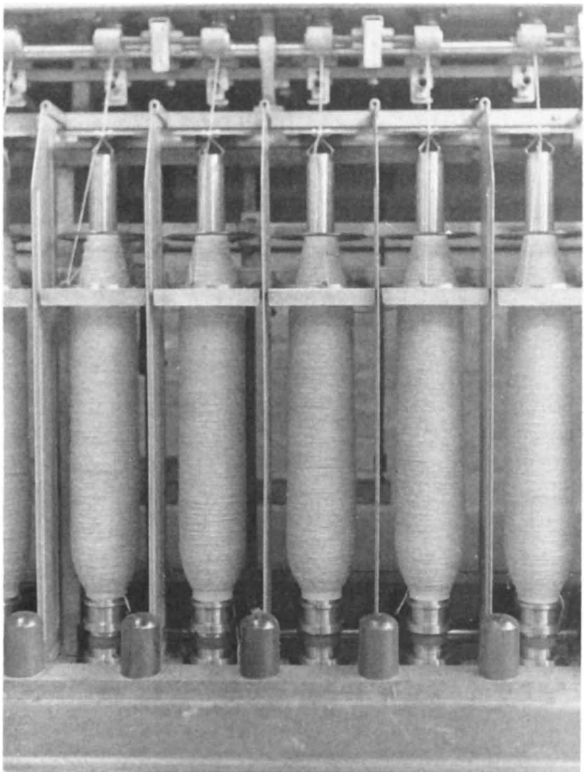

Plate 22. Woollen ring spinning frame. At the top of this close-up view the bottom of the false-twist tubes can be seen just above the front rollers. Each yarn passes down past the nozzle of the suction underclearer before passing through the yarn lappet guide. When the machine is running, the balloon tension is reduced by the fixed spindle top attachment. The yarn then passes down inside the balloon control ring and through the traveller (which is clearly visible on each spinning ring) before passing on to the bobbin. Courtesy of Haigh-Chadwick Ltd

Condenser cotton ringframes may use a double apron single-zone drafting arrangement operating with drafts of about 1.1 to 1.3, but without false twist fibre control; to a considerable extent, open-end spinning has ousted condenser cotton spinning.

Automatic underwinding

This consists of an electrically operated unit which lowers the ring rail to the doffing position so that a number of coils of yarn are wound on to the spindle below the package as the machine stops when the required length of yarn has been spun. Underwinding enables more rapid manual doffing because the yarn from the delivery rollers passes through the traveller to the spindle beneath the package and therefore remains undisturbed when the full package is removed and replaced by an empty one.

After doffing the lappets and control rings are lowered to the starting position manually and prior to starting up, the ring rail is raised to the spinning position.

Ringframe particulars

An indication of the widely differing conditions under which ring spinning operates is given in *Table 12.1*, and a semi-worsted frame is shown in *Plate 23*.

Cap spinning

Cap spinning was invented in 1828 by Charles Danforth in USA where it was rapidly developed to operate reliably at 5000 to 8000 rev/min. The method was never adopted by cotton spinners in the UK, but it became the principal method for spinning worsted yarns in the UK until its decline from 1950 onwards. Cap spinning was also used for acetate continuous filament yarns but this application has been superseded by ring spinning.

Table 12.1 *Some ringframe details*

Spinning system	*Count range (tex)*	*Ring diameter (mm)*	*Lift (mm)*	*Spindle speed (rev/min × 10^{-3})*	*Package capacity (kg)*
cotton	5–40	44–70	202–280	10–17	0.1–0.3
worsted	24–60	52–95	254–330	8–12	0.2–1.0
semi-worsted	60–600	76–140	430–585	5–7	1.0–2.0
woollen	48–130	44–102	254–305	3.8–8.8	0.1–0.5
woollen	160 plus	114–178	430–585	3–7	0.8–2.6
condenser cotton	60–300	57–76	254–305	3–6	0.2–0.4

Note: Exceptions to the above ranges of conditions inevitably arise in practice.

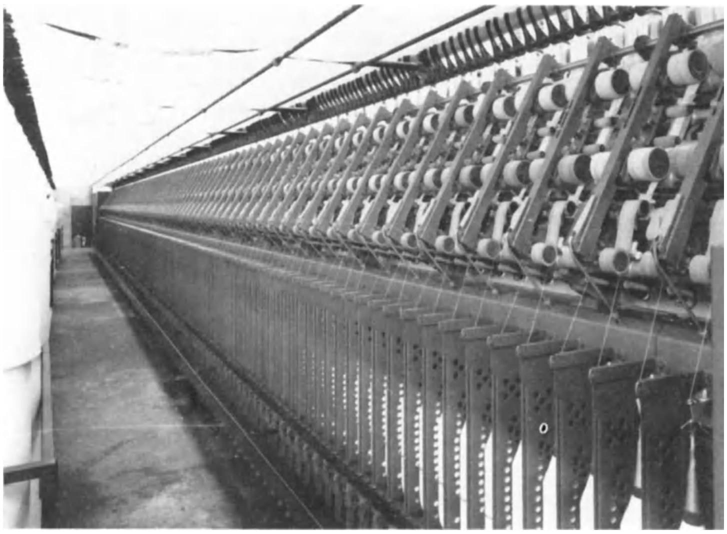

Plate 23. Semi-worsted ring spinning frame. This machine is designed to spin from slivers of up to 20 ktex containing wool, man-made fibres, or blends. The feed slivers can be seen passing overhead from the free-standing supply creel on the left. A two-zone drafting system enables drafts up to 250 to be applied where appropriate. The back zone ratch adjusts from 204 to 331 mm, and the front zone from 228 to 279 mm. The single bottom apron of the back zone is clearly visible, and double aprons are used in the front zone. The spirals of yarn around the spindle tip, which provide suppressed balloon spinning, can be seen on the nearest spindle. The spindle pitch is 114 mm and the spinning tube length is 450 mm; there can be from 28 to 172 spindles per side. Maximum front roller delivery speed is 40 m/min and the spindle speed can be up to 8500 rev/min. Courtesy of James Mackie & Sons Ltd

Because no spinning traveller was required, the cap frame was acknowledged as the best type of conventional frame for spinning oil-combed weaving yarns near to the fine count limit on the worsted system. Surprisingly, it was still being used in 1976 to spin 50's quality hogs wool near to limit counts (i.e. 37 to 50 tex); thicker counts can be spun satisfactorily on ringframes because a suitably heavy traveller can be used, but with fine counts the rigidity of such fibres creates problems with lighter ring spinning travellers.

Typical operating conditions for the two applications of cap spinning are given in *Table 12.2*.

In basic principle cap spinning is so much like ring spinning that relevant passages already dealt with under the heading of ring spinning will not be repeated.

The arrangement of the conventional cap spindle is shown in *Figure 12.7*.

In cap spinning it is common to refer to the 'spindle' speed in spite of the fact that the spindle itself is stationary. In fact the term 'spindle' speed in cap spinning really means the rotational speed of the tube on which is located the bobbin.

Besides supporting the stationary cap (a cylinder with an open lower end), the spindle also serves as a bearing for the tube which has a tape drive operating on its whorle. Excessive rotational speed of the bobbin and tube causes vibration of the spindle and cap; in extreme cases the cap can 'jump' from the

Table 12.2 ***Typical cap spinning frame details***

	Worsted spinning	*Continuous filament acetate spinning*
cap diameter (mm)	25–57	76–100
balloon height (mm)	200	450
spindle speed (rev/min)	5000–7500	8000
yarn delivery (m/min)	10–20	500
twist (t/m)	350–750	16
package capacity (g)	28–70	300
yarn count (tex)	15–44	5–50

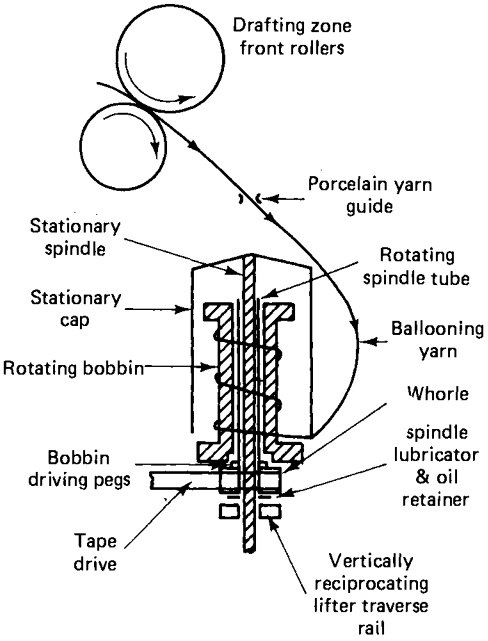

Figure 12.7 Conventional cap spinning frame (side elevation/section)

spindle and fall to the floor with the likelihood of it being damaged if the floor is concrete.

Rotation of the bobbin causes the yarn to be dragged round the cap edge thereby throwing the yarn outwards to form a balloon under the influence of centripetal acceleration, air drag, and yarn/cap-edge friction in a manner similar to that of ring spinning except that there is no traveller to provide a direct means of tension control.

With a constant bobbin speed (not actually achieved in normal practice), the balloon speed alters according to the package diameter so that marginally more twist is inserted when the bobbin is full; as in ring spinning the twist difference is so slight that it is unimportant in practice.

In cap spinning (unlike ring spinning) the balloon height remains constant because the cap is stationary, therefore the type of twist variation introduced in ring spinning by a moving ring rail does not occur in cap spinning. The yarn is traversed lengthwise on to the bobbin by the tube and bobbin being raised and lowered into and out of the cap by the lifter motion. On most cap frames this causes the spindle driving tapes to rub on the flanges of the spindle whorles for part of the time, thereby causing an intermittent reduction of spindle speed which in turn introduces twist variation along the yarn. Twist variation between spindles is also introduced by slippage in the tape drive which may have a mean of about 14% slippage. The variation of spindle speed on a conventional cap spinning frame with a 254 mm diameter cylinder driving the tapes, and 25.4 mm diameter spindle whorles is typically about 0.4% C.V.

A polyurethane foam oil retainer and lubricator fits between the spindle whorle and the lifter rail so that an oil film is maintained on the spindle at every traverse of the lifter.

Winding tension is directly proportional to the cap diameter and inversely proportional to the bobbin diameter, and spinning tension is approximately proportional to (balloon height)^2 and to (spindle speed)^2.

Air drag tends to stabilize the balloon shape so that spinning can take place over a wide range of yarn counts and spindle speeds although a smaller diameter cap is required to cover a finer count range. Because finer yarns tend to form narrower balloons they are usually spun at higher spindle speeds than are thick counts.

Tension is at a maximum and balloon radius is at a minimum when spinning on to the empty bobbin barrel; initially as the bobbin fills there is a decrease of tension as the angle of lead increases (θ, *Figure 12.2*). At this stage a free balloon is formed (i.e. a balloon which contacts the cap at its lower edge only) as shown in *Figure 12.8 (a)*. When the package diameter reaches a certain size, the reduction of yarn tension makes it no longer possible to form a free balloon when using a parallel sided cap, and the yarn commences 'licking' against (i.e. runs in contact with) the lower sides of the cap as shown in *Figure 12.8 (b)*.

As a result of licking, caps in regular use become highly polished. When new or re-used caps are fitted

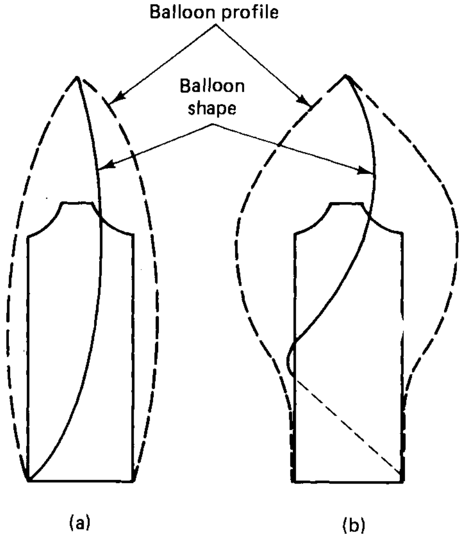

Figure 12.8 Cap spinning balloon profiles: (a) 'free' balloon formed when spinning on to an empty bobbin; (b) yarn 'licking' against cap as bobbin fills

to a frame it is not unusual to experience a high end-breakage rate until the caps become run-in; in such a case the yarn/cap friction may be reduced by spraying with paraffin when spinning commences.

Once licking has commenced the length of yarn in the balloon and in contact with the cap gradually increases in sympathy with the package diameter with the result that the further increases in package diameter do not cause any appreciable reduction of tension.

The developments of higher spindle speeds, larger packages, and a self-threading device came in the 1960s, by which time it was too late — improvements in ring spinning and the development of Repco self-twist spinning threatened the end of cap spinning.

Cap spinning machines are no longer produced.

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13

OPEN-END SPINNING

Historical background

During the 1960s there was a striking increase in preparatory processing speeds and consequently the actual spinning process became a bottleneck which impeded automating beyond the drawn sliver stage.

Because ring spinning offered little scope for further improvement, research was directed into alternative methods of spinning at higher speeds or with lower power consumption. Some of the methods have had widespread commercial application while others are still in the research and development or even speculation stage and might proceed no further. Ring spinning is still the most versatile system, and it will survive for many years for spinning yarns for which the new methods are not considered acceptable.

Future yarn manufacturing will not rely on a single system of spinning; no one system will satisfy the wide range of technological, economic, and aesthetic demands which will arise.

The principle of open-end spinning (alternatively known as 'break spinning' or 'free fibre spinning'.)

Of the new methods developed, open-end spinning seems to offer the widest application; various methods of open-end spinning have been invented, but some of these are not likely to be developed commercially.

Conventional spinning involves the rotation of the delivered yarn package in order to insert twist into the fibres emerging from the drafting zone. This is wasteful of power in that yarn already spun is being rotated, and it imposes speed limitations.

In open-end spinning the yarn twisting action is separated from the winding action and the package only needs to be rotated at the relatively low winding speed.

The basic principle of open-end spinning is illustrated in *Figure 13.1*. A continuous fibre supply, usually in the form of a sliver, has fibres detached from it and conveyed across a gap before the fibres are re-assembled by overlapping to form a continuous strand with the newly formed tail being rotated to insert twist. It is then only necessary to wind the yarn on to a package.

The essential features of the process may be summarized as: opening, transport, alignment, overlapping, and twist insertion.

Advantages of open-end spinning

Because it is no longer necessary to rotate the delivered yarn package, the limitations imposed by yarn ballooning no longer apply, and compared with

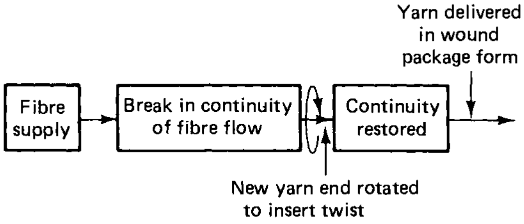


Figure 13.1 The basic principle of open-end spinning

ring spinning, open-end spinning has the following advantages:

(1) Higher speed of twist insertion giving yarn delivery speeds up to about 200 m/min, depending on machine type.
(2) Lower power consumption per kilogramme of yarn produced for short staple yarns thicker than about 20 to 30 tex, and for long staple yarns thicker than about 300 tex.
(3) Larger delivered package size — up to about 4 kg — usually in cheese form. This results in fewer knots being required.
(4) Elimination of some processes such as roving, frequently winding, and possibly others.
(5) It may be possible to use cheaper raw material.
(6) Reduced labour requirements and improved working conditions.
(7) About 2½% less waste for all counts.
(8) The operation can be continuous — packages can be doffed without stopping.
(9) Because of better yarn levelness it may be possible to use single open-end (OE) yarn instead of two-fold ring yarn in some fabrics.
(10) Significantly lower yarn fault content.
(11) There is no twist variation from empty to full package.
(12) Drafting waves introduced by preparatory processes are eliminated at the spinning operation.

Basic methods of open-end spinning

Although many individual OE spinning devices have been invented, they may be classified into the following groups:

(1) Vortex assembly
(2) Axial assembly
(3) Discontinuous assembly
(4) Friction spinning
(5) Rotor spinning

Vortex assembly

In practice this method is restricted to an air vortex. The basic principle is illustrated in *Figure 13.2*. The air flow spirals through the main tube in a general direction opposite to that of the yarn so that as fibres become attached to the yarn end they become helically orientated about the axis of the forming yarn.

Although the rotational speed of a simple vortex may be high, the actual twist insertion rate is limited to about 5 000 turns/min, and up to 20% of the fibres may fail to attach to the yarn tail. This can be improved either by using a supplementary twister, which is either mechanical or pneumatic, or by making the yarn roll around the inside of the tube to give yarn rotational speeds of up to 25 000 turns/min.

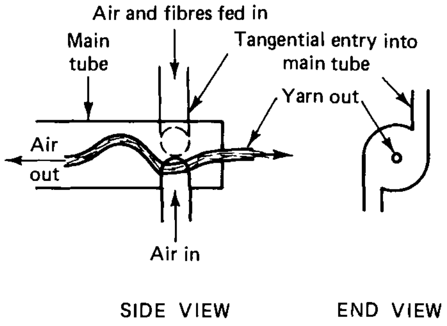


Figure 13.2 Vortex assembly

It has been suggested that an autolevelled card web could be divided to feed a bank of 50 to 100 autolevelling vortex tubes with unattached fibres being re-circulated to the card feed. Besides the obvious advantage of eliminating intermediate processes, it would also be possible to insert any other process into the sequence (such as heat-setting) without destroying continuity of production.

Widely varying fibre dimensions, and types as different as asbestos and jute have been spun, but stiff, crimpy fibres cannot be processed successfully.

Coarse yarns which are superficially similar to condenser-spun yarns can be spun at high speeds, but the yarns are relatively weak and unsuitable for warp so that although the method is simple, cheap, and robust, it has not yet been adopted widely.

A commercial machine operating on this principle, the PF1, has been developed in Poland. In this arrangement a partition with a central yarn withdrawal hole causes the fibres to be collected and condensed into a rotating ring of fibres which form the tail-end of the yarn.

The PF1 machine is fed by 2.5 to 5.0 ktex slivers, and produces yarns from 18 to 83 tex on cheese wound packages up to 2.5 kg. Twist insertion at speeds up to 140 000 turns per minute enables delivery speeds up to 200 m/min. Man-made fibres up to 3 dtex and up to 50 mm long may be spun 100% or in blends containing up to 50% cotton. It is claimed that compared with ring-spun, the yarns produced have lower long and short-term irregularity and no periodicity, 20 to 30% lower mean strength, but also a lower strength C.V., and more uniform twist.

End-breakage rates are stated to be from 5 to 17.5 per 100 'spindle'-hours, which is lower than that of ring spinning per kilogramme of yarn produced, and waste is minimized because the fibre feed is stopped automatically if an end is down; there is also a complete absence of dust and fly-waste.

Compared with ring spinning and their attendant roving frames, PF1 machines occupy about 40% of the floorspace, use slightly less power, and require about one third of the personnel per kilogramme of yarn produced.

Axial assembly

This involves air or electrostatic methods of control over fibre flow followed by fibre assembly along the axis of rotation with mechanical twist insertion. One method of this type is shown in *Figure 13.3*; the air is used to draw the fibres into the rotating needle basket which inserts twist into the tail of the forming yarn — alternatively pneumatic twist insertion could be used.

This method enables a rotating device of small radius to be used regardless of fibre length considerations, but the design and setting of the needles and the air flow rate are crucial. As in the vortex system, some fibres escape the yarn tail and may need to be re-circulated.

Yarns from 10 to 120 tex have spun at speeds of up to 20 000 rev/min, but the yarns were fuller and considerably weaker than ring-spun yarns.

Electrostatic methods have been widely discussed. The method can be used for fibre transport, alignment, and overlapping, but for opening or twist insertion the electrostatic forces are too weak, and difficulties arise. A system using charged fibres, rather than uncharged fibres, develops greater forces on the fibres, and using an opening roller seems to be the most suitable method of opening because it enables the air in the system to supplement the electrostatic field in the transport, alignment, and overlapping functions.

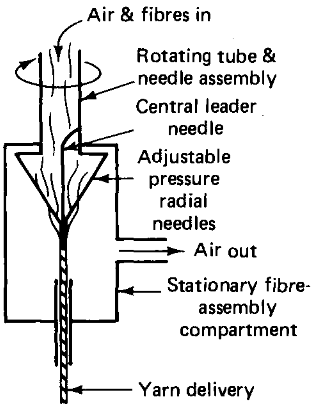


Figure 13.3 Axial assembly

The force acting on the fibre end is proportional to the product of the charge and the voltage gradient. Because the fibre charge is small a high voltage, such as 15 kV per 25 mm is necessary to produce sufficient force. High voltages increase the risk of dielectric breakdown and it is even possible for fibres to be destroyed by sparks, hence there is an upper limit to the voltage which can be used, and to the force which can be applied to the fibres.

Attempts to use electrostatic forces for twist insertion suffer from having a low twisting efficiency, which at high speeds leads to end-breakage because the relatively weak electrostatic forces are overcome by the stronger aerodynamic forces generated by the process.

Some difficulties may arise in commencing the spinning process, in piecening, and in processing blends containing fibres of widely different properties such as cotton and polyester, and danger or nuisance to operatives may arise from the use of high voltages.

Because a small diameter twist inserting head is used with axial assembly, there is the possibility of high speed with small power consumption which may perhaps enable such a system to compete with the rotor method at some time in the future.

Discontinuous assembly

This method consists of overlapping successive tufts of fibres followed by twist insertion as illustrated in *Figure 13.4*. The partially fluted roller detaches tufts of fibres from the slowly fed roving and overlaps them prior to withdrawal along the hollow axis of the roller; one turn of twist is inserted for each revolution of the roller, the circumference of which must exceed the maximum fibre length.

Yarn irregularity could be expected to be similar to that of the roving, but with a superimposed short wavelength due to the tufting. However at high speeds fibre control is difficult even when a suction device is fitted, hence there appears to be little potential for development of this method.

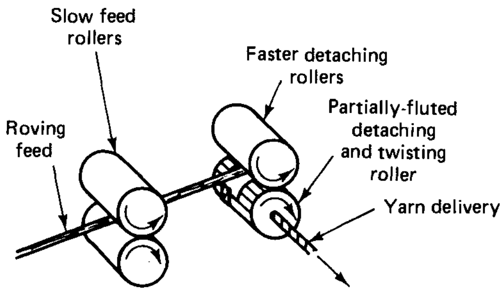


Figure 13.4 Discontinuous assembly

Friction spinning

Basically this method consists of fibre separation by a pinned or clothed roller, followed by re-assembly of the fibres to form a yarn, with twist inserted by frictional contact between the yarn surface and rotating cylinders or rollers.

Such an arrangement involves lower power consumption than rotor spinning, and lower yarn tension. The yarns produced contain no wrapper fibres (described on page 146) and hence they are better for use in cut-pile fabrics.

One system based on this principle, the DREF system, was introduced in the early 1970's and has continued to increase in popularity, and another system, the Platt Saco Lowell (PSL) friction spinning machine, was introduced in the early 1980s; no doubt there will be other developments along these lines in the future.

The DREF system (friction spinning)

This method is representated schematically in *Figure 13.5*. The total input of 15 to 40 ktex card sliver/s is fed through a series of rollers to the card roller which conveys individual fibres into an air stream in which the fibres become aligned horizontally. They descend to form a wedge between two rotating suction cylinders which twist the open end of the forming yarn. The yarn is drawn off and wound on to a package of up to 10 kg at speeds up to 300 m/min.

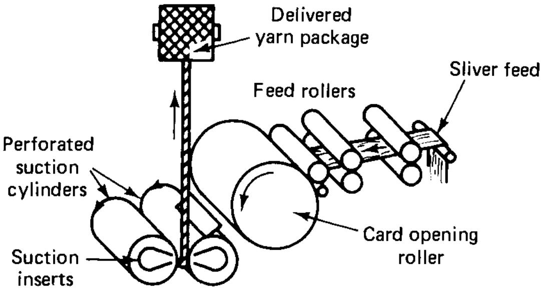


Figure 13.5 The DREF system (friction spinning)

The system is intended for yarn from 30 to 300 tex for carpets, blankets, upholstery, clothing, and industrial fabrics made from long staple fibres such as wool, man-made fibres, or blends of a variety of types, fineness, and lengths from 32 to 200 mm. Wool grease up to 0.8% and added oil up to 1.2% do not create problems with this particular method of open-end spinning. The system does not involve high rotational speeds — the suction cylinders rotate at speed from 2800 to 6000 rev/min — and tension applied to the forming yarn is low. The production of core yarns, knop yarns, and fancy coloured effects, combining continuous filament, elastomerics, and staple fibres is also possible on the DREF 3 machine shown in *Plate 24*.

This system is increasing in popularity and may become popular for the production of 'woollen' type yarns.

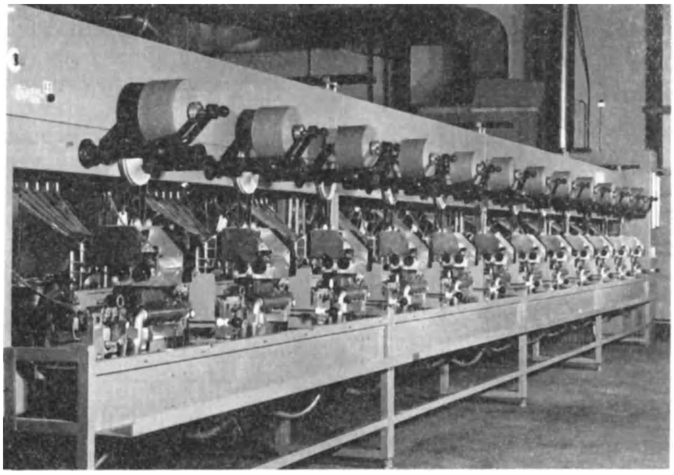


Plate 24. Twelve-head dref 3 open-end spinning machine. This machine can have up to 96 heads. Each head has six slivers feeding from the back in a similar manner to that of the Dref 2 machine. In addition Dref 3 has a separate sliver of up to 3.5 ktex fed to a drafting zone applying a draft from 100 to 150 to form the parallel-fibre core of the yarn. This sliver feed at the nearest head is clearly visible at the extreme left-hand end of the machine; alternatively a continuous filament core can be used. Yarns from 33 to 167 tex are delivered at speeds up to 300 m/min in an upward direction from the right-hand end of the suction cylinders, which can rotate at speeds from 3000 to 6000 rev/min. The delivered yarn packages of 150 mm traverse and up to 400 mm diameter are clearly visible near the top of the machine. Courtesy of Dr Ernst Fehrer A.G.

The PSL friction spinning machine

A schematic diagram showing the threadpath of this machine is shown in *Figure 13.6*. The machine is intended to spin yarns from about 15 to 60 tex at delivery speeds up to 300 m/min from cotton, man-made fibre, or blends, with a maximum staple length of 40 mm and a maximum fibre fineness of 3.3 dtex. Yarns containing cotton are cleaner and have fewer neps and small faults than ring-spun yarns.

Drafts from 60 to 240 can be applied, with the opening roller rotating at speeds from 4500 to 10 000 rev/min, and the friction rollers running at speeds from 2200 to 10 000 rev/min.

The delivered package capacity is 4.2 kg, measuring 150 mm long × 290 mm diameter. Optional features include: high angle cones; waxing; automatic stop/start; momentary power failure control; automatic piecening; and automatic doffing.

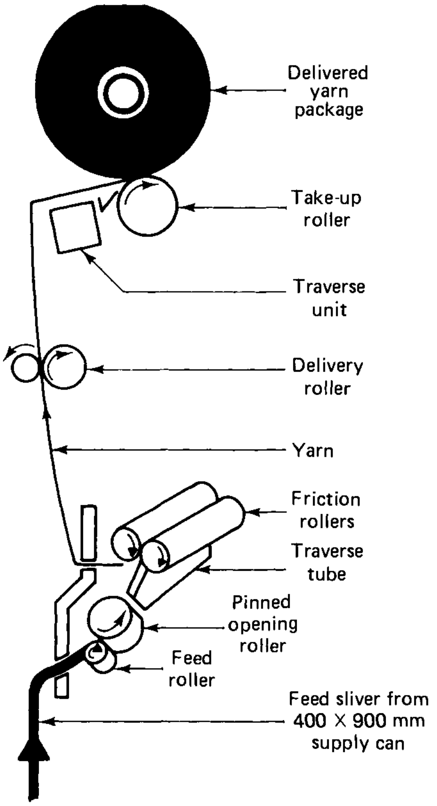


Figure 13.6 The PSL (Platt Saco Lowell) friction spinning machine

Rotor open-end spinning

This, the most successful method of open-end spinning, has been subjected to intensive research and development with the result that a variety of detailed applications has emerged; the basic principle, illustrated in *Figure 13.7(a)* remains unaltered.

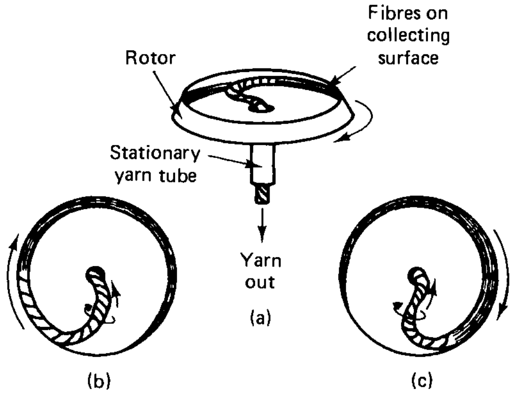


Figure 13.7 Rotor spinning principles: (a) yarn formation; (b) normal withdrawal; (c) reverse withdrawal

Fibre assembly

Ideally after preliminary separation, individual fibres are carried in an air stream into the rotor and laid in contact with the collecting surface so that a continuous strand of fibres is assembled around the circumference.

Rotor twist insertion and yarn withdrawal

To commence spinning a 'seed' yarn is introduced into the yarn tube until it contacts the collecting surface and becomes trapped in the strand of fibres. Yarn withdrawal then commences so that the fibre layer is peeled from the collecting surface and theoretically one turn of twist is inserted for each revolution of the gyrating yarn end. Continuity is maintained by the continuous stream of fibres arriving on the collecting surface to replace the fibres removed as the withdrawal point moves steadily around the collecting surface, usually in the same direction as the rotor rotation as shown in *Figure 13.7(b)*. This may be termed 'normal' withdrawal; the yarn follows a smooth curve and yarns of good appearance are produced. Occasionally there is a spontaneous change of motion of the yarn withdrawal point so that relatively it moves around the rotor in the direction opposite to that of rotation as shown in *Figure 13.7(c)*; this may be described as 'reverse' withdrawal. In this case because of air drag, the yarn forms an 'S' curve and yarn appearance is adversely affected. It is important to note that the direction of twist insertion is determined by the direction of rotation of the rotor, and that it remains unchanged whether normal or reverse withdrawal takes place, and that the amount of twist inserted is virtually constant throughout the package.

The forming yarn is withdrawn from the rotor by take-up rollers and is passed to a winding head which usually winds a cheese type package of 2 to 3 kg. Constant winding tension must be maintained as the package mass increases otherwise there might be a reduction in yarn count on the outer layers.

Features of rotor spinning machines

A number of different types of rotor machines have been developed; the main differences lie in the methods of opening and feeding, the types of rotors and bearings, and the general features which determine suitability for different types of fibres and ranges of yarn counts. The terms 'first generation' and 'second generation' have been used with reference to rotor spinning machines, but this terminology is best avoided because it does not clearly differentiate between the types. A fully automatic rotor spinning machine is shown in *Plate 25*.

Critical metal parts of OE machines must be sufficiently hard and abrasion resistant to withstand the processing of hard synthetic fibres, otherwise the wearing of fine grooves would cause local accumulations of fibre thereby adversely affecting yarn quality and end-breakages.

Opening methods

The majority of rotor machines use a 50 to 80 mm diameter card-clothed opening roller (alternatively called the opener, the beater roller, or the disintegrator) which functions in a manner similar to that of a takerin roller on a carding machine; it is designed to be fed by sliver usually ranging from about 40 to 300 times thicker than the yarn count to be produced, depending on the machine design.

As a general rule finer feed slivers are used for spinning finer yarns at higher drafts, and a reduced sliver count may be necessary for bulky fibres such as acrylics.

Too slow a fibre feed from thick sliver means a longer 'attack' time of the opening roller, leading to fibre damage and excessive dust formation; the converse gives insufficient opening time and, there-

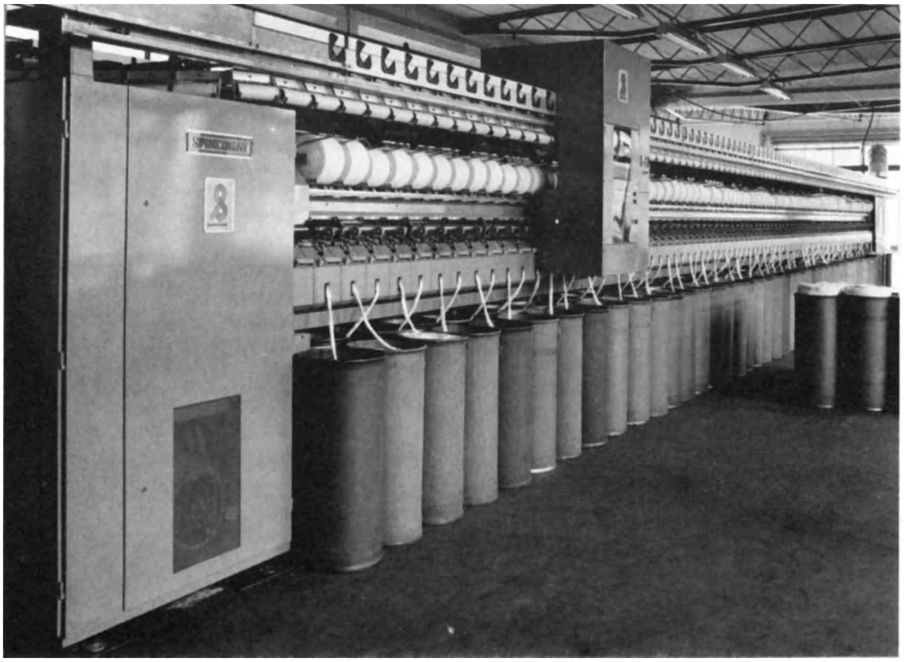


Plate 25. Automatic rotor spinning machine. This is a double-sided machine which can have up to 108 rotors per side at a pitch of 195 mm. Rotor speeds up to 80 000 rev/min are mechanically possible, with drafts from 25 to 200. The 'Automat' unit is clearly visible part-way along the machine. This unit automatically cleans the rotors, makes piecenings, and doffs, providing a transfer tail. An empty tube is available above each full package; when the full package is removed it is pushed backwards and it is carried on a conveyor belt to the machine end. The interchangeable opening rollers, interchangeable rotors, and the rotor bearings for this machine are shown in *Plates 26* to *28*, respectively. Courtesy of Schubert & Salzer A.G.

fore, inadequate opening. Hence, for example, a draft of 37 may be used to spin 200 tex yarn from 7.4 ktex sliver, whereas 20 tex yarn might be spun from 2.8 ktex sliver with a draft of 140.

Opening roller surface speed usually may be selected from within the range 800 to 2500 m/min, but there is an optimum opening speed for a given fibre. Too slow tends to cause fibre lapping and irregularly spaced thick and thin places in the yarn, whereas too fast may cause excessive dust and fibre breakage or even fibre melting in the case of synthetics.

Higher opening speeds may be required to provide increased opening force under the following circumstances:

(1) Increased feed sliver count, even when the feed rate in grammes per minute is constant.
(2) Increased fibre length.
(3) Three-dimensional crimped fibres compared with two-dimensional crimp.
(4) Finer fibre diameter, because of the increased fibre surface area.
(5) Increased rate of feed with a constant sliver count.

The card clothing used on opening rollers is usually of the rigid metallic type, varying from a face angle of about 65° and 18.5 points per cm^2 for cotton, to 80° or 100° and 15 points/cm^2 for man-made fibre hence a machine may be restricted to spinning specified fibres. If the fibre range is exceeded for a given machine there may be deterioration in yarn properties, end-breakage rate, and fibre breakage, with lapping of fibres on the opening roller. Interchangeable opening rollers can overcome this difficulty; some are shown in *Plate 26*.

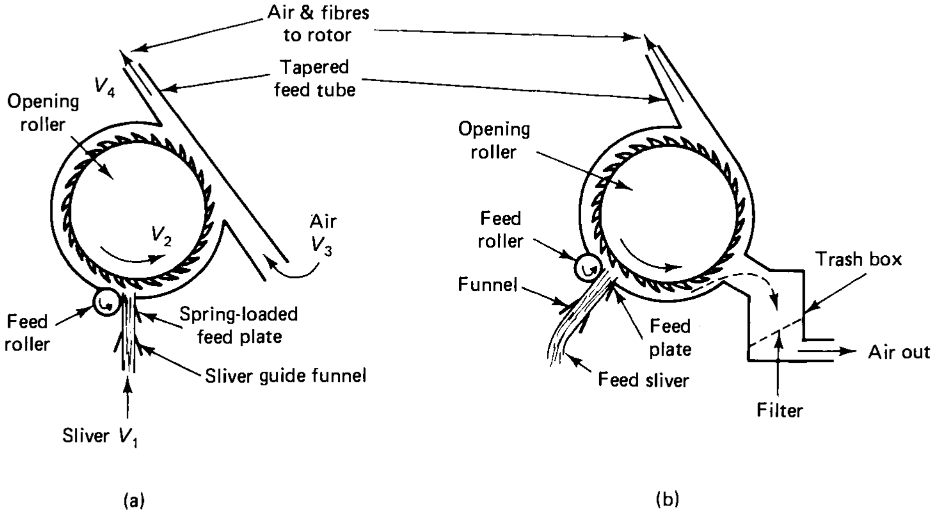
Removal of fibres from the opener is by controlled air flow, aided by centrifugal acceleration. The ratio of (air speed)/opener surface speed) should be in the region of 1.5 to 4.0; a higher ratio is associated with increased yarn tenacity because of the improved fibre orientation.

The biaxial arrangement of opening roller is most commonly used, in which the opening roller shaft is either perpendicular to or parallel to the rotor shaft. There are two types of of biaxial opener feeds with a typical opener surface speed of up to about 1 650 m/min:

The first is the simple opener feed, where there is an increase of velocity from V_1 to V_4 as indicated in *Figure 13.8(a)*.

The second is the trash removal type (*Figure 13.8(b)*), where an external air source is required to provide the necessary air flow for satisfactory performance of the trash box with a minimum fibre loss. Air flow to the rotor may be provided by an external source or by a self-pumping rotor which has a series of concentric holes at some distance from the centre through which air is ejected by centrifugal force.

Plate 26. Interchangeable opening rollers for rotor spinning machine. The 80 mm diameter opening rollers, which can rotate at speeds from 3000 to 9000 rev/min, can be changed easily and quickly by releasing a clamp. Viewed from left to right: pinned roller, rigid wire roller for cotton, and a rigid wire roller for man-made fibres. Courtesy of Schubert & Salzer A.G.



(a) (b)

Figure 13.8 Opening roller arrangements: (a) simple opener feed; (b) trash removal feed

The percentage of trash extracted is increased and yarn nep content is decreased with an increased opening speed and/or a widening of the channel leading to the trash box.

An alternative to the biaxial method is the coaxial system in which the opener is mounted on the same axis as the rotor shaft; the coaxial system has not been used widely.

Fibre transfer

After opening, the fibres must be conveyed to the collecting surface of the rotor. With a biaxial opener; the fibres are transported to the rotor by air currents in a feed tube as shown in *Figure 13.8*; greater acceleration is applied to crimped fibres and also at higher air speeds. Higher air speeds lead to reduced yarn irregularity.

Ideally fibres should pass down the feed tube one at a time, but in practice provided that the average number of fibres in the feed tube cross-section is four or less, a near 'random' or 'limit irregularity' fibre distribution in the yarn will result; in general between 5 and 10 fibres may lead to difficulties.

Fibres passing along the feed tube are able to relax and therefore tensions are much more evenly distributed in OE yarns and there is less fibre migration than in ring-spun yarns.

There are different possible positions of the feed tube relative to the rotor. Early rotor designs used a central feed tube; the only advantage of this arrangement was that it was possible to spin either S or Z twist merely by reversing the direction of rotor rotation. On the other hand with such an arrangement there were at least two right-angled turns in the fibre flow-path which could contribute to fibre buckling as well as problems with air turbulence near the rotor centre and a greater incidence of wrapper fibres; also the rotor radius had to be at least equal to the maximum fibre length. Hence the disadvantages of this arrangement outweighed the one marginal advantage.

Consequently a tangentially placed feed tube has been adopted (*Figure 13.9*). The tube is usually tapered thinner towards the exit end so that the accelerating air may align and straighten out the fibres before their leading ends emerge from the tube to contact a smooth surface of the faster moving rotor known as the 'slide wall' which slopes at an angle of from 20° to 40° to the rotor axis. This thereby increases the likelihood that the fibres will be fully straightened before they enter the actual collecting groove. If too many fibres are fed alongside each other, the rotor tends to accelerate tufts of fibres, thereby increasing yarn irregularity.

The amount of rotation during which a given fibre moves into the collecting groove depends on the rotor diameter, the slide wall angle, and the axial distance from the feed tube exit to the collecting groove. For fibres with different frictional properties the use of different angles of slope may have a significant influence on yarn tenacity.

With a tangential feed tube, because the fibres are fed direct to the rotor circumference they are less able to foul the length of gyrating yarn inside the rotor (as may arise with a central feed tube), but some bridging fibres and wrapper fibres are still unavoidable. A feed tube with the opposite angle of entry is needed if it is required to spin with the opposite direction of twist.

Using a tangential feed tube makes it possible to have yarn withdrawal at the same side of the rotor

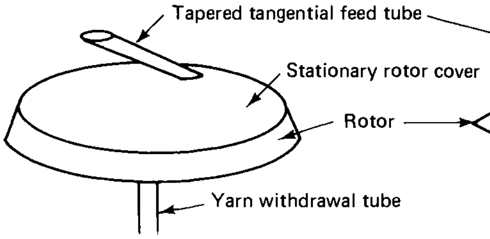


Figure 13.9 Tangenitial feed tube at opposite side of rotor plane from yarn withdrawal

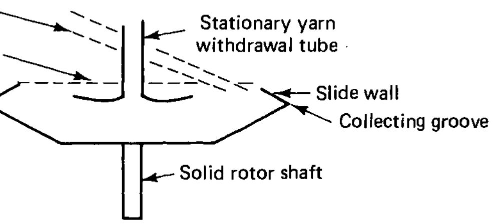


Figure 13.10 Feed and withdrawal tubes at same side of rotor plane: solid rotor shaft

plane as the feed (*Figure 13.10*), and to have a solid rotor shaft; this leads to the possibility of having interchangeable rotors, as shown in Plate 28.

For a given rate of production, $n \times v$ = constant, where n = mean number of fibres in the cross-section of the tube, and v = the mean fibre velocity in the feed tube. If the production rate is increased it follows that n must be increased because v is determined by the air conditions which are usually independent of the production rate or the rotor speed. Hence at a higher production rate the tuft size in the feed tube must be increased.

Bridging fibres

It seems that the change from normal to reverse withdrawal may be caused by some bridging fibres, i.e. fibres which are fed across the point of withdrawal. Bridging fibres are unavoidable and even if they do not cause a change from normal to reverse withdrawal each one must cause the formation of a leading-hook fibre in the yarn as it leaves the collecting surface, hence a large number of leading-hook fibres are usually present in rotor spun yarns, giving a reduced effective fibre length in the yarn and hence a lower yarn tenacity.

The probable occurrence of bridging fibres may be calculated:

$$\% \text{ Bridging fibres} = \frac{\text{mean fibre extent} \times 100}{\text{rotor circumference}}$$

If it is assumed that mean fibre extent equals rotor radius, then it can be shown that there must be at least 16% hooked fibres formed at withdrawal even if the fibres were straight and parallel when assembled on the collecting surface.

Wrapper fibres

Some fibres arrive at the collecting surface just as the tail end of the yarn is being withdrawn at that point. This prevents such fibres from settling into the collecting groove along part of their length before withdrawal, with the result that they may disturb some of the other fibres in the groove and form either a loose spiral around the outside of the yarn but yet are firmly anchored in the yarn core and cannot be displaced lengthways, or form a tightly-wrapped close-wound spiral. More wrapper fibres are formed at higher spinning twists because the tail end of the yarn passes the feed tube more times. Wrapper fibres may increase the visual appearance of yarn irregularity by compressing the inner core unevenly at different points along the yarn length; this form of irregularity may escape detection by the usual capacitance levelness tests. Carpet yarns require a minimum of wrapper fibres otherwise the yarn will not burst after cutting — hence minimum twist is needed in open-end carpet yarns for cut pile. Wrapper fibres make little contribution to yarn strength hence a measure of the number of wrapper fibres can be obtained by testing the strength of yarn both before and after twist removal — more wrapper fibres cause a relative increase of the 'untwisted' yarn strength.

Rotor design

The early commercial machines used self-pumping rotors with a series of holes near the circumference. It was claimed that a machine with self-pumping rotors has a lower total power requirement than one requiring an external air source, but on the other hand if one or more of the holes become blocked by impurities it is highly probable that periodic yarn will be produced. This danger can be reduced either by positioning the holes nearer to the centre of the rotor, i.e. further away from the collecting rurface, or by enclosing a plain rotor (i.e. without holes) in a low-pressure chamber, or by a combination of both a self-pumping rotor and a low-pressure chamber. There has been a general move towards the external air source arrangement, frequently combined with a non-pumping rotor. There are five main factors to be considered in relation to this development:

(1) It may be associated with a trash removal device of the form shown in *Figure 13.8* (*b*) which has a typical cleaning efficiency of about 40% for cotton. This permits the production of cleaner yarns and/or the use of lower grade cottons.

(2) An external source of suction gives greater freedom of control over air flow independently of the rotor speed requirements; in the event of rotor stoppage because of an end-break, full air flow remains available to provide self-clearing and cleaning of the rotor.

(3) The plain rotor design is of particular advantage in the case of large diameter rotors for long staple spinning where high rotor speeds are precluded by power considerations and where safety factors regarding fatigue and bursting make the provision of holes for self-pumping inadvisable.

(4) Smooth non-pumping rotors make less noise, and because they require less driving power, they are subjected to reduced bearing stress.

(5) Self-pumping rotors may lead to excessive power consumption and excessive airflow at high rotor speeds such as 60 000 rev/min or more.

Variations in the cross-sectional shape of rotors (*Figure 13.11*) have shown that it is possible to improve fibre alignment and therefore yarn tenacity; the fibres are compressed into a narrow groove to form a more compact fibre layer which is more easily twisted into a yarn.

The 'scavenging' performance of a rotor also can be influenced by the rotor shape, i.e. the ability of the withdrawing yarn to remove particles of impurity which have been fed into the rotor and which otherwise would accumulate at the collecting surface thereby causing poor spinning conditions; scavenging is not influenced by normal or reverse yarn withdrawal.

Particle accumulation is the commonest cause of yarn periodicity and is a particularly important factor in the spinning of wool on a rotor machine. The centrifugal force applied to trash particles at the collecting surface is proportional to (rotational speed)^2, hence speed increases make it more difficult for the yarn to dislodge such particles, and may lead to a deterioration of yarn quality.

Rotor bearings and drive

Two main groups of bearings have been investigated for rotor spinning: slider bearings, and roller bearings.

The two types of slider bearings: air bearings and magnetic bearings cannot be belt driven because the radial forces involved would be too great. Therefore each spinning position would require an individual motor — at present such motors have a driving efficiency of less than 60% and consequently at a given rotor speed the drive power consumed would be almost twice that of roller bearings. Air bearings are capable of the fastest rotational speeds, but the power consumed by the bearing itself (quite apart from the drive) is approximately ten times greater than for other types. The power required to rotate a given rotor itself remains unchanged whatever type of bearing is used; the total power consumption, based on 46 mm diameter rotor running at 80 000 rev/min, for the three bearing types is:

air bearings	500 W
magnetic bearings	275 W
roller bearings	210 W

(P. Muller, open-end spinning symposium, Bradford University, 1974).

Roller bearings may be directly mounted on the rotor shaft, but they have a shorter working life than the disc-on-roller bearing system, the basic principles of which are shown in *Figure 13.12.* and *Plate 27.* With this arrangement the tangential belt drive is direct to the rotor shaft and with a disc diameter eight times greater than the rotor shaft, the rotor can be run at 80 000 rev/min for five years of

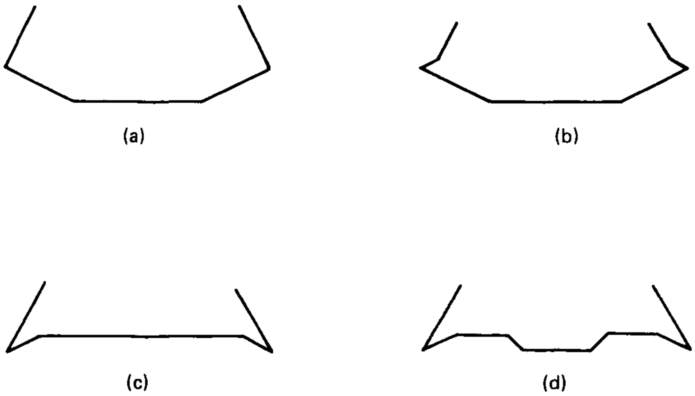

(a) (b) (c) (d)

Figure 13.11 Examples of rotor (side elevation/sectional shapes)

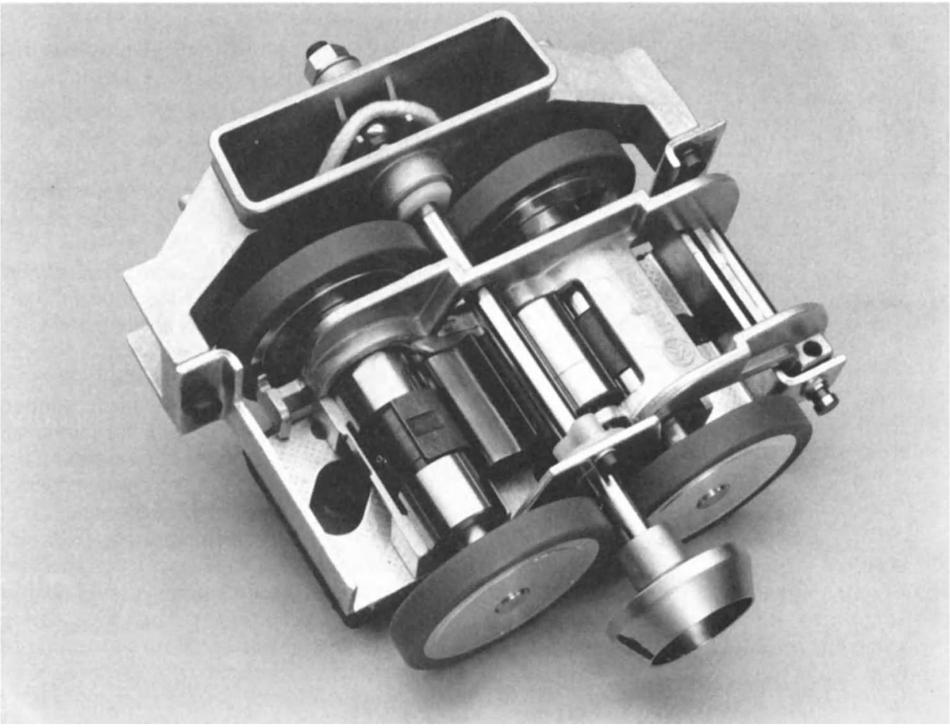


Plate 27. Disc-on-roller rotor bearing unit. Although this system permits rotor speeds up to 80 000 rev/min, the roller bearings themselves rotate at a much slower speed, thereby providing a long working life. It also makes for easy and quick exchange of the rotor size. Courtesy of Schubert & Salzer A.G.

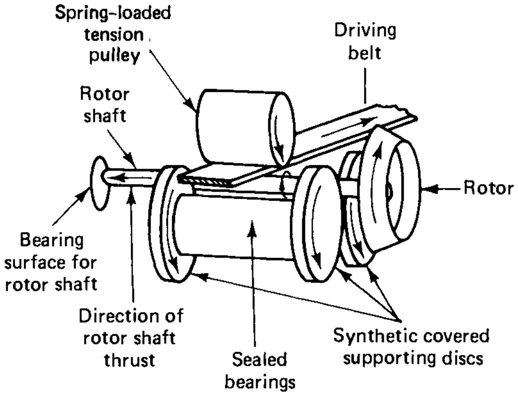


Figure 13.12 Disc-on-roller bearings

three-shift working without attention to the sealed bearings which rotate at only 10 000 rev/min. The lower centrifugal force on the ball bearings at this speed permits greater freedom in designing the bearing besides reducing the wear and tear. A driving belt surface speed of 40 m/s is required to drive the 9 mm rotor shaft at 80 000 rev/min (allowing for about 6% belt slippage). The twin discs are slightly inclined to maintain the rotor shaft thrust on the end bearing surface; when the rotor chamber is opened the rotor shaft has the tension pulley and belt lifted clear and a brake applied simultaneously. With the twin disc arrangement the rotor may be changed in less than 10 seconds; a set of interchangeable rotors is shown in *Plate 28*. Exchangeability of rotors has the important advantage that the minimum permissible rotor diameter can be used for each material fibre length thereby enabling the maximum rotational speed to be used without involving excessive yarn tension or power consumption; in turn this permits a minimum amount of spinning twist. A range of different rotor diameters can therefore increase the fibre and count range of a given machine.

Most rotor spinning machines have a tangential belt drive to the rotors, but some have individual frequency-controlled motors.

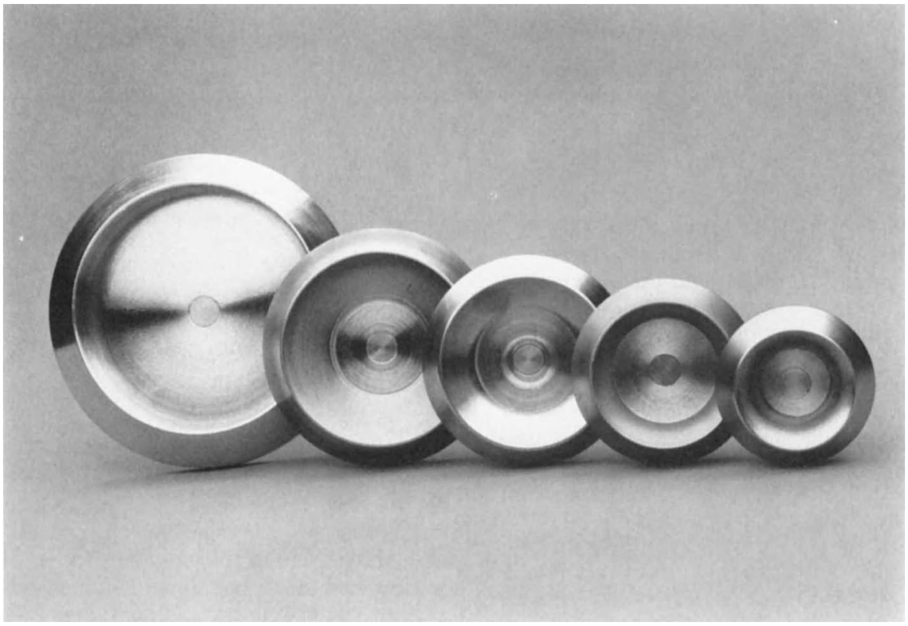


Plate 28. Interchangeable rotors for open-end spinning. With a dics-on-roller bearing system, the rotors can be exchanged easily. From left to right the rotor diameters shown are: 80, 65, 56, 48 and 40 mm. A 92 mm rotor (not shown) is also available. Courtesy of Schubert & Salzer A.G.

Technical aspects of rotor spinning

Twist and draft calculations

The examples given here are based on a 30 tex yarn being spun from 4 ktex feed sliver, with a rotor diameter of 60 mm, rotor speed 41 000 rev/min, and a yarn delivery speed of 50 m/min.

The yarn withdrawal point at the collecting surface (i.e. the gyrating arm of yarn inside the rotor) must rotate at a speed slightly different from that of the rotor because of the 'withdrawal revolutions', these are analogous to the 'winding-on revolutions' in flyer processing described on page 89. Yarn delivery (m/min) = withdrawal rev/min × rotor circumference (m) hence

$$\text{Withdrawal rev/min} = \frac{50 \times 10^3}{60\pi} = 266 \text{ rev/min}$$

Theoretical twist

(1) With normal withdrawal

Gyrating yarn rev/min = (rotor rev/min) + (withdrawal rev/min)
41 000 + 266 = 41 266 rev/min hence

$$\text{Theoretical twist} = \frac{41\ 266}{50} = 825 \text{ t/m}$$

(2) With reverse withdrawal

Gyrating yarn rev/min =
(rotor rev/min) − (withdrawal rev/min)
= 41 000 − 266 = 40 734 rev/min
hence

$$\text{Theoretical twist} = \frac{40\ 734}{50} = 815 \text{ t/m}$$

Calculated twist

$$\text{Calculated twist (t/m)} = \frac{\text{rotor speed (rev/min)}}{\text{yarn delivery (m/min)}}$$

$$= \frac{41\,000}{50} = 820 \text{ t/m}$$

In practice the calculated twist is normally quoted in rotor spinning for three main reasons: firstly the difference between theoretical and calculated twist is very small, secondly the yarn withdrawal point may move in either direction relative to the rotor, and thirdly because of the torsional rigidity of fibres in the collecting groove, there is a reaction to the turning moment so that in practice there is a loss of twist. Consequently the actual twist in a yarn may be from 10% to 30% less than the calculated twist, depending on fibre type, twist level, and yarn count.

Surface speeds

$$\begin{matrix}\text{Collecting}\\ \text{surface speed}\end{matrix} = \begin{bmatrix}\text{rotor circum-}\\ \text{ference (m)}\end{bmatrix} \times \begin{bmatrix}\text{rotor speed}\\ \text{(rev/min)}\end{bmatrix}$$

$$= \frac{60\pi \times 41\,000}{1000} = 7625 \text{ m/min}$$

$$\begin{matrix}\text{Feed roller}\\ \text{surface speed}\end{matrix} = \frac{\text{yarn delivery speed} \times \text{yarn count}}{\text{sliver count}}$$

$$= \frac{50 \times 30}{4000} = 0.375 \text{ m/min}$$

Acceleration should take place at the opener and in the feed tube as shown in *Figure.13.8(a)* where V_1 to V_4 represent progressive speed increases. In this example an opening roller surface speed of about 1 700 m/min and a mean air speed of about 5300 m/min in the feed tube have been assumed.

Cross-sectional number of fibres ($\bar{x}f$)

This is the mean number of fibres travelling alongside each other at any point in the sequence of flow.

The mean number of fibres passing any given point in the sequence per unit of time must be a constant, hence for a given point,

$\bar{x}f \times$ mean fibre speed = constant

For this example 3.3 dtex fibre has been assumed, hence the mean number of fibres in the yarn cross-section = 30/0.33 = 90. Therefore the mean number of fibres per minute passing out of the yarn withdrawal tube $\propto$ (mean number of fibres in the yarn cross-section) × (yarn surface speed (m/min)), i.e. 90 × 50 = 4500, a constant.
Therefore

$\bar{x}f$ at a given point

$$= \frac{4500}{\text{mean fibre speed at that point (m/min)}}$$

Therefore the mean number of fibres in feed sliver cross-section = 4 000/0.33 = 12 000. If it is assumed that the fibre speed is equal to the opening roller surface speed, and the feed tube air speed, then at those points in the flow,

$$\bar{x}f \text{ at the opener surface} = \frac{4\,500}{1\,700} = 2.65, \text{ and}$$

$$\bar{x}f \text{ in the feed tube} = \frac{4\,500}{5\,300} = 0.85$$

In practice, however, $\bar{x}f$ will not be constant at different points along the feed tube because fibres are accelerated, and in any case they do not achieve the same speed as the air; this maintains aerodynamic drag on them to improve straightening.

$$\bar{x}f \text{ at the collecting surface} = \frac{4\,500}{7\,265} = 0.59$$

In other words the 'stream' of fibres arriving at the collecting surface on average has a space between each consecutive fibre. The number of times the 'stream' of fibres is superimposed to form a yarn, i.e.

the doublings

$$= \frac{\text{number of fibres in the yarn cross-section}}{\bar{x}f \text{ at the collecting surface}}$$

$$= \frac{90}{0.59} = 152.5$$

This is equivalent to using doublings as the last act prior to yarn formation and accounts for the relatively low short-term irregularity of rotor spun yarns and the intimate fibre mixing even with blends of long and short fibres; the cross-sectional homogeneity of feed sliver is not necessary provided that the proportion of each component remains constant at any point along the sliver. An alternative expression is:
doublings = spinning twist (t/m) × rotor circ. (m)
hence the effective doubling rate is influenced by twist and by rotor diameter. It should be noted that the limit irregularity due to a random fibre arrangement cannot be eliminated and that the decrease in yarn irregularity is limited to a particular region of wavelength; periodic yarn faults which do not correspond in wavelength to the rotor circumference will be perpetuated in the yarn, and an alteration of the number of doublings in the rotor will have negligible influence on the amplitude of periodic irregularities.

Change of draft and twist

Assuming that it was required to change from the above conditions to spinning 50 tex yarn with 630 t/m calculated, at the same rotor speed, then

Calculated yarn delivery

$$\text{speed} = \frac{41000}{630} = 65 \text{ m/min}$$

Feed roller surface

$$\text{speed} = \frac{65 \times 50}{4\,000} = 0.813 \text{ m/min}$$

This would give an increase of 0.813/0.375 = 2.17 times the rate of production, assuming the same productive efficiency.

The structure of open-end yarns

Because fibres have some freedom of movement during twist insertion, the outer fibres tend to slip more than the core fibres. Consequently unlike ring-spun yarns, OE yarns consist of a three-part structure: a densely packed core consisting of about 80% of the fibres substantially aligned with the yarn axis; loosely packed fibres twisted around the core at a considerable angle to the axis; and wrapper fibres on the outside.

In a ring-spun yarn nearly all the fibres migrate whereas although some individual fibres in OE yarns are located in more than one part of the structure, the lower incidence of fibre migration in OE yarns along with the reduced fibre extent, contributes to lower yarn strength.

Cleanliness of fibre feed

The problem of impurities in the feed sliver is more acute with OE spinning than with ring spinning partly because there are fewer operations between the carding and spinning processes, but also because of the more critical standards required by the OE spinning process itself. The rotor acts as a centrifuge which tends to separate dust and trash from cotton fibres and accumulates them in the collecting surface groove.

Although the accumulation of impurities in the rotor does not appear to increase specific yarn faults, it leads to a deterioration of yarn strength, hairiness, levelness and appearance, and to an increase in the end-breakage rate. Yarn periodicity may also arise, particularly with self-pumping rotor machines.

Individual trash particles with a mass of more than 0.15 mg interfere with removal of fibres from the collecting surface to such an extent that end-breaks usually follow, particularly with fine yarns.

When spinning cotton a deposit of vegetable matter builds up in the rotor, ranging from microparticles 1 μm wide to larger particles greater than 50 μm wide; the rate of accumulation depends on the airflow, fibre feed, cleanliness, yarn count, and whether the machine has a trash extraction device.

It is desirable to be able to spin at least one full doff without cleaning the rotors. For trash extraction machines 0.8% non-lint content in the feed sliver would satisfy this requirement, but 0.2% would be required for other machines. This means that if an existing cleaning line for ring spinning were used the non-lint content of the raw cotton would have to be not more than $2\frac{1}{2}$%, which means that about 80% of the world's cotton would be excluded from OE spinning, and this percentage would rise as the use of mechanical harvesting increased

There is no correlation between ginning method and dust accumulation in the rotor whereas there is close correlation between the latter and the harvesting method.

Trash extraction OE machines remove heavy trash particles such as husk, seed, and leaf fragments, but dust and fine particles are drawn into the rotor by the airflow which is necessary to prevent loss of fibre.

The use of trash extraction machines may permit the use of lower grades of cotton and even reprocessed waste, thereby permitting the economic advantages of producing upgraded yarns. In addition the maintenance of uniformly clean rotors limits the progressive deterioration of yarn quality and of end-breakages.

An important precaution is to use better cleaning during preliminary processing where removal of dust and of trash may be regarded as two distinct problems. The use of beaters and grid bars alone is inadequate because the removal of fine dust can only be achieved by suction; hence the use of fine tuft opening and intensive condensers is one way of improving cotton fibre preparation for OE spinning.

A further method is to use tandem carding with intermediate and final cruising rollers in conjunction with dust extraction equipment. This can give about 30% higher production than a single swift card, combined with greater trash and wax removal, better fibre individualization, parallelization and mixing, improved yarn strength, and about 40% of the spinning end-breaks compared with single high-production carding. Typical cleaning efficiencies are about 80% for a single card, and about 93% for a tandem card. Hence when spinning on a trash removal machine which has a cleaning efficiency of about 40%, approximately 12% of the original trash fed into the card enters the rotor with single carding, or 4% of the original trash with tandem carding. In addition to the improved cleaning, part of the benefit of tandem carding arises from the improved fibre orientation which tends to reduce fibre damage at the opening roller. The use of crushing rollers in carding also leads to a lower loss of fibre into the trash box of a trash removal machine and a reduced number of neps per gramme of yarn.

In the case of man-made fibres, although the problem of impurity accumulation in the rotor is not as acute as with cotton, nevertheless freedom from fused, undrawn, or over-length fibres is important, as well as lubrication which must not leave sticky deposits or powder on the machine parts. A trash removal type of machine may remove thick fibres and double-cuts and entangled fibres from man-made fibres without interfering with the normal fibre flow. High crimp synthetics are not really suitable for rotor spinning, and matt fibres have a severe abrasive effect with the danger that all thread guiding parts may be damaged in a very short time; the opening roller clothing must also be of sufficient hardness.

Sliver preparation for open-end spinning

The sliver feed to many rotor spinning machines with opening roller feed is usually about 4 ktex for most short staple fibres (or about 3 ktex for acrylic fibres, which tend to be bulky), although some machines have a feed of about 7.4 ktex.

Generally a finer sliver is used for spinning finer yarns. Slivers for most carpet yarn rotor machines may be up to 8 ktex; they must be prepared with a minimum of lubricant.

The rotor machine gives excellent intimate short-term fibre mixing and therefore is good for blends provided that the longer-term uniformity and mixing is adequate. Hence the early preparatory processes must provide autolevelling and maximum pre-mixing; this may determine whether one or two drawframes are required after carding for short staple fibres. Too few operations result in an inferior yarn quality — too many operations decrease the feed sliver cohesion. Satisfactory yarn strength and levelness is usually obtained most economically from two drawframe passages.

Feeding a majority of trailing hooks into the rotor spinning machine influences OE yarn strength less than it does in ring spinning, and it has little influence on OE yarn irregularity.

For semi-worsted type yarns used in upholstery, carpets, blankets, and curtains, spun from 60 to 125 mm, 9 to 20 dtex man-made fibre, the card may be followed by three intersecting gill boxes, the first with an autoleveller, or perhaps two gill boxes and one drawframe. Fewer doublings or a heavier feed sliver count gives poorer spinning results.

Because it is difficult to ensure an adequate supply of wool suitable for semi-worsted processing, carpet yarn spinners of 100% wool and wool-rich blends tend to retain the woollen system. Open-end yarns from semi-worsted preparation give a woollen type yarn appearance compared with a semi-worsted ring spun yarn, hence woollen carpet yarn manufacturers are interested in developments in OE spinning because of the potential benefits. One difficulty is that the material must have oil added to aid carding and drafting, but this must not accumulate in the rotor groove because it would cause the formation of a sticky deposit which would trap fine particles and cause a poor spinning performance.

Waste fibres such as cotton comb noils or card flat strips are as clean, fine, and strong, as the longer fibres from which they have been removed, but may be too short for roller drafting, a typical mean fibre length being 9 to 12 mm. In such circumstances the OE spinning machine may be fed direct by autolevelling-card sliver in which a small percentage of longer fibre has been blended. Unlike the ring spinning of carded cotton yarn, it may be better to feed a majority of leading hooks into the OE machine. Either double carding or an autolevelling card may be used to produce a sliver for direct rotor spinning but the disadvantage of such an arrangement is that the card production may be limited by the sliver thickness of about 4 ktex required for the rotor spinning machine with an opening roller feed. An alternative is to blend a minimum of 20% of carrier fibre longer than about 20 mm and have a drafting zone built on the card to apply a draft of 1.4 to 2.0; in this way the card can produce a sliver of about 7 ktex which is reduced to about 4 ktex in the drafting zone; fibre parallelization also may be improved in this way.

Spinning tension and fine count limit

For satisfactory performance the minimum mean number of fibres in the yarn cross-section should be about 100, or perhaps 80 under favourable conditions, and the maximum is about 500, or maybe 600 under favourable conditions. On the worsted system this would limit the spinning of 100% merino wool to relatively thick counts and has stimulated interest in blends with fine man-made fibres.

The fine count limit depends on the relationship between the tenacity of the formative yarn and the tension developed inside the rotor. The main forces involved are illustrated in *Figure 13.13*. The mean withdrawal tension is slightly influenced by air drag and largely determined by centripetal force—which is proportional to (rotational speed)^2, (rotor diameter)^2, and yarn mass.

According to H. Stalder (New Methods of Yarn Production, 157, Textile Institute, 1972) the actual tension at the collecting surface is very small, being about 1.4 times greater than the centripetal component of yarn tension, and the mean yarn withdrawal

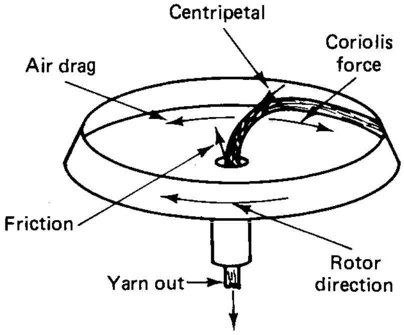


Figure 13.13 The main forces involved in rotor spinning

tension at the rotor centre may be about 10 times greater than that at the collecting surface; only a minor influence on yarn withdrawal tension is exerted by Coriolis forces, but the resistance to bending of the fibres, and by gravity.

The empirical formula $T = 0.72\, m\omega^2 R^2$ gives close agreement with practice, where T = withdrawal tension (N), m = yarn count (tex × 10^{-6}. i.e. kg/m), ω = rotor angular velocity (rad/s), and R = rotor radius (m).

Power consumption

Neglecting losses in the drives and ancillary power consumed such as suction, the power consumption of the rotor has a linear relationship with both the (rotor diameter)^4 and the (rotor speed)^3. Although data given by different authorities varies, the relationship is of the form shown in *Figure 13.14* and can be represented by the formula: $P = k \times d^4 \times h \times \omega^3$, where P = power consumption due to air drag, d = rotor diameter, h = rotor height, ω = rotor angular velocity, and k is a constant depending on the detailed machine design.

Hence the maximum economic speed may be lower than the maximum technically possible speed.

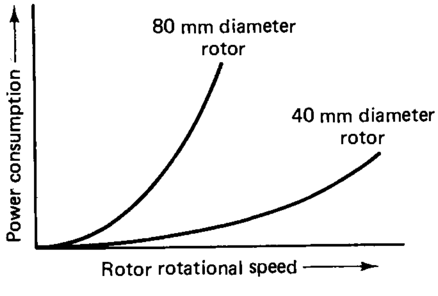


Figure 13.14 The relationship between rotor speed, diameter and power consumption

Approximately 60% or more of the total power is consumed by the rotors in OE spinning, compared with about 90% consumed by spindle rotation in ring spinning. For the same power consumption a rotor of about 65 mm diameter may rotate approximately three times faster than an equivalent ring spindle.

Rotor speed

Rotor speeds used in practice are determined mainly by economic factors, of which power consumption becomes dominant at high speeds, and by spinning conditions as indicated by the end-breakage rate and the yarn quality.

The general economic influence of rotor speed is similar in principle to that of spindle speed in ring spinning as indicated in *Figure.9.2.*

The optimum rotor speed at which the cost per kilogramme of yarn produced is at a minimum will increase as power costs are reduced, and will decrease as the capital cost of machines is reduced, although the total spinning costs will reduce in either case.

Higher speeds lead to an increased mean, and variation, of yarn withdrawal tension, a reduced elongation at break, and an increased variation of yarn tenacity, hence the statistical probability of an end-break increases. Yarn irregularity and general imperfections such as neps also increase with rotor speed, and the likelihood of yarn periodicity increases with the accumulation of particles at the collecting surface.

$$\text{Piecening efficiency} = \frac{\text{number of ends repaired}}{\text{number of repair attempts}}$$

and this decreases at higher rotor speeds because of the increased timing accuracy needed in the shorter time available. The maximum yarn speed at which manual piecening efficiency is satisfactory is about 90 m/min, hence at higher speeds some automatic form of piecening is necessary.

Analysis by the writer of recommended practical rotor speeds yields the formula:

$$N = \frac{3400 - 10\,|100 - D|}{D} \pm 20\%,$$

where N = rotor rev/min × 10^{-3}, and D = rotor diameter (mm). The range of speeds given by the formula for each diameter does not indicate the maximum permitted by drive and bearings, but rather the speeds being used in practice. Much lower speeds are used for long staple spinning with large diameter rotors, largely because of the influence of diameter on power consumption, and also because of the consideration of rotor stresses. Expressed in graph form the shape of the curves is not likely to alter greatly in the future; at most a general shift to higher speeds might be expected.

The benefit of higher rotor speeds compared with ring spindle speeds is eroded to some extent by the need to insert up to 25% more twist into some OE yarns compared with ring spun yarns.

Rotor diameter

From the product point of view the rotor diameter should be as large as possible in relation to the fibre length, but in practice the diameter restricts the technically possible and the economically acceptable speed because of power consumption considerations. On the other hand small diameter rotors may require cleaning more frequently.

Fibre length must be selected for end-product quality. For example, although good yarn test data and appearance may be obtained from noils and re-processed cotton waste fibres, for some end-uses inferiority may become evident after laundering compared with yarn from, say, middling cotton. Similarly carpet yarns can be spun from relatively short fibre lengths, such as 60 mm, but performance would be inadequate compared with 120 mm mean fibre length.

Consequently, because rotor diameter is closely related to fibre length, machines have been developed to process yarns intended for particular end-uses — alternatively machines with interchangeable parts may be used.

Machines have been made with the following rotor dimensions: 55 to 65 mm diameter for cotton and short staple man-made fibre in the 1.6 to 3.3 dtex range, commonly for spinning yarns up to 100 tex, and sometimes to 200 or 250 tex; about 100 mm diameter for 3.3 to 11.0 dtex fibre for home furnishing yarns from 60 to 500 tex; and 130 mm diameter for 8.9 to 16.7 dtex fibre for carpet yarns from 200 to 1000 tex.

The following formulae give a guide to the normal relationship between the rotor diameter and fibre length:

$$D_{\max} = D_{\min} + 20$$

$$D_{\min} = L + C$$

where L = maximum fibre length (mm), $C = \frac{1}{2}(60 - L) > 0$, $D_{\max}$ = maximum rotor diameter (mm), $D_{\min}$ = minimum rotor diameter (mm), and C is a correction which applies only to fibre lengths shorter than 60 mm.

Spinning twist and end-breakages

The twist inserted must develop sufficient 'yarn torque' in the gyrating formative yarn to cause it to rotate on its own axis to form a finite twisted length of yarn in order to gather the fibres together at the collecting surface groove. This means that if the twist is less than a certain critical amount the yarn formation process can not continue even though the yarn strength at that twist in itself would be adequate. On the other hand too much twist would form an excessive length of twisted yarn against the collecting surface, causing other fibres to be held on the outside of the already twisted section and thereby increasing the number of wrapper fibres.

Commercially most yarns are spun with twist to give approximately maximum strength, and this is higher than the minimum possible except at high rotor speeds. At low speeds the yarn torque required at first decreases as rotor speed is increased due to more compact fibre packing at the collecting surface. Hence when working at low rotor speeds, within limits an increased rotor speed gives an improved spinning performance, increased yarn strength, or the possibility of using a lower spinning twist.

However, once maximum compactness has been reached any further rotor speed increase require more twist to provide the yarn torque necessary to overcome the increased centrifugal force — hence the minimum possible twist then increases as rotor speed increases as shown in *Figure 13.15*.

Maximum twist is limited by the fact that at the high twist levels involved, any further increase of twist beyond the optimum causes a reduction of yarn strength as shown in *Figure.9.5*. Consequently in order to give increased yarn strength, the maximum possible twist level drops rapidly at high rotor speeds with the result that the range of possible twist becomes more restricted at higher speeds as shown by the shaded area in *Figure 13.15*. Hence as rotor speed is increased a point must be reached at which spinning becomes impossible because the minimum and maximum twists coincide as shown at A in *Figure 13.15*, this is probably about 100 000 rev/min when processing 32 mm cotton to 37 tex with a 46

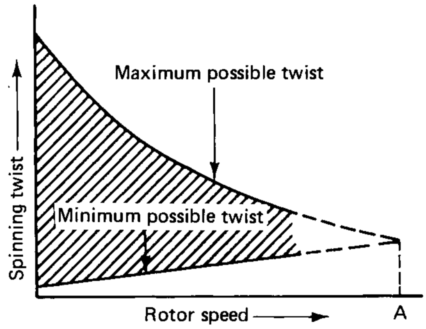


Figure 13.15 Range of possible spinning twists in OE spinning

mm diameter rotor (P. Grosberg, Sympoisium, Bradford University, 1974). For similar reasons at high rotor speeds it is not possible to spin yarns as fine as those which can be spun at lower speeds. Hence for some fibres there is a maximum rotor speed beyond which there is an increased end-breakage rate even if the spinning twist is increased.

The absence of a uniform helical twist in OE yarns may make it necessary to insert more twist than would otherwise be necessary, hence in general OE spinning twists are about 25% higher than equivalent ring-spun yarns both in cotton yarns, and in long staple yarns, but this does not necessarily apply to all fibres, and in the case of wool fibres some OE yarns have been spun with twist similar to that used for ring-spun yarn.

The twist in the gyrating formative yarn inside the rotor is usually higher than the final yarn twist because as they yarn rotates it *rolls* around the end of the yarn withdrawal tube, producing a false-twist effect which is in the same direction as the final twist inserted by the rotor. The amount of false-twist generated depends on the design and surface of the yarn withdrawal tube; a higher false-twist effect may permit a lower final yarn twist for satisfactory performance.

This has proved to be particularly important in rotor spinning of wool fibres where a knurled bell-shaped yarn withdrawal tube may be advantageous. It is important that the surface frictional effect of the tube should remain unchanged over long periods of use.

A suitably shaped withdrawal tube of the type shown in *Figure 13.10* also serves as a barrier between the incoming fibres and the gyrating yarn thereby reducing the incidence of wrapper fibres.

When end-breaks occur in OE spinning a break with a tapered tail as long as the rotor circumference indicates insufficient twist, whereas an abrupt termination is more typical of a break caused by excessive twist.

As in ring spinning, an end-break occurs when yarn tension exceeds yarn strength for a sufficient period of time. Therefore mean yarn strength must exceed mean yarn tension by a factor which depends mainly on the standard deviation of yarn strength. There are two main reasons why the factor is less than that required in ring spinning: firstly because in OE spinning the random tension variations are proportional to the short-term variations in yarn mass whereas in ring spinning the variations in yarn mass have a smaller influence due to the balloon yarn length being greater than that of the gyrating yarn length in OE spinning; and secondly because systematic variations of tension in ring spinning are related to variations of the balloon length and package winding diameter, whereas in OE spinning the mean yarn tension remains constant throughout the build of a package.

The use of higher speeds in OE spinning increases the standard deviation of both yarn strength and yarn tension so that at higher speeds a greater factor of (mean strength/mean tension) is required. Hence the mean and variation of yarn strength has an important influence on maximum rotor speed because of its effect on the end-breakage rate.

End-breakage rates within the limits of about 5 to 15 end-breaks per 100 rotor-hours are acceptable in OE spinning, and with trash extraction machines, rates lower than 2 end-breaks per 100 rotor-hours may be achieved when spinning cotton. From the point of view of length of yarn produced per break, the equivalent ring spinning end-breakage rate would be much lower, being approximately proportional to spindle speed.

General features of rotor spinning machines

Besides the usual facilities for altering rotor speed, opener speed, draft, and twist, many machines provide additional facilities of the following types:

(1) Machines may be made single-sided or double-sided. Single-sided machines may be fed from existing drawframe or card sliver supply cans approximately 400 mm diameter × 1200 mm high located in a free-standing creel, with a downward flow of fibres from the rotor to the winding head. Such an arrangement is more suitable for coarse counts.

(2) Double-sided machines occupy less floorspace for a given output and are designed to feed from specially produced small cans as shown in *Plate 17* (e.g. 300 mm diameter × 760 mm high); in this case an upward fibre flow from the rotor to the winding head is appropriate as shown in *Plate 25*. The use of upward or downward fibre flow makes no difference to performance because the gravitational forces involved are relatively small.

(3) Yarn waxing may be carried out on some rotor machines.

(4) Provision may be made for yarn clearing at the winding head.

(5) There may be pneumatic transfer of trash to a common container at the end of the machine with duplicated waste filter units which permit cleaning without interruption of production.

(6) Yarn detection must be provided which stops the feed sliver when an end breaks. This leads to a significant reduction in the amount of spinning waste — an important economic advantage compared with ring spinning. On machines with an external air source this may be combined with automatic individual rotor braking, thereby releasing any accumulated particles into the air duct.

(7) Yarn length counters may actuate signal lamps to indicate the need for doffing, with an automatic synchronized stop if too long an over-run is permitted by the operative.
(8) Air suction 'third hand' may be provided whereby spinning continues during doffing, but the spun yarn is held by air suction so that on completion of doffing the yarn forms the tail at the end of the package tube. With such an arrangement, doffing can take about 30 seconds including rotor cleaning with a brush.
(9) Continuous operation can be achieved by having a package transfer arrangement with two winding heads provided for each rotor so that full packages can be removed while the next package is being formed; this method may be most advantageous on long staple spinning machines for thick carpet yarns.
(10) Machines may provide automatic conveyance of the heavy full packages to the required destinations as indicated in *Plate 25*.
(11) The stop-start cycle may involve the formation of a loop of yarn when the machine stops; the loop is automaticallly fed back to form a piecening on re-starting, when the rotors, beaters, and suction system are brought up to normal running conditions in an automatically controlled sequence — this facility is frequently described as automatic spinning-in.
(12) Automatic cleaning and piecening at predetermined time intervals can be used as shown in *Plate 25*.

Economic aspects of rotor spinning

Besides the influence of economic factors on rotor speed already mentioned, it is of interest to compare the economics of rotor spinning with ring spinning.

A detailed comparison in absolute units soon becomes out of date although the general principles remain unaltered. *Figure 13.16* shows the general differences between the costs of rotor spinning and ring spinning (including roving) for a range of yarn counts spun from short staple fibres.

Floorspace requirements are greater for ring spinning, and increase disproportionately at finer counts.

Approximately $2\frac{1}{2}\%$ less waste is made in OE spinning ($1\frac{1}{2}\%$ compared with 4% for ring spinning including roving), the saving being approximately constant at all counts.

Power costs are less for fine count ring spinning but they rise rapidly for thick counts, whereas the power for OE spinning is hardly influenced by count or package size.

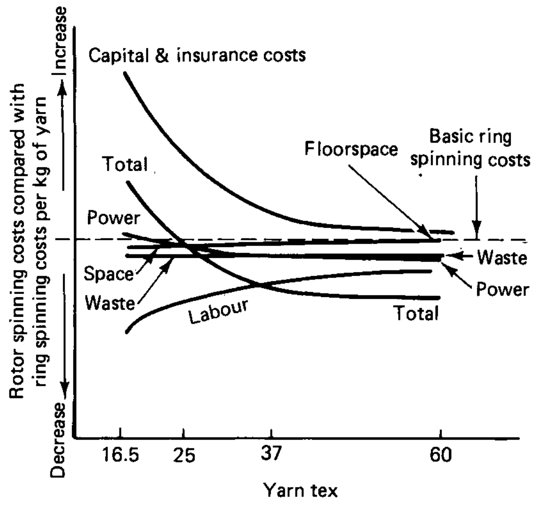


Figure 13.16 General comparison of ring spinning and rotor spinning costs

Labour cost savings are relatively higher for OE spinning at fine counts because of the advantages of large packages and no roving process; working conditions are generally cleaner and more pleasant with OE spinning, and the end-breakage rate per unit of production is lower. Rather fewer than half the number of workers (both direct and indirect) are required to obtain the same output of 30 tex cotton yarn.

Capital and insurance costs are greater for OE spinning and increase disproportionately for finer counts because of the lower production rate.

Total costs are equal at about 24 tex (the 'break-even' count) for the assumptions on which *Figure 13.16* is based; for finer counts higher capital and power costs exceed the savings in labour costs.

An increase of capital costs or power costs would increase the break-even count whereas an increase in labour costs or the elimination of winding, which is possible in about 60% of cases, particularly in vertical organizations, would have the opposite effect.

Hence the break-even count depends very much on detailed circumstances: 30 or 37 tex with rewinding, and 20 or 25 tex without, are likely for short staple spinning. Because the capital cost of the original self-pumping type machines is lower than that of the trash extraction machines, the use of tandem carding to prepare for spinning on the former types may even reduce the break-even count to about 15 tex for cotton yarns.

In the case of cotton, cheaper raw materials might be used than in ring spinning, including noils, provided that they are well cleaned.

For man-made fibre carpet yarns, labour and floorspace costs are greatly in favour of OE spinning, and capital costs are similar. Only power costs exceed ring spinning costs for fine yarns, but as power accounts for only about 6% of the total cost the over-all break-even count is about 150 tex compared with ring-spun semi-worsted, i.e. OE yarns thicker than about 150 tex are cheaper; count for count, woollen-spun yarns are more expensive than semi-worsted yarns. For semi-worsted type yarns the productive efficiency of OE spinning is about 95% compared with about 80% for ring spinning.

Besides the technological and economic factors mentioned previously, an important but difficult to quantify consideration is that of product value. Compared with ring spinning the advantages of package form and size, aesthetic properties of the product, strength, durability, and subsequent processing advantages may well be of greater importance than the technological factors, in determining the economic benefits of open-end spinning.

Open-end yarn end-uses

Open-end yarns differ from ring-spun yarns in many respects. This does not mean that they are either superior or inferior, but it does mean that they will produce different characteristics in the end-product. Open-end yarns may be used to advantage in fabrics where regularity and cleanliness are of prime importance, where price may be more important than other considerations, and where the characteristics of OE yarns are an advantage.

OE yarns can be used in pile fabrics, apparel, household, and some industrial uses. The following have been described as satisfactory end-uses for OE yarns: heavy weight sateens and poplins; corduroy; velveteen; continuous filament warp/spun weft fabrics; rainwear; denims; jeans; drills; sheets and pillowcases; bedspreads; printed fabrics; curtains and window blinds; upholstery; filter cloths and cleaning cloths; dress goods and shirtings; single and double jersey; raschel; rib interlock and fully fashioned underwear; rugs; carpets; blankets; winceyette; surgical lint; terry towel; diapers; hand-knitting; woollen-type outerwear fabrics; short fibre and variable-length blends.

Open-end yarns generally are *not* suitable for combed yarn applications, yarns requiring high strength, applications where lustre or low twist is required for aesthetic reasons, two or three colour mottle yarns, fine counts, or fabrics requiring a soft handle.

OE yarns should not be mixed indescriminately with ring-spun yarns although ring-spun warp and OE weft is satisfactory.

Ring spinning remains a formidable competitor for OE spinning; it is simple to operate and much more flexible than OE spinning, producing stronger yarns with parallel fibres, particularly in the fine count range.

Further reading

Break Spinning, Shirley Institute, Manchester (1968)

DYSON, E. (Ed), *Rotor Spinning*, Textile Trade Press, Stockport (1975)

NIELD, R., *Open-end Spinning*, Textile Institute (1975)

14

REPCO SELF-TWIST SPINNING

The Repco self-twist system was initially intended for the production of two-fold worsted weaving yarns, but it has since been developed further.

The principle of ST spinning

The yarn is made by inserting twist in alternating directions so that a length of yarn containing S twist is followed by one containing Z twist, and vice-versa. The yarn itself can be twisted in this way without the consequent limitations associated with package rotation and balloon formation which apply in ring spinning.

Two such strands are brought into contact with each other along their length as they subsequently untwist, causing them to wrap around each other, thereby forming an alternating-twist two-ply structure in which the torque of the two strands is balanced by the folding torque of the pair; the process is defined as self-twisting.

It is important to note that at the point where the direction of ply twist changes, tangential slippage of the two strands must be prevented by the intermeshing of protruding fibres; difficulty would be encountered if, for example, two multifilament smooth continuous filament yarns were self-twisted.

Self-twist yarn

Self-twist yarn is essentially a two-ply structure (although in principle there could be more than two components) in which the self-twist stabilizes the twist and strength in the structure so that yarns can be made to withstand loads up to 60 mN/tex in 100% wool, or higher with synthetics.

It is important to appreciate that the application of tension to an ST yarn causes the zero-twist points to rotate so that the subsequent amount of self-twist depends on tension and the viscoelastic properties of the fibres.

Twisted self-twist (STT) yarn

Normally for weaving purposes an ST yarn will have twist inserted so that the STT yarn finally contains uni-directional twist; there will be cyclic twist variation in such a yarn.

The self-twist spinning machine

The Mark 1 version of the machine has four delivery packages in an over-all floorspace of 1475 mm × 660 mm giving an output equivalent to 100 ring spindles when spinning R63 tex/2 yarn. The Mark 2 version, which has five deliveries in an over-all floorspace of 2464 mm × 730 mm, and gives about 70% more production than the Mark 1 machine, has not been adopted widely.

The machine is made with only a small number of deliveries because an end-break stops the whole machine and this would lead to an unacceptably low productive efficiency if there were a large number of deliveries.

The system was originally recommended for producing weaving yarns from R110 tex/2 down to the fine count limit of the material being processed. Suitable materials include 100% wool of 34μm mean fibre diameter (i.e. 48/50's wool quality) or finer with an oil content not exceeding $1\frac{1}{2}$%, preferably the mean fibre length should not be less than 50 mm

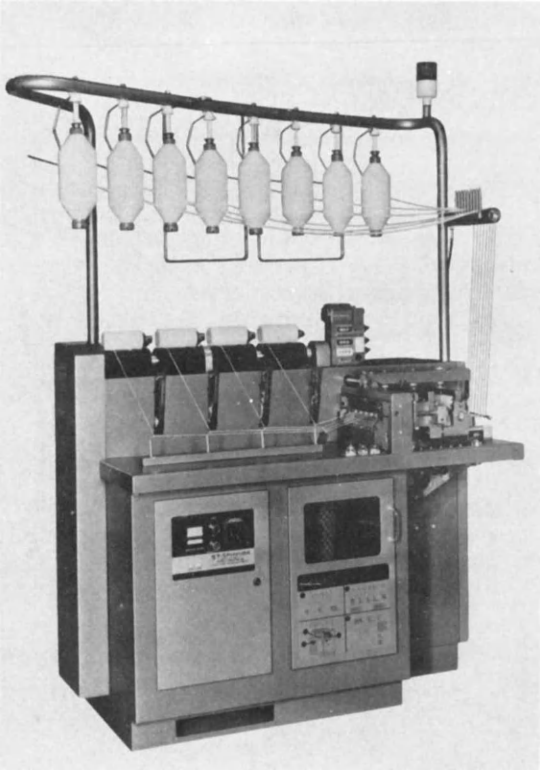


Plate 29. Self-twist spinning machine. The umbrella creel accommodates eight supply rovings which pass alongside each other through the double-apron drafting zone before alternating twist is inserted by the reciprocating twisting rollers. Adjacent pairs of single strands are combined to provide four packages each containing a two-strand self-twisted yarn which can be used directly as a feed to a two-for-one folding machine. Delivery speed is 220 m/min irrespective of yarn count. Courtesy of Platt Saco Lowell (UK) Ltd

in blends of wool and man-made fibre of 3.3 to 6.7 dtex.

The following are the main features of the machine:

Supply creel

A minimum friction umbrella creel accommodates the rovings. Bobbin lead rovings, which can withstand the high unwinding tension caused by rapid acceleration at start-up, are preferred with a maximum roving twist for wool of $20.8/\sqrt{(\text{count (ktex)})}$ t/m; twist about 30% lower may be used for man-made fibre. As an alternative to cone rovings the creel can be designed to accommodate twist-free double-mêche rovings in which case adequate roving strength of about 400 mN must be ensured by suitable rubbing conditions at the roving operation.

It is most important that rovings should be fault-free in order to minimize machine stoppages. Rovings produced on a flyer lead drawing box are not suitable because the minimum possible twist is too great for the drafting zone.

Drafting zone

The drafting zone is a modified double-apron system with back rollers, aprons, and front rollers. The main features of the drafting zone include:

(1) The back and front bottom rollers are spirally fluted.

(2) The eight (Mark 1) or ten (Mark 2) rovings follow parallel paths, 19 mm apart with a roving traverse of 6 mm, between one pair of wide aprons. The gap between the top and botton apron can be adjusted at the front roller end by using different coloured spacers.

(3) The top front roller of the drafting zone is grooved so that a shroud can separate the adjacent ends and prevent fibres from being trapped in two neighbouring strands. Such fibres may be called 'linking fibres' (the alternative name of 'bridging fibres' might be confused with open-end spinning). Linking fibres may lead to increased machine stoppages; their frequency is very dependent on fibre diameter, and is virtually zero for wool fibres finer than 23 μm.

(4) Break draft is fixed at 1.1 Total drafts within the limits of 18 to 45 are selected from a range of 49 ratios by adjustment of two knobs. Optimum draft is in the region of 25 for wool and 40 for synthetics.

(5) Ratch is adjustable from 216 to 273 mm in steps of 19 mm without the use of tools or gauges.

(6) Each strand passes through a flume 0.7 mm wide between the aprons and the front roller nip to restrict the strand width and minimize the amount of fly-waste produced.

(7) Roller weighting is by adjustable spring pressure from a pendulum weighting arm which is pneumatically locked in its working position while the machine is running.

Twist insertion

After the strands leave the drafting zone they pass between a pair of synthetic-rubber covered rollers which cooperatively rotate and axially oscillate in opposition. Thus the strand is gripped at the twisting point between two elastomeric surfaces which carry the strand forward and simultaneously rotate it about its axis in alternating directions. The rollers are mounted on externally pressurized internal air bearings which permit virtually frictionless motion both rotationally and axially and appear to have an almost indefinite life provided the air is clean and at correct pressure when in use — the latter is ensured by having a pressure limit switch: the advantages of low friction, stable roller position, and no possibility of lubricant contamination stem from this arrangement.

The upper roller bearing is mounted on a pivot enabling the upper roller to rest on the lower roller under selected gravitational loading so that slight temperature changes and synthetic-rubber expansion will not alter the rate of twist insertion. A hydraulic shock absorber damps rapid movement or vibration.

Epicyclic drives are used to transmit both the rotational and the simple harmonic oscillatory motion to the rollers. This arrangement restricts the mechanism to a single stroke amplitude of 75 mm and a calculated yarn delivery per stroke of 220 mm, but permits 1000 oscillations/min. (Mark 1).

The rollers are 40 mm diameter, 229 mm long (Mark 1), and are at a nip distance of 50 mm from the drafting zone front roller nip.

For a given roller pressure, increased speed gives lower twist insertion, hence a solenoid is fitted to reduce the load applied when the inching button is used to run the machine at the reduced delivery speed of 22 m/min. Twist differences are minimized during starting and stopping by the effects of the hydraulic damper attached to the upper roller assembly combined with the rapid acceleration during starting and deceleration during stopping.

For a given applied load, the twisting rollers automatically insert more twist into a finer yarn. This is apparent when the simple theory of the rolling of a strand of circular cross-section between the rollers is considered:

$$\text{Strand twist} = \frac{S}{2\pi r}$$

where S is the roller stroke and r is the strand radius, hence assuming constant yarn density,

$$\text{Strand twist} \propto \frac{1}{\sqrt{\text{count}}}$$

Within limits the amount of twist inserted can be raised by increasing the roller loading; this method is used to alter the twist insertion rate without altering the speed of delivery. The amount of twist is also influenced by the number of yarns being spun, hence when running out a fibre lot, if a reduced number of yarns is being delivered, the roller loading must be decreased accordingly. Increases in roller loading in excess of approximately 3 N does not give any significantly higher twist level for fine yarns, but a higher load is required to obtain a given level of self-twist when spinning thick counts from coarse fibres, and loads in excess of 5 N may be used.

It is significant that the same high delivery speed can be maintained for any yarn count with virtually the same power consumption. Therefore when spinning finer counts the ST system becomes increasingly favourable compared with ring spinning where lower delivery speeds must be used in order to insert the higher amounts of twist required.

Removal of fly waste

The percentage of fly waste released is similar to that in conventional spinning, but because of the very high speed of yarn delivery, the amount of fly waste per unit of time and space is very high. For this reason a shroud is provided in the twisting region to keep all the rollers and their surrounds free of fibres. Broken ends are collected by a suction slot.

Yarn convergence guides and yarn phasing

Ceramic guides are used to bring the two strands together as they emerge from the oscillating rollers (*Figure 14.1*), in this way the path length of one strand (b) is increased relative to the other (a) so that the two strands converge partially out of phase as shown in *Figure 14.2*. The zero ply twist occurs at points where the two strands have opposite directions of twist within them. On the other hand, zero twist in one strand occurs alongside a twisted section of the other strand, which therefore maintains the ply twist at that point. A yarn of this type is called a phased ST yarn, and in general it has no particular zones of weakness, therefore it breaks at any random point along its length.

The amount of phasing in the yarn is expressed in relation to the full cycle length of 360°. Phasing is

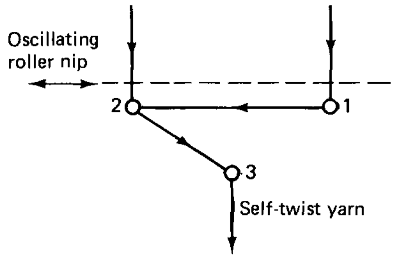


Figure 14.1 Yarn convergence guides

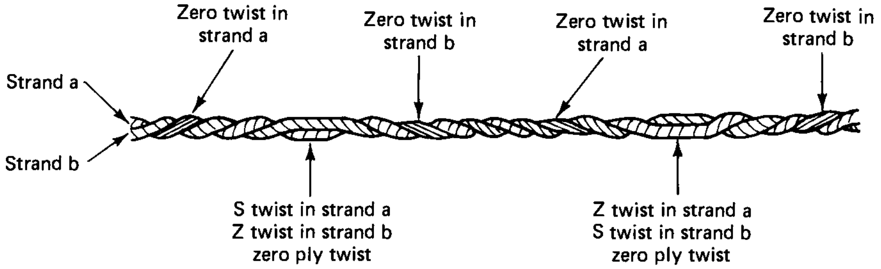


Figure 14.2 Phased ST yarn

calculated from strand path length differences, but in the yarn the phase actually obtained is lower due to twist re-distribution between the points of convergence and the twisting rollers. With a 220 mm cycle length a displacement of 22 mm has been adopted as standard for 100% wool on the commercial machine. This corresponds to a calculated phasing of 36°.

When low twist is inserted, ST yarn becomes much weaker than an equivalent ring-spun two-fold yarn. On the other hand when excessively high twist factors are used, yarn strength decreases in the same way as conventional yarns, due to the over-twisting effect described on page 106.

Yarn delivery

From the convergence guides each of the self-twisted yarns passes to a separate grooved traverse roller cheese winder making parallel cheeses 127 mm wide × 152 mm diameter up to a maximum diameter of 254 mm.

Winding tension should be about equal to: count (tex) × 3.3 mN; excessive winding tension reduces the ST level.

General features of the St spinning machine

The following features have been incorporated in the machine:

(1) A photoelectric stop motion for the feed ends.
(2) Delivered yarn end-break detectors.
(3) An air bearing pressure-failure stop switch operating at 235 kPa.
(4) A yarn length stop motion.
(5) Machine guard interlock switches.
(6) An air suction failure stop switch.
(7) Controlled acceleration and braking at starting and stopping.
(8) Warning lights to indicate the cause of a stoppage.

Advantages of self-twist spinning

The following items are compared with worsted ring spinning unless otherwise stated:

(1) Low yarn tensions — because of freedom from balloon formation.
(2) Low end-breakage rates — spinning breakdown is nearly always caused by gross roving faults, hence a high standard of roving is essential for the ST process.
(3) The spinning count limit is about 15% finer — for merino wool this means a lower limit of about R30 tex/2. There should be at least 35 fibres per strand cross-section for 100% wool, or 32 fibres per strand for 100% man-made fibres, compared with about 40 fibres in a ring-spun yarn.
(4) Only about 45 % of the power consumption is used to produce the same output.
(5) Twist is inserted at a high speed.
(6) The yarn delivery speed is 220 m/min (Mark 1) regardless of yarn count or amount of twist inserted.
(7) Floorspace is only about 20% for the same output, depending on yarn count.
(8) The two-fold yarn delivery is wound in cheese form; it may be regarded as an assembly-wound package for subsequent twisting without re-winding being necessary, although lubricant should be added to minimize fly waste in two-for-one yarn folding.
(9) Labour requirement is approximately only 60% of that of ring spinning — one operative can mind about 8 to 12 machines with a machine productive efficiency of about 82 to 88% over the count range R100 tex/2 to R 28 tex/2 respectively, including creeling, winding, and doffing to produce the equivalent of about 750 to 1500 ring spindles, depending on yarn count.
(10) Working conditions are clean and quiet.
(11) A maximum of about 0.7% of fly waste is produced on all counts of 100% wool yarns; suction cleaning is provided to prevent fly waste contamination of the yarn or transfer of fibres to adjacent machines.

(12) Average production costs for all counts are only about 78% of conventional ring spinning per kilogramme of yarn produced.
(13) Less spinning waste is made.
(14) The machine does not require major alterations, such as different ring diameters or different travellers, to enable a wide range of yarn counts to be spun.
(15) Maintenance requirements are only about 2% of ring spinning for an equivalent output.
(16) Stocks of material in work can be reduced.
(17) ST yarns in knitted fabrics give a soft full handle, stitch clarity, and absence of fabric skewing.

Limitations of the self-twist system

(1) Yarn clearing can only be applied to two-fold yarns, resulting in two-fold knots.
(2) Although ST yarns can be made strong enough for weaving, in most constructions they give a streaky appearance due to the cyclic twist reversal and the parallel strands at the change-over points. ST yarns of sufficient strength can be used successfully as weft in warp-faced structures.
(3) STT yarn appearance is not acceptable in certain fabric structures, particularly with some contrasting colour twists, hence yarns must be directed into suitable fabrics; this is more easily done in a vertical organization.
(4) STT yarns are not suitable for knitting because:
    (i) minimum folding twist is restricted to a relatively high amount, and
    (ii) cyclic twist variation causes variable stitch distortion. The stress dependence of the ply twist of the basic ST yarn structure is the major reason why such yarns are not satisfactory for knitted structures. It is not possible to introduce the yarn into a knitted fabric with the ply-twist/strand-twist ratio corresponding to the wet-relaxed fabric state.
(5) ST yarn strength may be insufficient with a mean fibre length shorter than 50 mm.
(6) ST yarns are not strong enough to withstand the tension imposed at the first stage of the Hamel two-stage system of yarn folding because the low rate of twist insertion weakens the ST yarn. However ST yarns can be processed on an uptwister such as the second stage of the Hamel process provided that the packages can fit the spindle and container.

Self-twist yarn definitions

The twist distribution in ST yarns is approximately sinusoidal because of the harmonic motion of the twisting rollers. Consequently the twist relationships in phased yarns are complex. Although simplified relations are not scientifically correct, they do provide a means of understanding ST structures.

Cycle length

Two consecutive zones of S and Z twist (which are of equal length), plus their associated zones of zero twist, comprise one cycle length. On the commercial machine this has been standardized at 220 mm.

Self-twist per half cycle

This is the number of turns of ply twist per half cycle; it is easily measured under no-load conditions from yarn gripped at two adjacent twist change-over zones.

Average self-twist

This is the number of turns of self-twist in one twist zone, divided by the nominal length of that zone. Because the twist distribution in self-twist yarns is approximately sinusoidal, average twist is used as a convenient method of expressing the amount of twist.

Self-twist factor (STF)

STF = average self-twist (t/m) × $\sqrt{}$count (tex)

STF is more convenient to use than absolute values of twist because STF is almost independent of yarn count when the twist insertion roller conditions are kept constant. It is suggested that STF = 1540 for initial trial spinning conditions for 100% wool; it may then be necessary to increase or decrease the STF according to the yarn strength actually obtained. Synthetics and blends usually have adequate strength with lower values of ST when they are to be made into STT yarns. It should be noted that twist factors can be added in the same way as absolute values of twist can be added.

Self-twist yarn count

It is usual to emphasise the two-strand structure of the yarn by writing the fold-to-single tex notation (e.g. R30 tex/2). It is necessary to draft an ST yarn to about 5 to 10% finer than the ultimate yarn count, because of length contraction due to twist insertion and relaxation.

Twisted self-twist yarn (STT)

Using a conventional yarn twisting operation, a suitable amount of uni-directional twist can be inserted to produce STT yarns suitable for use in many fabrics.

Pairing twist (PT)

As uni-directional twist is added to a self-twist yarn, initially the twist in one zone increases and the twist in the other zone decreases. This process is illustrated in the idealized progressive sketches shown in *Figure 14.3* where (a) represents the original ST yarn. The twist displacement continues through (b) until there is a section of yarn in which the two strands lie parallel as shown in (c); this condition is called 'pairing' and the amount of uni-directional twist which has been added is called 'pairing twist'. Yarn in this form would result in streaky fabric with patterning caused by the periodic twist variation.

Further addition of twist forms a uni-directionally twisted yarn as shown at (d) which still has noticeable twist variation, and then finally yarn as shown at (e) where the variation, although still present, is less apparent.

In any yarn, a given increment of twist, changes the twist angle by a large amount when the twist is low, but much less when the twist is high. Consequently after twisting up to pairing twist level, a given increment of twist changes the ply twist angle of the high-twist zones much less than that of the low-twist zones. Thus the twist angles of the two zones become more near equal. This occurs rapidly at first, but progressively diminishes.

In practice the twist changes in an ST yarn do not occur in such an orderly manner as *Figure 14.3* might suggest, because pairing tends to appear in a short section of the yarn, moving to another point as further twist is added. This is because the original approximately sinusoidal distribution has the uni-directional twist uniformly superimposed along it.

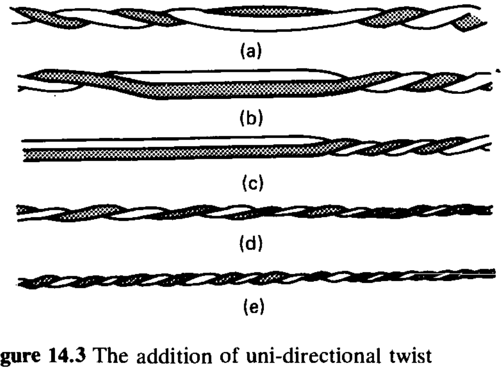


Figure 14.3 The addition of uni-directional twist

Pairing twist factor (PTF)

This is the minimum amount of uni-directional twist needed just to remove the opposite direction of self-twist; it is expressed in the form of a twist factor:

PTF = pairing twist (t/m) × √count (tex)

The relationship between STF and PTF

Extensive research has shown that on average

PTF = 1.55 × STF

Individual yarns have been found which differ significantly, but the above is a reliable practical guide. This is very useful because direct measurement of PTF is tedious and inaccurate. At the same time PTF must be known in order to determine the required added twist.

Added twist factor (ATF)

This is the total added uni-directional twist in an STT yarn expressed as a twist factor:

ATF = total added twist (t/m) × √count (tex)

Relationship between PTF and ATF

Experience has shown that for 100% wool yarn there is an optimum added twist corresponding to:

ATF = PTF + 880

for yarns to produce fabrics with characteristics similar to those of conventional woven worsted suitings. Lower twist gives patterning, and higher twist causes streakiness because of the complex interactions between the strand twists and ply twist at different points along the yarn. In one zone the original strand twist is in the opposite direction to the added twist while in alternate zones both ply and strand twists are in the same direction. The amount of added twist is critical to both yarn and fabric appearance and it must never be reduced by more than 8% unless there is a corresponding reduction of self-twist.

Increased self-twist or increased added twist increases the difference in apparent cross-sectional thickness between the two zones. Yarn diameter effects and differences in yarn configuration in fabrics cause streaks to appear in much the same way as with conventional thick and thin yarns.

Fortunately the recommended amount of added twist corresponds to the twist required for maximum yarn tenacity ; a low level of added twist also keeps the uni-directional twisting costs to a minimum.

The ATF is, therefore, determined from the easily measured self-twist per half cycle. The suggested initial value of self-twist per half cycle and the corresponding added twist for a range of yarn counts can be calculated from the following formulae:

Recommended self-twist (turns/$\frac{1}{2}$cycle) =

$$\frac{170}{\sqrt{\text{count (tex)}}} = T$$

(this corresponds to an average self-twist of

$$\frac{1540}{\sqrt{\text{count (tex)}}}\ \text{t/m})$$

Added twist = pairing twist + twist angle component

$$\text{Pairing twist (t/m)} = \frac{T \times 1.55}{0.11} = \frac{T}{0.071}$$

where 0.11 is the half-cycle length, and 1.55 = $\frac{\text{PTF}}{\text{STF}}$

$$\text{The twist angle component} = \frac{880}{\sqrt{\text{count (tex)}}}$$

The twist angle component is the amount of twist over and above pairing which is required to make the ply twist angles more similar to each other in the two zones. It follows from the above that:

$$\text{Added twist (t/m)} = \frac{T}{0.071} \quad \frac{880}{\sqrt{\text{count (tex)}}}$$

In certain fabrics such as high twist crêpe effects, or those with a milled finish which have less critical twist requirements, the twist ratios may be considerably different from those outlined above.

ST requirements for STT yarns

STT yarns made with a low added twist from ST yarns with a low STF have a low tenacity, but the tenacity rises at higher added twist levels. This does not apply to STT yarns made from ST yarns with high STF, and furthermore high uni-directional twist is necessary, which is costly; hence it is important to adhere closely to the recommended relationship between self-twist and added twist.

It is apparent that for STT weaving yarn purposes an ST yarn with a low STF is required. In practice a sample of ST yarn should be made with self-twist = $170/\sqrt{(\text{count (tex)})}$ turns/half cycle, and then tested for strength. If necessary the self-twist is then adjusted to give a yarn tenacity of about 20 mN/tex which is the minimum acceptable yarn tenacity to withstand the twisting operation.

As with conventional yarns an undue increase in uni-directional twist results in a reduction of yarn strength; yarn strength may also be influenced by the type of fibre lubricant used.

Recommended processing sequence for STT yarns

(1) Spin on to cheeses.
(2) Twist insertion. ST yarn must be withdrawn over-end due to the weakness of the ST yarn. The ST yarn cheese can be placed direct on the spindle of a two-for-one twisting operation.
(3) Relax by steaming on the twisted package.
(4) Wind and clear.
(5) Normal weaving preparatory processes.
(6) Weaving.

The use of self-twist yarns for knitting

Self-twist yarn is, by definition, a balanced twist yarn. Development work has shown that it can be used satisfactorily in many knitted structures without the addition of uni-directional twist.

Nevertheless under some conditions of lighting it is possible to see differential light reflection effects caused by the different twist directions. In solid-shade fabrics with single-feed knitting it may cause an irregular appearance when viewed from certain angles. The use of multi-end feeding or coloured fabric designs, either printed or jacquard, conceals the effect.

An increased amount of self-twist is needed for yarns which are to be used in knitted fabrics in order to give a yarn tenacity of about 35 mN/tex.

The ST yarns used for knitting may be regarded as forming two main groups:

(1) High bulk acrylics

The principles of bulked acrylic yarn production are described in Chapter 22.

In this case the recommended twist roller pressure is that which produces the maximum self-twist, and bulking should be carried out immediately after spinning to avoid loss of twist. Continuous bulking is to be preferred followed by package dyeing if required, in order to minimize processing tensions. Hank dyeing can be used but great care must be exercised with regard to processing tensions, yarn/liquor ratios, and rates of liquor flow. During relaxing a loss of self-twist is usual, and in some cases this may lead to a loss of strength of up to 60% with hank relaxing/dyeing compared with up to 30% with continuous bulking.

An increase of self-twist acrylic yarn tenacity of about 25 to 30% can be achieved by increasing the phase angle to about 65°, giving fewer yarn breaks in re-winding after hank dyeing, and an improved fabric appearance. This change is easily arranged by moving the yarn guide (number 1 in *Figure 14.1*) about 15 mm further away from the twisting rollers than the standard position.

(2) Regular yarns

This group includes non-bulked acrylics, wool, polyester/wool, polyester/viscose, etc. Suitable fibre selection enables ample yarn strength to be obtained. The main applications have been with R25tex/2 to R33 tex/2 in double jersey and single jersey structures where single ring-spun yarns are normally used. During knitting the application of tension prior to the feed-in point, combined with the inhibiting effect of knitting elements to the passage of ply twist, causes ST yarns to rotate and become trapped in the fabric with nett torsional energy. In single knitted fabrics this may cause an irregular fabric appearance due to variable stitch distortion. This effect can be minimized by: steaming the yarn on the spinning package at a suitably high temperature for the fibre type prior to winding and waxing; by using a low yarn input tension; and by knitting a tight structure. Any process which increases yarn bulk — such as steaming wool yarn in a relaxed state instead of on the package — reduces the resistance to twist-flow past the knitting elements and thereby further reduces stitch distortion.

Multiple yarn feeds are needed for fully-fashioned knitting where it is necessary to maintain tension to control the yarn, particularly during stitch transfer. This problem does not arise in warp knitting, double jersey, or with bulked yarns.

Further developments of self-twist techniques

Because ST yarns are essentially a two-strand structure they cannot be spun finely enough or cheaply enough to replace single yarns for fine-gauge knitting. On the other hand single ring-spun yarns have the disadvantages of low strength and twist liveliness when spun to fine counts for fine-gauge knitting, and at the same time STT yarns are also twist-lively.

The two most important developments based on self-twist are the Selfil machine developed by CSIRO, Geelong, Australia, and the production of wrapped core-spun yarns on a Repco machine developed by SAWTRI, South Africa. Reference to other developments is given at the end of this chapter.

The production of selfil yarns

Although ST yarns can be used for knitting, because they are a two-strand structure, they cannot be spun as fine as single ring-spun yarns. The concept of replacing one strand with a fine continuous filament yarn removes this count limitation and produces a yarn structure shown diagrammatically in *Figure 14.4*. This structure has low strength and abrasion resistance and so a second continuous filament yarn is combined with it by means of a second ST unit to produce the structure represented in *Figure 14.5*. The continuous filament yarns apply pressure to the outer layer of fibres in the single staple fibre strand, enabling them to contribute more to the yarn strength.

Selfil yarn as represented in *Figure 14.5* is a completely balanced three-strand structure which does not need to be twisted, steamed, or re-wound before dyeing. The yarn is suitable for fine-gauge knitting where staple yarns have not been completely successful. The yarn is also suitable for heavier fabrics throughout the whole range of knitted structures including warp knitting, although fabric appearance may not be satisfactory in some particular knitted structures due to the coincidence of the cyclic variation with fabric structural dimensions.

The first continuous yarn joins the single staple fibre strand on the output side of the twist rollers similar to those used on the original ST machine; the continuous filament yarn is wrapped around the staple fibre strand in alternating directions as shown in *Figure 14.4*

The second continuous filament component is added to the yarn by an intermittent twisting device,

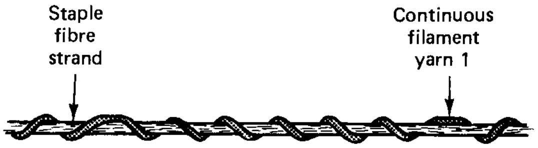


Figure 14.4 first-stage selfil yarn

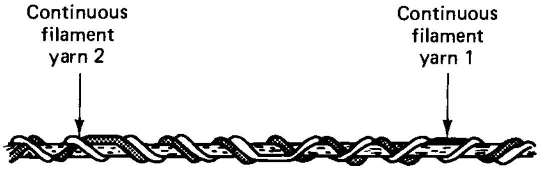


Figure 14.5 Final selfil yarn

because the yarn strength is sufficient to withstand such treatment.

Yarn of 150 tex contains 2.9% (2.3%) of continuous filament component, and 22 tex yarn contains 20% (15.4%) of continuous filament component when using 22 dtex (17 dtex) continuous filament yarn, respectively.

Selfil fine count limits

Assuming 40 fibres in the yarn cross-section to give satisfactory drafting and yarn regularity, and 22 dtex nylon continuous filament yarn, the count limits for wool-rich yarns correspond closely to the formula:

Fine count limit (tex) = $0.04155\{\text{mean fibre diameter } (\mu\text{m})\}^2 + 4$

This has implications for knitting yarn requirements: for example, a yarn suitable for 22 gauge double-jersey fabric would require wool not coarser than 21 μm mean fibre diameter.

Although the Selfil process may be attractive for the production of wool-rich yarns, it is unlikely to be of great interest for spinning any man-made staple fibres which are relatively cheap because the inclusion of up to 20% of a relatively expensive fine continuous filament nylon yarn may make the product too expensive.

The production of ST wrapped core yarns

Various experiments were carried out at SAWTRI culminating in the production of wrapped core mohair yarn.

A multifilament nylon yarn was fed in behind the front rollers into the centre of the strand of drafted staple fibres on a self-twist machine to form a continuous filament yarn core. The adjacent position was fed with a continuous filament nylon yarn only, which therefore became self-twisted around the core-spun strand.

Uni-directional twist insertion followed and it was found that the two continuous filament yarns became surrounded by mohair fibres but with the fibre ends trapped inside, thereby producing a yarn which appeared to be predominantly natural fibre on the surface.

Mohair yarns were spun to half the usual count limit by this method at a delivery speed of 220 m/min using the Repco machine, compared with the conventional speed of about 8 m/min. The 16 tex yarn produced from super kids mohair (23.0 μm mean fibre diameter, 35% C.V.) and two 22 dtex 7 filament nylon yarns, contained about 75% mohair/25% nylon with 14 filaments and 15 mohair fibres in the mean yarn cross-section. These yarns were used as weft in ultra-light-weight woven fabrics and for fine gauge knitting.

Similar yarns were produced using wool as the staple fibre, giving 10 and 12 tex yarns to be knitted on a 28 gauge double jersey machine without problems. It was suggested that by using shrink-proofed wool tops, such yarns could provide machine-washable double jersey fabrics.

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15

SPINNING DEVELOPMENTS

Besides the developments of OE and ST spinning, the search for alternatives to ring spinning have led to a number of different methods becoming available which have not had the same rapid commercial acceptance; these methods of spinning include twistless, fasciated, two Bobtex methods, spin-folding, and front-folding.

Twistless yarns

The strength of a conventional spun yarn depends to a large extent on the amount of twist inserted. In general, up to a point, more twist may be used to increase yarn strength as shown in *Figure 9.5*, but this has the disadvantage of imparting a harsh handle to the fabric. Presumably if a twistless yarn could be made it would overcome this disadvantage.

Once a twistless yarn has been assembled into a suitably structured fabric, the compacting forces created by the fabric structure itself hold the system together, hence it is quite possible for both warp and weft to be twistless.

Compared with conventional yarns, twistless yarns have the following outstanding characteristics:

(1) Increased diameter such that a 20% reduction in woven fabric sett gives a similar fabric cover.
(2) Equal or greater fabric strength may be obtained in the direction of the twistless yarn.
(3) Fabric lustre may resemble that of real silk in the case of suitable cotton-weft fabrics.
(4) Cotton fabrics are highly absorbent after bleaching, giving improved depth of colour in dyeing and printing.
(5) Fabrics can have a softer handle.
(6) The non-torque yarn eliminates stitch distortion in knitted fabrics.

Twistless spinning

The direct production of zero-twist staple yarn has the attraction that it overcomes the limitations imposed by the ring spinning system on the production rate, power consumption, and package capacity.

Because delivery speeds are independent of yarn count, twistless spinning may be particularly attractive for fine count spinning. TNO (Toegepast Natuurwetenschappelijk Onderzoek Vezelinstituut — the Applied Scientific Research Fibres Institute, Delft, Holland) state that twistless yarn is cheaper than OE yarn for counts finer than about 15 to 20 tex.

The TNO system

The original TNO system of twistless spinning of cotton has reached an advanced stage of development with yarn delivery speeds of 125 to 150 m/min based on three major factors:

(1) The use of an inactive starch which permits yarn winding without drying.
(2) The use of a false-twist consolidation device.
(3) The use of wet processing enabling a simplified drafting zone to be used.

The roving is usually boiled in an alkaline solution to remove fatty matter and then drafted in an almost vertically upward direction in a wet state by a simple drafting zone with drafts of 8 to 15. Advantages of this arrangement are that fibre control is virtually independent of ratch thereby enabling larger rollers to be used at high speeds with reduced likelihood of lapping, and that yarn levelness tends to improve as delivery speed increases up to 255 m/min. A fixed ratch of 60 mm is suitable for drafting cottons with effective lengths ranging from 19 mm for a Bengal cotton to 45 mm for a Sea Island cotton.

The pilot plant which was used for TNO twistless yarns is represented in *Figure 15.1*. The adhesive is applied via the front rollers of the drafting zone, and an air-vortex false-twister is used at an effective speed of 20 000 rev/min to impart temporary strength, and to consolidate the strand as it passes to the delivered package of about 1 kg. The completed package is later steamed to convert the starch into an active film of adhesive before being dried at 100 °C and then unwound from the inside. Subsequent sizing is not necessary, and no attempt is made to recover the cheap adhesive during fabric finishing.

Yarn counts from 2.6 to 75 tex have been spun from cotton with tenacity and extension at break generally only one half or two thirds of conventional ring-spun yarn. Man-made fibre and blended cotton yarns vary considerably in strength and extensibility, depending on the adhesive bond obtained with different fibres; generally extension at break is lower or appreciably lower than for ring-spun yarns.

The low extensibility may limit subsequent processing, and dyeing can be done only in roving or fabric form. Yarn winding usually entails a loss of strength and care must be taken to avoid acute-angle changes of yarn path.

A later TNO twistless spinning development known as the ‘Twilo‘ process involves the use of 5 to 10% of PVA fibres blended into the sliver, giving better adhesion than starch with most man-made fibres. Wet drafting and air vortex false-twisting are still used, but the activation and drying of the adhesive is completed on the spinning frame with package winding following at yarn speeds up to 600 m/min. The major disadvantage of this system is that the cost of the PVA fibre is quite high, and yet it must be washed out of the fabric in finishing.

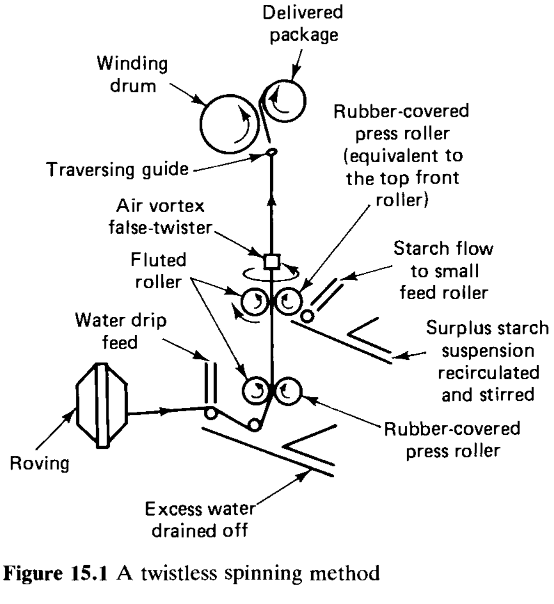

Figure 15.1 A twistless spinning method

The Pavena system

The basis of the Pavena system, introduced by Rieter of Switzerland, consists of impregnating drawframe sliver with 2 to 4% by mass of bonding substances and dye if required; surplus liquid is squeezed off and the sliver is condensed to a strand of fibres by the application of an extremely high pressure of up to 20 MPa. Drying and winding follow at a speed of up to 300 m/min; this gives an impregnation time of less than 0.01 of a second.

A number of bonded strands from the first stage are fed as doublings through a simple drafting zone with a fixed ratch of 75 mm for fibres up to 60 mm long. When the fibres are gripped by the front rollers, the adhesive bond between the fibres is broken, which causes a rapid decrease in the drafting force so that individual fibres are withdrawn with negligible force. Because there are virtually no floating fibres the ratch is not critical, and drafts up to 200 are possible.

The delivered strand is re-bonded by an impregnation bath similar to the first stage, dried, and wound. The product is known as ‘Paset’ yarn and is produced in counts ranging from 80 to 660 tex.

An alternative arrangement which does *not* produce a twistless yarn, is to feed a single bonded strand from the first stage into a ring frame with a simple drafting zone to produce a twisted yarn. In this case the need for twist insertion at the roving stage is eliminated, a range of yarn counts finer than the ‘Paset’ yarns can be produced, and the product is known as ‘Pavil’ yarn; production rates are limited by the usual ring spinning constraints.

It seems evident that the applications of twistless yarns are likely to be restricted to fabrics which benefit from their particular characteristics, such as bed linen; because weight for weight twistless fabrics have lower air and water permeability, and higher tearing and tensile fabric strength, it has been suggested that they would be particularly useful for tent cloths.

Semi-molten polymer-core yarns

The Bobtex ICS (Integrated Composite Spinning) system is of this type, it incorporates three components: a continuous filament carrier in the core; extruded molten polymer, and ; staple fibres. The final yarn consists of a continuous filament core surrounded by solidified polmer in which is embedded the outer layer of staple fibres.

The basic principle of the ICS spinning machine is illustrated in *Figure 15.2*. The polymer is fed in pellet, flake, or powder form and the fibres are fed in sliver form. The molten polymer is extruded downwards through a multi-hole spinnerette and drawn into the nip of the laminating rollers to form a composite strand with the staple fibres which usually have been opened by a pinned roller, thereby surrounding the continuous filament carrier. The strand is then false-twisted while in a semi-molten condition by a friction twister cooled, and wound at 600 m/min or more on to packages of about 4kg.

In order to maintain reasonable productive efficiency with such a high delivery speed, when the package is full, winding is transferred to an adjacent winding head, enabling full packages to be removed by the operative later.

It follows that the continuous filament carrier must be subjected to false-twist, whereas some real twist remains in the molten-polymer matrix because of inter-molecular slippage, and in the staple fibre sheath because of inter-fibre slippage; hence there is a differential twist in the structure.

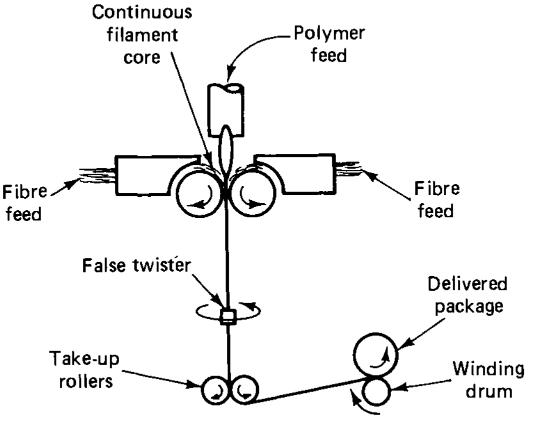

Figure 15.2 Semi-molten polymer-core spinning

The ultimate effect of a composite formed in this way results in a product with characteristics different from those of the individual components. The addition of twist produces a typical tenacity/twist curve as shown in *Figure 15.3*.

Because fibres are fed from two sides, widely divergent fibre types and dimensions can be combined together to give properties not otherwise obtainable, and low-cost short and irregular fibres can be processed by this method. Furthermore the relative proportions of staple fibre and polymer core can be varied from 15 to 85% of the total yarn mass respectively, and vice-versa, although 30 to 70% is more usual and about 50% is preferable. Yarn flexibility is influenced by the percentage and by the type of polymer used, although, for economic reasons, emphasis has been placed on using low-cost polyethylene polymer. Finer diameter staple fibres can be expected to give a better cover and handle to the product than coarse fibres.

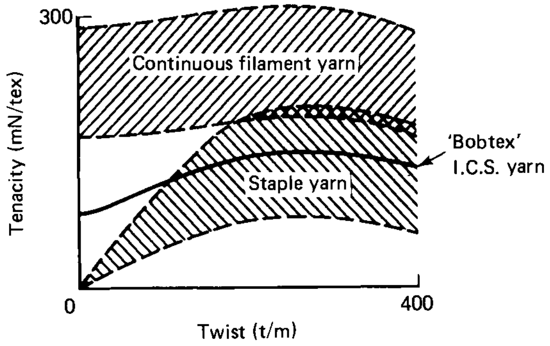

Figure 15.5 Tenacity/twist curve comparisions

Although fine yarns can be produced, emphasis has been on yarns coarser than about 60 tex for industrial fabrics, household textiles, furnishings, and carpet backings, rather than apparel.

The fineness and percentage of the continuous filament component is an important cost factor as well as having a considerable influence on yarn properties; a greater range of component percentage possibilities is available at coarser yarn counts. Specific examples of three-component yarns produced for particular end-uses include: 35% viscose staple/35% nylon continuous filament/30% polyethylene matrix to make 45 tex weft yarn for use in denim, and a 200 tex upholstery yarn made from 65% viscose-nylon staple blend/17% viscose continuous filament/18% polypropylene matrix.

Advantages claimed for the Bobtex ICS system include:

(1) The yarn substantially exhibits the typical surface texture and appearance of a spun yarn, and yet benefits from the strength and continuity of the polymer matrix and the carrier filaments.
(2) High delivery speeds are possible.
(3) Some conventional staple fibre processes are eliminated.
(4) The use of a cheap polymer may enable yarn to be produced at a price per kilogramme not exceeding that of the staple component only.
(5) The limitations of the original staple fibre conventional technology no longer apply, the only requirement being a uniform supply of staple fibre; widely divergent fibres may be combined into the same yarn.

Axial fibre-slippage twist insertion

At first glance this method of yarn production appears to make use of false-twist insertion, but because rotational fibre slippage takes place, the delivered yarn contains real twist. The situation is analogous to that of the Bobtex ICS system in which inter-molecular slippage of the molten polymer upstream of the false-twister permits the formation of real twist; in slipped-fibre twist insertion the fluid polymer of the ICS system is replaced by air as the fluid which permits rotational fibre displacement.

Jet spinning

In the early 1960s DuPont (USA) patented a method for producing what they called a 'fasciated' yarn, which is composed of a core of parallel overlapping staple fibres, bound together by surface wrapping fibres which constitute a minor proportion of the population. As represented in *Figure 15.4*, this structure differs from a ring-spun yarn in which all fibres participate in the helical twist formation to some extent. The helix angle of the fasciated yarn surface fibres varies from about 10° to 80° compared with 15° to 25° in most ring-spun yarns.

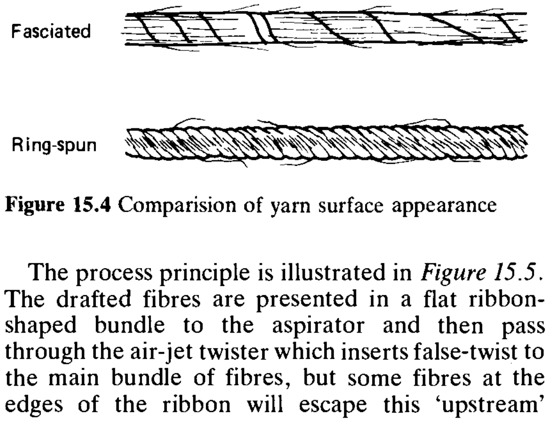

Figure 15.4 Comparision of yarn surface appearance

The process principle is illustrated in *Figure 15.5*. The drafted fibres are presented in a flat ribbon-shaped bundle to the aspirator and then pass through the air-jet twister which inserts false-twist to the main bundle of fibres, but some fibres at the edges of the ribbon will escape this 'upstream' twisting effect to some extent. When the fibres pass downstream, the main bundle of fibres rotates in a contrary direction as the false-twist is cancelled, but the edge-fibres will tend to rotate with the main bundle because of the increased fibre contact, thereby being untwisted to a greater extent than their original twist. Therefore the surface fibres will be given a real twist in the opposite direction to that of the upstream twist; the amount of twist will depend on the relative amount of free length of the edge-fibres before they join the main bundle.

An important feature of the process is the high rate of twist insertion which makes it possible to have high yarn delivery speeds compared with ring spinning, particularly with fine counts.

The DuPont system appears to be suitable for fibre lengths in the region of 125 to 150 mm spun to counts of about 8 tex or thicker. As might be expected, compared with conventional yarns, the yarns have negligible torque, and the bulk and cover is greater, they have lower extension at break and greater bending rigidity, and they combine some of the aesthetic characteristics of both spun and continuous filament yarns; as with twistless yarns, they give a deep dyed or printed shade.

Fasciated yarns have been used in both woven and knitted fabrics and to produce crêpe-like effects in fine woven fabrics by using differential fibre shrinkage. The DuPont system was never widely adopted, but like many ideas it has been subjected to further study and development.

In the early 1980s the most widely mentioned name for further developments in the jet spinning of staple fibres was that of Murata, although there were others such as Toyoda, Toray, and Howa. Although the details of each system may differ, the general principle is basically the same as for fasciated yarns, with a main point of difference being that on the newer systems, the jet twist insertion takes place after the front rollers of a double apron drafting zone.

The main features of the newer systems are that they are designed to process cotton, short staple man-made fibres, or blends, to yarn counts ranging

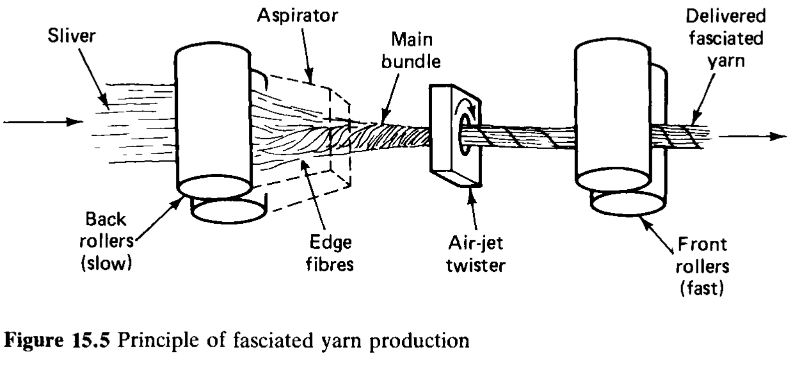

Figure 15.5 Principle of fasciated yarn production

from about 7.5 to 30 tex at delivery speeds ranging from 100 to 200 m/min. For cotton to be processed alone it must be fine and of uniform fibre length distribution; nevertheless, the yarn is likely to be deficient in strength. Better yarn strength is achieved when polyester fibres are present, although even then the yarn strength is not likely to exceed about 85% of that for similar ring-spun yarn. There is also a tendency for fabric handle to be harsh.

The roving process is eliminated because the jet spinning machines spin direct from sliver. The machines incorporate automatic: piecening; doffing; yarn clearing; and package transfer.

Bobtex ABS (Aerodynamic brake Spinning)

A schematic diagram of the Bobtex ABS principle is shown in *Figure 15.6*. Staple fibres from a sliver are fed to a takerin type of opening device and passed to a fibre feed roller where they are held by air suction as they are carried over the upper half of its circumference. The rate of airflow and the partial pressure nip are adjustable in order to provide the necessary braking effect for a spin-draw-slip release. As the trailing ends of fibres pass through the partial nip, they are no longer held by the aerodynamic brake forces. The torque applied by the twister below causes them to rotate axially and slip against the leading ends of the fibres still restrained above. Simultaneously the yarn so formed is drawn off by the take-up rollers, thus creating the spin-draw-slip. The amount of final yarn twist in the yarn is equal to the rotational fibre slippage induced, and is opposite in direction to the upstream twist.

Because the twist insertion device is axial, a high speed compatible with low power consumption should make it possible to process a wide range of different fibre lengths at delivery speeds up to 300 m/min.

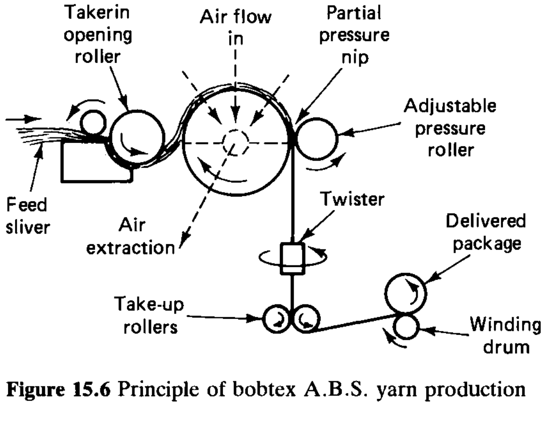

Figure 15.6 Principle of bobtex A.B.S. yarn production

Spin-folding

This is a technique combining the spinning, folding, and winding processes into one operation. The system was operated by a worsted spinner in Bradford from about 1945 to about 1965, but despite substantially reduced production costs compared with conventional two-fold yarns it has never been adopted widely outside Russia, where it has been applied; this is because of the restrictive technological limitations imposed by the process.

The basic principles of the system are shown in *Figure 15.7*. A roving is drafted into a yarn which is passed through the hollow rotating spindle on which is mounted a pre-spun package of single yarn. The pre-spun yarn is withdrawn from the package and taken down inside the hollow spindle to combine with the newly-spun yarn from the drafting zone.

The limitations of ring and traveller are thereby avoided, but the problems of package rotation and ballooning still remain. The major advantage is in the combination of three processes into one operation so that for a given total production only 50% of the ring spindles are required to produce the pre-spun yarn packages.

With the clockwise spindle rotation shown in *Figure 15.7*, the yarn from the drafting zone has Z false-twist inserted into it between the delivery rollers and the spindle top; this twist is cancelled out below the spindle. At the same time the two yarns are twisted round each other with S twist between the spindle bottom and the take-up rollers. The original spinning twist in the pre-spun yarn must be a suitable amount of Z twist to be removed by the S folding twist to give zero residual spinning twist in each single strand of the ultimate yarn.

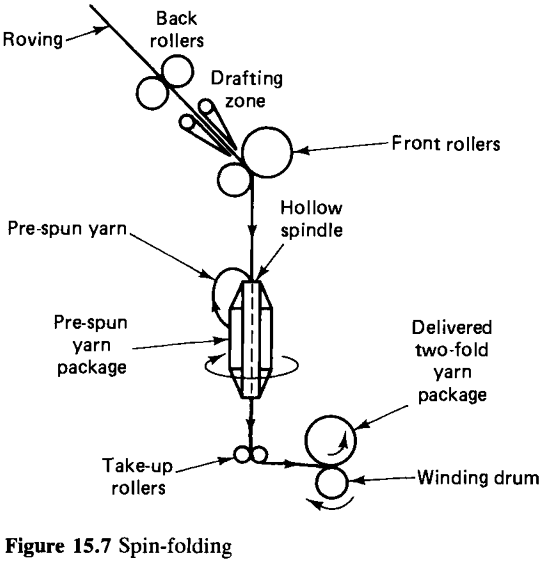

Figure 15.7 Spin-folding

Hence folding twist must always be equal in amount, but opposite in direction, to the spinning twist; this restricts the flexibility of the system, and does not permit the lower amounts of folding twist which are often used, and which give an increased delivery speed with conventional folding methods.

Details of the threading and tensioning devices are not shown in *Figure 15.7*. One difficulty is the prevention of unequal tensions in the single strands — the newly-spun yarn tends to spiral around the pre-spun yarn. Other difficulties arise with piecening either of the two single yarns, and with the making of a yarn count check; single-end yarn clearing is also impossible.

Wrap-spun yarns

The basic principle consists of drafting a staple fibre sliver and delivering it on a machine similar to that shown in *Figure 15.7*, but with the pre-spun yarn package replaced by a continuous filament yarn supply package.

The resultant yarn consists of a twistless strand of staple fibres around which is twisted a fine continuous filament yarn of about 4 dtex; alternatively two continuous filament yarns can be used in S-Z directions respectively, by having two hollow spindles, one above the other, and rotating in opposite directions. The continuous filament, which forms from 1% to 5% of the ultimate yarn, depending on the count, beds into the staple fibres and is hardly visible. Yarn delivery speeds of about 60 m/min can be achieved, and fine counts can be spun because the staple fibre strand is not subjected to balloon tensions.

Compared with ring spinning, wrap-spinning can enable: finer yarn counts from a given fibre supply; or coarser fibres to be used for a given yarn count; and increased yarn strength. Wrap-spun yarns are particularly suitable for use in fine-gauge tufted carpets which are beyond the range of semi-worsted yarns, and they give good fabric cover.

The axifugal system

In effect this is a further development of spin-folding which utilizes a centrifugal method of spinning and yarn folding. Yarn is spun into the rotating container by the centrifugal system as shown in *Figure 15.8(a)* until the container is full. The yarn tube is then stopped at the top of its traverse and the loop of yarn between the yarn tube and the rotating container is drawn down through the hollow spindle by a probe.

The yarn then passes from the front rollers straight through the hollow spindle as shown in *Figure 15.8(b)*, with false-twist insertion taking place. At the same time the first-spun yarn is withdrawn from the container so that its strand twist is removed while the two strands are twisted around each other.

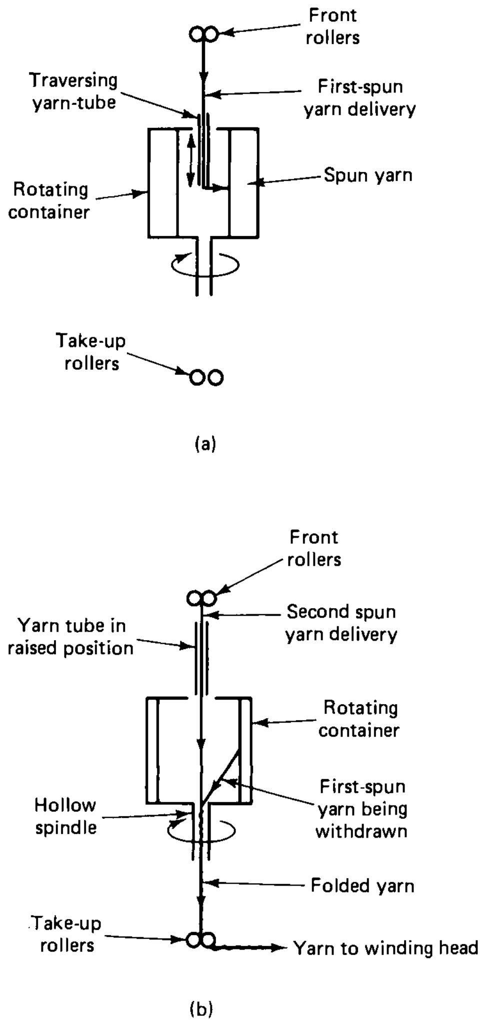

Figure 15.8 Axifugal yarn production: (a) stage 1 – spinning the first yarn; (b) stage 2 – spinning the second yarn and simultaneously folding it with the first yarn

When the first-spun yarn is exhausted, the yarn is severed below the spindle and the process reverts to the first stage until the full cycle has been repeated once more; the container rotates continuously in the same direction without stopping between cycles.

Power consumption per kilogramme of yarn produced is lower, firstly because rings, travellers, and ballooning are eliminated, and secondly because only one of the single strands is handled twice; therefore two axifugal spindles replace three conventional ones. Consequently the total energy requirement is about 66% of that used in conventional ring processing, less floorspace is needed, and because yarn tensions are low, higher speeds may be used.

Although the system was originated for continuous filament yarn processing, it has also been developed for staple yarn production for end-uses such as hosiery, blankets, carpets, and furnishing-fabrics.

Front folding

It is claimed that drafting two rovings separated from each other in the drafting zone at a distance apart of 20 to 30 mm, and then combining the two strands *after* they leave the front rollers, gives improved spinning and permits increases of up to 40% in production.

By applying false-twist to one of the strands at a high speed by air vortex, and then converging the two strands together with different path lengths, a stable yarn containing real twist can be produced, with levelness improved by the out-of-phase combination of irregularities formed during drafting. Yarn delivery speeds in excess of 400 m/min have been claimed with false-twist insertion at 1×10^6 rev/min with minimal yarn tension.

Another development based on the front folding principle is the licensed 'Sirospun' system; it is a joint development of IWS (the International Wool Secretariat), CSIRO (an Australian research organisation), and Repco.

Trapped false-twist in the two-strand yarn produced helps to anchor strand surface fibres within the two-strand structure, thereby reducing yarn hairiness and improving abrasion resistance.

An important feature of the Sirospun system is a simple mechanical 'breakout' device: if one strand breaks or runs out, the other strand is trapped and then breaks, thereby avoiding the formation of faulty single-strand yarn.

Whereas conventional two-fold yarns can be made into a torque balanced structure, the yarns produced by front folding are twist-lively and require setting to eliminate the torque.

Compared with two-fold yarns, 100% wool Sirospun yarns have: 5% greater tenacity; 10 – 30% greater extension at break; and a slightly higher yarn irregularity. The abrasion resistance is claimed to lie between conventional two-fold and single yarns of the same resultant count and twist content.

Felted yarns

A process, developed by the International Wool Secretariat, is based on the felting properties of wool. and is called the 'Periloc' process.

This involves the aqueous felting, at about 62 °C,of a continuous strand of fibres moving along inside a polyurethane tube which is subjected to a rhythmic wave-like series of compressions provided by a set of rotating rollers. Additional chemical treatment may be incorporated in the process, such as moth-proofing, for example.

The rate and amount of felting depends on the speed at which the fibre strand is fed in and withdrawn, and on the frequency of the compressions. Yarn from 500 to 6000 tex may be delivered on to a reeling machine to produce hanks at a rate of about 5 to 35 m/min.

A range of polyurethane tubes with internal diameters of 4, 5, 5.5, 6, 7, and 8 mm are available to cover the yarn count range, and tubes are said to have a working life of 100 to 120 hours; replacement costs per unit of production appear to be slightly lower than apron replacement costs on conventional machines.

Development work has included either the processing of a single thick sliver in each tube to produce a single yarn, or the feeding of a number of finer single woollen-spun carpet yarns to produce a single yarn in which the original ends are combined, but can still be identified individually.

A more recent felted yarn process has been patented by William Tatham Ltd in which are used a number of rubbing aprons similar to those on a woollen condenser, but immersed in the solution. The felting rate depends on the mechanical settings of the aprons and the solution temperature; under commercial conditions the delivery speed may be from 20 to 60 m/min.

The use of felted yarns in carpets improves wear performance, and may also increase design potential. Consequently interest in felted carpet yarns has led to the development of a tumble-felting process in New Zealand which can be applied to most types of spun yarns and also to folded yarns. Basically the process involves the use of a tumble-dryer under carefully controlled conditions of temperature, humidity, and time, in order to confer the benefits of felting on existing carpet yarns.

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16

YARN FOLDING

The position occupied by folding in the sequence of operations is shown in the Appendix for various systems of yarn manufacture.

Folded yarns

Yarn folding is also known by the alternative names of plying (particularly for hand-knitting yarns, otherwise known as 'fingering' yarns), doubling (in Lancashire), or twisting (in Yorkshire); it consists of combining two or more single yarns together by twisting them around each other in one operation.

The number of single components is usually specified by stating the number of 'folds': for example two single yarns folded together are described as a two-fold yarn, similarly it is common to name three-fold and four-fold yarns; the term multi-fold may be used collectively to describe yarns with more than two single components although it is more usually used for yarns with more than four components.

When multi-coloured folded yarns are produced, care must be taken to ensure that the different coloured supply yarns are creeled in the same order at every spindle in order to avoid apparent differences in yarn colour.

Cabled yarns

These are produced by combining together a folded yarn with one or more other yarn/s by twisting them around each other, hence cabled yarns involve two or more processes of twist insertion after spinning; an exception to this rule applies to continuous filament tyre cords where a two-fold yarn might be described as a cabled cord, and the folding twist might be called the cable twist.

Some sewing threads are cabled yarns with a structure designed to give a compact non-torque, minimum stretch, minimum irregularity, and maximum strength yarn.

The objective of yarn folding

The production of folded yarns is expensive compared with a single yarn of the same resultant count. For example if a two-fold yarn is to be made, then the single yarn must be spun to approximately half the resultant count. This means that about three times as many spinning spindles are required to obtain the same output as would be obtained by spinning a single yarn direct to the final resultant count; in addition there is the cost of the folding operation.

Despite their additional cost, folded yarns are frequently produced because of one or more of the benefits which may be obtained:

(1) When two or more identical single yarns are combined together they lose their individual identities and become merely part of the final thread. The result is that yarn irregularity is reduced. This fact can be demonstrated as follows:

$$\mathrm{CV_F} = \frac{\mathrm{CV_S}}{\sqrt{F}} \qquad (16.1)$$

where CV = percentage coefficient of variation, S = single, and F = number of single components in the folded yarn.

In the case of contrasting coloured components the improved levelness may not be noticeable visually.

The reason for the improvement of yarn levelness is apparent from consideration of the causes of yarn irregularity:

For a given stock of fibre

$$\mathrm{CV}_a^2 = R^2 + X^2 \tag{16.2}$$

where CV_a = the actual C.V.% of a single yarn, R = the random component of irregularity (the limit irregularity), and X = the additional component of irregularity due to all other causes.

$$R = \frac{K}{\sqrt{n}} \tag{16.3}$$

where K is a constant for a given fibre stock, and n = the mean number of fibres in the yarn cross-section. Hence from (16.2) and (16.3), for a given single yarn spun to a count of T tex,

$$\mathrm{CV}_a = \sqrt{\left\{\left(\frac{K}{\sqrt{n}}\right)^2 + X^2\right\}} \tag{16.4}$$

and for a folded yarn made from the above single to a resultant count of FT tex, where F is the number of singles folded together, it follows from (16.1) and (16.4) that:

CV_a of an FT tex folded yarn

$$= \frac{1}{\sqrt{F}} \sqrt{\left\{\left(\frac{K}{\sqrt{n}}\right)^2 + X^2\right\}}$$

$$= \sqrt{\left\{\left(\frac{K}{\sqrt{(Fn)}}\right)^2 + \frac{X^2}{F}\right\}} \tag{16.5}$$

However, for a *single* yarn spun to FT tex, the number of fibres in the single yarn cross-section = Fn, and

CV_a of an FT tex single yarn

$$= \sqrt{\left\{\left(\frac{K}{\sqrt{(Fn)}}\right)^2 + X^2\right\}} \tag{16.6}$$

The additional component (X) of yarn irregularity due to causes other than random fibre distribution is approximately constant for a given form of fibre control and a given fibre stock, hence it is apparent that for practical values of X which exceed zero:

$$\sqrt{\left\{\left(\frac{K}{\sqrt{(Fn)}}\right)^2 + X^2\right\}} > \sqrt{\left\{\left(\frac{K}{\sqrt{(Fn)}}\right)^2 + \frac{X^2}{F}\right\}}$$

i.e. the irregularity of a single yarn of FT tex exceeds the irregularity of a folded yarn with a resultant count of FT tex.

(2) In general the mean yarn strength is increased — the effect of folding twist on yarn strength follows a similar pattern to the effect of twist on single yarn strength, i.e. strength increases with twist to a maximum and then decreases. The amount of strength increase depends on the details of the yarn construction and on the tension applied during folding — a higher tension increases yarn strength. The rate of strength increase becomes higher as folding twist is increased and therefore yarn tension becomes more critical at higher folding twists.

It is possible for a two-fold yarn to have up to twice the tenacity of the single yarn component (i.e. four times the single yarn strength), although a ratio of folded/single yarn tenacity of between 1.1 and 1.7 is more common with cotton yarns, being greater for finer yarns. Because pressure is a applied to the outside of each single component, folded yarns utilize the strength contribution of the ineffective layer of fibres; the influence of this layer of fibres on yarn tenacity is discussed on page 209. Good correlation exists between the strength of folded yarns and their single components.

(3) The variation of yarn strength is reduced: for example, a two-fold yarn strength C.V.% may be only 0.35 to 0.45 times that of the single component yarn.

(4) Balanced twist (i.e. non-torque) folded yarns can be produced.

(5) By a suitable combination of spinning twist and folding twist, within limits yarns may be made more compact or bulkier, thereby influencing yarn softness.

(6) Yarn elongation at break can be controlled within limits, mainly by the tension applied during folding; less tension increases elongation. An increased amount of spinning twist or folding twist increases yarn elongation at break although with cotton yarns the effect is negligible except at high levels of twist. The condition for minimum extensibility is when the spinning and folding twists are balanced in such a way that the individual fibres are parallel to the resulting yarn axis.

With worsted yarns the breaking load and extension at break are significantly correlated. Good correlation exists between the breaking extension of folded yarns and their single component breaking extension.

(7) Improved lustre may be obtained by using a suitable twist and applying maximum tension.

(8) Novelty yarns may be produced by using one or more of the following methods:
   (i) Combination of different fibre types to give a distinctive appearance or behaviour to the yarn.
   (ii) Combination of different colours to produce colour twists, marls, etc.
   (iii) Combination of different yarn thicknesses to produce spiral yarns.
   (iv) Combination of different yarn lengths to produce effects such as knops, gimps, and bouclé yarns.
   (v) The use of unusual amounts of twist to produce special effects such as frescoes and crêpes.

By suitable combinations of spinning and folding twists, a range of yarns differing widely in their physical characteristics can be produced. However most yarns destined to become folded yarns are spun with the minimum twist required to give a good spin as described in Chapter 9; there is little to be gained by inserting more twist in the single, especially if folded yarn strength is the criterion unless a low folding twist is to be used in which case an increased spinning twist will be reflected in the folded yarn strength.

S on Z yarns

The vast majority of folded yarns have the folding twist in the opposite direction to the spinning twist. For the sake of brevity this situation is subsequently referred to as S on Z, although the same conclusions can be drawn for Z on S. Under such circumstances with low amounts of folding twist the folded yarn becomes longer than the single components. As folding twist is increased the amount of extension is decreased until a point is reached at which the folded yarn length is equal to the length which the single components were before folding commenced; further increase of folding twist then leads to increasing amounts of length contraction. A wide range of amounts of twist may be employed, and in cotton yarns the folding twist is frequently specified by the customer, the *F/S* twist ratio (i.e. folding twist/spinning twist) being usually considerably higher than in worsted spinning: e.g. a ratio of 1.7 may be regarded as normal to hard for a two-fold cotton weaving yarn. It is less usual for the customer to specify twist in worsted yarns although it is done sometimes, and so the standard yarns produced can be classified into a small number of main groups. In the worsted industry the following relationships are adhered to fairly closely:

(1) Coating yarns

$\frac{F}{S}$ twist ratio = 1

Approximately all the original spinning twist is removed leaving zero residual spinning twist in each single strand. The straight fibre arrangement in the strands gives the maximum yarn strength in worsted yarns and suitable elasticity for weaving purposes, and a compact appearance. The contraction in length caused by wrapping two singles round each other is counteracted by the extension caused by the removal of twist from the fibres within each individual strand. Hence the length of folded yarn produced equals the length of each single component and so the single components may be spun to the nominal count.

In order to achieve maximum yarn strength cotton yarns have a relatively higher folding twist (because of the shorter fibre length), and so a different relationship applies; this is described on page 178.

(2) Colour twists

$\frac{F}{S}$ twist ratio = 1.5

This twist is used for folding together yarns containing contrasting coloured fibres which are not intimately mixed together. The reason for the higher twist is that twist distribution in a yarn depends on local yarn thickness, i.e. 'twist runs to the thin places' as described on pages 60 and 107. Hence the visual appearance of yarn irregularity may be accentuated by uneven twist distribution which becomes more apparent when contrasting coloured components are used. As explained on page 163, the insertion of additional twist changes the angle of folding twist more in the low-twist zones than in the high-twist zones, making the twist angles become more nearly equal and hence visually less noticeable. A further benefit derived from using higher folding twist is that smaller units of colour are visible in the yarn thus giving a more uniform woven fabric appearance — insufficient twist might cause a peculiar streaky or 'feathery' effect due to the the coincidence or near-coincidence of the distance between adjacent colour spots in the yarn with the distance between adjacent ends or picks in the woven fabric. This twist combination gives a compact, twist-lively yarn in which all the original spinning twist is removed and replaced by about 50% of twist in the opposite direction. Consequently there is a length contraction of about 3.5 to 5% which means that the single yarn must be spun at 0.95 to 0.965 × nominal count in order that the final folded yarn has the correct count.

(3) Knitting yarns

$\frac{F}{S}$ twist ratio = 0.5

After folding, approximately half the original spinning twist will remain in each single strand. This gives a soft handling bulky yarn, with good extension properties, suitable for knitting. The retention of some spinning twist in the single strands minimizes pilling in knitted fabrics. During the folding operation this type of yarn becomes about 1.5% longer than the original single components, hence the single yarn must be spun to about 1.015 × nominal count to produce a final folded yarn of the correct count.

Besides the three most commonly used twists described above, there are minor variations such as warp twist = coating twist − 40 t/m, and gaberdine twist = coating twist + 40 t/m, but there is one modification which may be regarded as being more important:

Balanced twist

This is the amount of twist required to make a yarn completely free from the tendency to snarl which is common in many yarns. This non-torque characteristic is particularly important for certain applications in knitwear. In the wool textile industry it has been traditional to state that for a balanced twist two-fold yarn $F/S = 2/3$, and this relationship has been shown to produce the least skewing in a woven fabric; almost the same relationship has been reported for cotton yarn.

Folding twist for maximum strength of cotton yarns

Analysis of extensive results for cotton yarns given by Dakin for S on Z twist shows that for yarns from two-fold to seven-fold: maximum strength F/S ratio $= 3.253N^{-0.345}$. Where N is the number of single components folded together.

Z on Z yarns

Besides all the S on Z yarns described above, there are yarns with other arrangements such as twist-on-twist i.e. with the folding twist in the same direction as the spinning twist — here referred to as Z on Z, although the same remarks apply to S on S yarns.

With this arrangement the folding twist is additive to the single strand twist, giving a compact yarn suitable for crêpe yarns and bold striping threads. Upto a point as folding twist is increased, this gives increased extension at break for two-fold cotton yarns, and maximum strength is reached when the F/S ratio is about 1.4, whereas for two-fold worsted yarns, the ratio is about 0.5 for maximum strength and extension. When optimum folding twist is used, Z on Z two-fold yarns are always stronger and more extensible than S on Z yarns made from the same single yarn components.

Z on Z yarns are very twist-lively and must be steam-set in an autoclave. The folding operation always causes a length contraction, therefore the single yarns must be spun finer than the nominal count by an amount determined by the twist relationship in order to produce the correct final folded yarn count.

Yarn folding routine

Although various different machine combinations can be used, the following is the most usual sequence of operations to follow after spinning when a folded yarn is required:

(1) Single yarn automatic winding and clearing. This enables faults to be removed from the single components, and be replaced by single knots or by yarn splicing
(2) Assembly winding. This puts the required number of component threads alongside each other on a package of a size suitable for supplying the following machine.
(3) Yarn folding. This inserts the required amount and direction of folding twist into the yarn.
(4) Cone winding. This puts the yarn on to a package which is suitable for delivery to the customer. Yarn additives such as wax may be added. A separate cone winding operation might not be necessary if the folding machine delivers a suitable package.

Yarn folding machinery

The machinery requirements depend on the type of yarn which is to be made. From this point of view the yarns may be broadly grouped into three categories:

Two-fold yarns.
Multi-fold yarns.
Fancy yarns.

Conventional ring folding

Conventional ring machines operate on the same principle as the spinning machine except that instead of a drafting zone, a capstan or roller nip arrangement is used to deliver the component yarns at the required speed. Each supply yarn passes through an end-detector so that if one thread breaks, it operates a mechanism which prevents the accidental production of a yarn with the wrong number of single components. There are two different approaches to this problem:

(i) If one thread breaks, the other one is either cut or broken. This arrangement can be used for two-fold yarns and when folding direct from spinning packages, but it causes a two-fold knot to be tied.
(ii) If one thread breaks, the detector stops delivery of the other single component yarn/s and also stops the individual spindle. This arrange-

ment is more expensive than method (i), but it permits a single component knot to be tied without severing the remaining thread/s; this type of machine can be used for two-fold and multi-fold yarns.

Fancy yarn folding

Fancy folding machines are used only by a small specialized section of the industry. The machines must be capable of giving a fluctuating or intermittent yarn delivery for one or more of the components, with provision for controlling the variations in feed as required.

Two-stage yarn folding (the Hamel system)

As the name implies, this process consists of two operations. Supply packages to the first operation consist of cleared single yarn on cone. The first operation basically consists of a type (ii) 125 mm diameter ring machine with about 300 to 390 mm lift as described above, with a single balloon control ring, and with a parallel traverse producing a package which is very suitable for over-end unwinding. This machine (Plate 30) is used in an unconventional manner in that it inserts only about 20 t/m. Consequently it has a high delivery speed of up to 350 m/min, and if the machines were run for the same number of hours per week, one first-stage spindle could supply about 30 to 40 spindles at the second stage, depending on the final yarn count and twist.

For the majority of yarns, the first-stage twist is in the same direction as the second-stage twist, and so the final twist is the sum of the two processes. If the single yarn contains a low amount of spinning twist, or if the single yarn is irregular in diameter and twist, the first-stage twist may be inserted in the same direction as the spinning twist in order to increase the yarn strength and decrease end-breakages at both stages.

The package produced by the first stage contains a measured length of yarn and is designed to fit into the container of the second-stage machine. Care must be taken to avoid yarn disturbance during transfer between the two machines and so a trolley-mounted creel is used for transport. The first operation may be regarded as an alternative to assembly winding.

The second-stage machine is a form of up-twister, i.e. instead of yarn being delivered on to a rotating

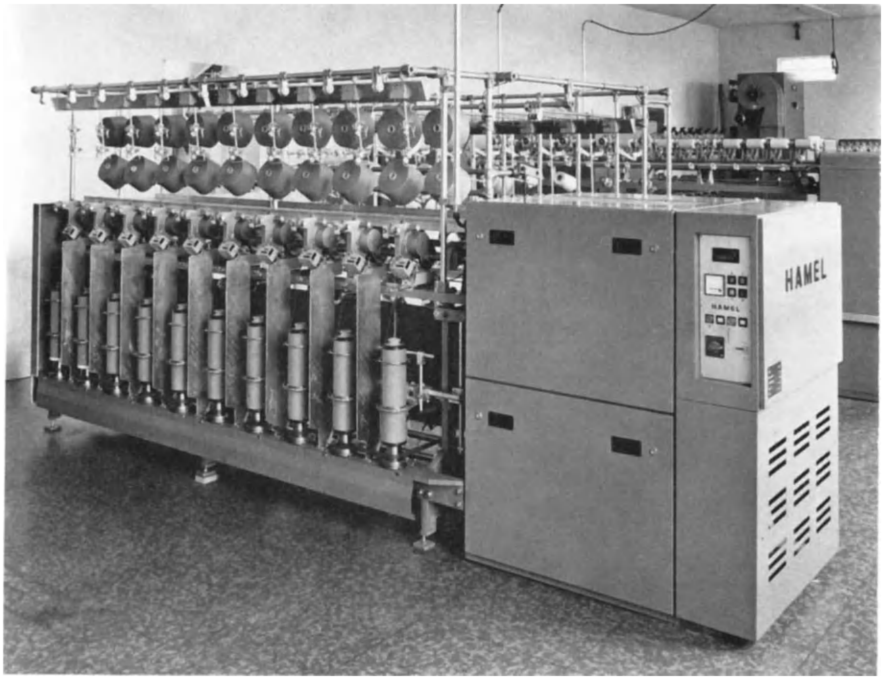

Plate 30. First operation of two-stage yarn folding. The creel supplies two (or more) large packages of cleared single yarn to each spindle via broken-end detectors. One balloon control ring is used in conjunction with the ring and traveller at each spindle to produce a parallel traversed package to fit the second-stage machine supply yarn container. The machine has a maximum spindle speed of 6500 rev/min and the delivered package has a mass of up to 1 kg for the 295 mm traverse length or up to 1.5 kg for the 387 mm traverse. Courtesy of Carl Hamel A.G.

package as in ring spinning, the supply yarn is fed upwards from a rotating supply package, thereby inserting twist. The package from the first stage is placed in an enclosed container which has an outlet hole at the top through which the yarn passes. The container may rotate at speeds up to 12000 rev/min although if power supply costs are excessive, a slightly lower speed might be used. As the yarns are already pre-twisted slightly, and tension is limited by the smooth-sided container which prevents balloon formation and limits air drag, end-breakages are extremely unlikely and if an end-break does occur, the container prevents the nuisance of lashing ends. Power consumption remains virtually the same when different yarn counts or twists are processed, being about 55% less than if the package were not enclosed.

The second stage (*Plate 31*) is intended to be run for up to 168 hours per week, unattended for most of the time, except for cleaning, creeling, and doffing. This can be arranged by processing thicker yarns during the week on two-shift working, with the machines running unattended overnight, and by processing fine yarn counts at the weekend after a single Saturday morning shift, so that the machines run unattended over the weekend. The second-stage machine is fitted with a switch which can stop the frame automatically at any time up to a limit of 160 hours after setting. The 0.8 to 1.5 kg package produced is delivered by a cheese or cone winding head with an electrical pattern-breaker, and it contains only single component knots even when multifold yarns are produced, therefore re-winding may not be necessary.

The main attraction of this system is the low yarn tension involved which makes the method ideal for yarns finer than R37 tex/2, although yarns up to R100 tex/2 can be processed. Because of the low tensions, the folded yarns have higher elasticity and higher elongation at break than ring processed yarns. The absence of fly to adjacent spindles makes the system attractive to coloured-yarn producers, without the provision of expensive ancillary suction or blowing equipment. Twist distribution is very uniform because of the absence of balloon height changes in the second stage — twist variations due to the first stage are cancelled out by the over-end withdrawal at the second stage. The system is versatile in that it requires very little in machine adjustments when changing from one extreme count to the other; the first stage has a standard ring and bobbin size and only needs a traveller change, while the second stage only needs a change of twist insertion and perhaps a different yarn threading at the tension device mounted above the outlet hole of the container.

The two-stage system is not suitable for making STT yarns from ST yarns because the low twist of the first stage reduces the yarn strength; neither is it suitable for the wet-folding of cotton yarns, where it is necessary to apply moisture to the single components before twist is inserted.

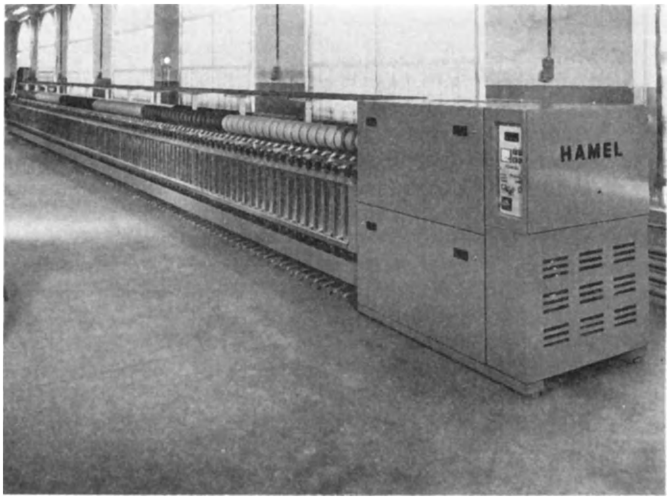

Plate 31. Second operation of two-stage yarn folding. This machine is a form of up-twister. The supply yarn package and the spindle-mounted vertical container enclosing it both rotate at about 9500 rev/min. The yarn is drawn upwards and is shown here being wound on to a cheese; alternatively 4°20′ cones can be used. Because of the absence of fly-waste, contrasting colours may be processed on adjacent spindles, as shown. Courtesy of Carl Hamel A.G.

Two-for-one yarn folding

Despite the yarn tensions involved this method is suitable for a wide range of yarn counts. It operates at spindle speeds up to about 14 000 rev/min for fine counts on 500 gramme supply packages or up to about 9000 rev/min for thicker counts on larger supply packages up to about 3 kg, but the twist insertion rate is twice the spindle speed because each revolution inserts two turns of twist.

The general principle of this method is shown in *Figure 16.1*. The most commonly used method of preventing rotation of the assembly-wound supply package is magnetic, although gravitational and epicyclic systems are also used. The threads, indicated by the broken line, are withdrawn from the stationary supply package via a yarn guide mounted on the freely-rotating arm. The yarn passes through the hollow rotating spindle and through an outlet hole near the bottom to form a balloon between the balloon separators. The yarn then passes through a guide and is taken upwards to a winding head as shown in *Plate 32*; in the event of an end-break or if a supply package runs out, the spindle and take-up package are both stopped.

Provision is made to control the yarn tension in the balloon and at the winding head; successful processing depends on correct tensioning of the yarn in order to obtain a uniform twist distribution.

Each revolution of the spindle inserts one turn of twist into the yarn passing down inside it, and at the same time rotates the balloon through one revolution thereby inserting twist in the balloon. The two turns simultaneously inserted are in the same direction, and therefore are additive.

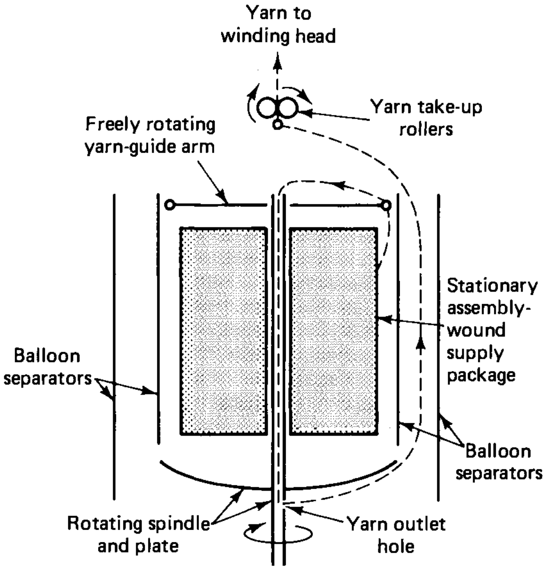

Figure 16.1 Principle of the two-for-one spindle (side elevation/section)

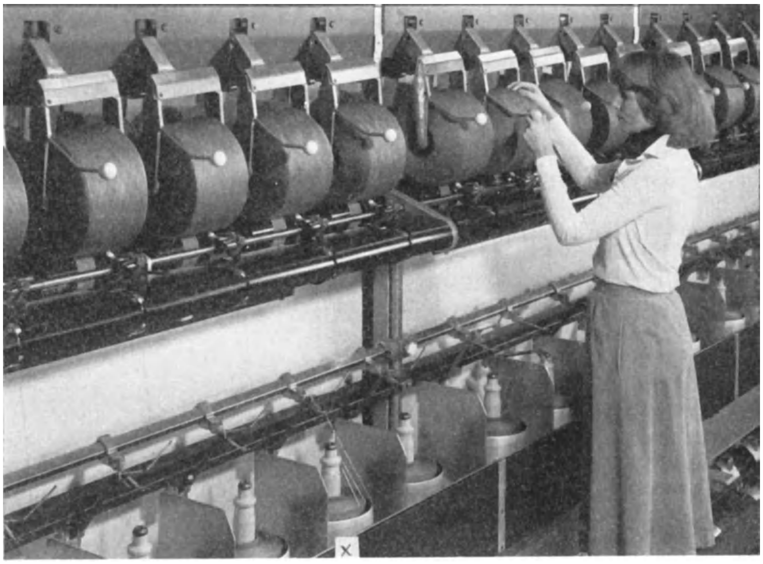

Plate 32. Two-for-one yarn folding. This particular machine can be used to fold yarns from R28 tex/2 to R84 tex/2 at spindle speeds up to 11 000 rev/min giving 22 000 turns of twist per minute; other models are available for other count ranges. On this model the yarn is supplied from two separate single yarn packages mounted one above the other on the spindle; the two threads can be seen best passing to the spindle top on the spindle marked X. At the same position the folded yarn can be seen passing from outside the cylindrical container to the yarn guide mounted vertically above the spindle. Courtesy of Volkmann GMBH & Co

Because the spindle pitch is wide — usually about 250 mm or more – the machines may be made with an upper and a lower deck of spindles. The two decks have independent control of spindle speed and direction of rotation, and each side of each deck can insert different amounts of twist. Because this method of twist insertion does not involve high speed rotation of either the supply or delivery package, it has a relatively low power consumption; large supply packages of up to 3 kg — depending on yarn count — mean that labour requirements are low, and re-winding may not be necessary. The system is eminently suitable for making ST yarns into STT yarns because assembly-winding is not necessary; it cannot be used for the wet-folding of cotton yarns.

A further developement of this system eliminates the need for producing an assembly-wound supply package. Instead, two smaller packages are mounted one above the other as shown in *Figure 16.2*. With this arrangement it is not possible to have a freely rotating yarn guide, and so the unwinding yarn drags up the sides of the supply packages as shown by the broken lines in *Figure 16.2*, and the top of the spindle has a smoothly curved profile to minimize yarn tension. Nevertheless, because of the greater tension, this method can not be used for some fine or weak yarns which can be processed on machines of the type represented in *Figure 16.1*.

Two-for-one machines may now incorporate a waxing or lubricating device, or yarn overfeed for soft packages for dyeing so that re-winding can be omitted under suitable circumstances.

Dual up/down folding

Machines of this type have combined up-twisting and down-twisting by rotating the supply package at a high speed while withdrawing the yarn over-end and then passing it down on to a conventional ring spindle.

This type of machine was widely used for the production of fine-count crepe yarns, and makes of machines included the Watson-Lister machine and the Saco-Lowell machine.

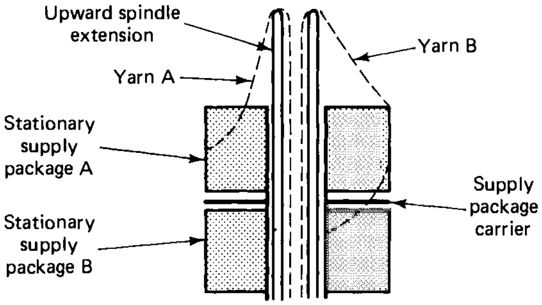

Figure 16.2 Two-for-one spindle with twin supply packages

The axifugal system

This system involves both spinning and folding in the same operation; it has already been described on *p* 172.

Spin-folding

This system was described on *p* 171 because it involves both spinning and yarn folding in one operation.

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17

YARN PREPARATION

After spinning or folding, yarns may be subjected to a number of processes, of which winding is the most widely used by yarn manufacturers. For a long time winding was considered to be a simple, unimportant, non-productive process because it merely transferred the yarn from one kind of package to another.

It is now appreciated that winding is important because of the opportunity it provides for fault removal and for the increased processing efficiency of subsequent processes.

If winding is performed incorrectly it can introduce yarn faults and although the difference in imperfections before and after winding without clearing is not generally significant, yarn hairiness increases each time a yarn is wound and the increase is greater at higher winding speeds.

During winding, advantage is taken to carry out operations such as yarn conditioning, yarn waxing, and yarn clearing, i.e. fault removal.

Other processes such as reeling, weft winding, and warping and sizing may also be carried out by the spinner although warping is frequently performed by the cloth manufacturer, and automatic Unifil pirn winding usually takes place at the loom when required.

The two packages most commonly wound by spinners are the parallel-sided cheese, and the cone (*Figure 17.1*)

The parallel-sided cheese package

The winding of a cheese allows a constant yarn speed to be used and so it is a useful take-up package for processes such as ST spinning and continuous filament yarn texturing where yarn is presented to the winding head at a constant rate.

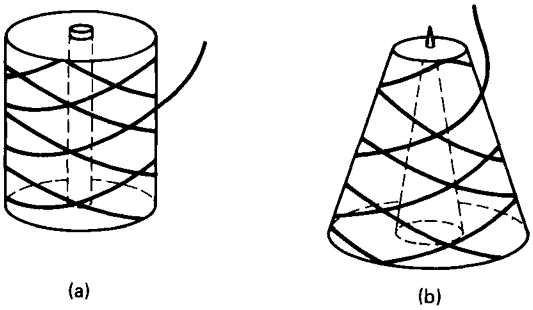


Figure 17.1 Commonly wound package shapes: (a) cheese; (b) cone

Cheeses are also used as an assembly-wound supply package for two-for-one yarn folding machines and for package dyeing.

Package dyeing requires a uniform low package density, particularly at the ends of the package, with the yarn wound on to a perforated former. The efficiency of wetting-out a package is inversely related to the package density.

Minimum package density is achieved with an angle of wind of 45° as defined later in this chapter but if a winding machine is to be used for both dyeing packages and normal packages, a compromise angle must be used. After dyeing a re-winding process is usually needed to release the perforated formers and provide a firmer package for further handling and transport.

For a cheese package the ratio diameter/traverse length is usually about 1.2 to 1.3 although larger diamter packages can be made; large diameter packages are less stable and more easily damaged.

Yarn may be unwound from cheeses either by side withdrawal and package rotation, or by over-end withdrawal.

The side withdrawal combined with package rotation method limits the yarn speed which usefully can be employed, causes problems with over-running of cheeses if a sudden stop has to be made, and leads to increased tension as the package radius decreases, but it does not cause any change of twist in the unwound yarn, and may be advantageous when unwinding flat yarns such as metallic decorative threads where the twist must not be varied.

If yarn is unwound from a cheese by over-end withdrawal, the twist is changed by an amount equal to $1/\pi D$ where D is the instantaneous diameter of the package. Hence the amount of change increases as the package empties; whether the twist change is additive to or subtractive from the yarn twist depends on whether the yarn twist is S or Z and on the direction of withdrawal. Therefore it is desirable always to place the packages the same way up so that unwinding takes place from all the supply packages in one direction of rotation only, when viewed from above. Over-end withdrawal of yarn from cheeses causes high yarn/package friction, the level of which changes as the package radius diminishes. This effect may be minimized by having a yarn guide which directs the yarn around a circular path with a radius greater than that of the package.

Cones have become the most popular package because they can be made larger than cheeses, and in high speed over-end unwinding the yarn tension can be controlled more satisfactorily; the ratio maximum diameter/traverse length is usually about 1.7, and the ratio mean diameter/traverse length, which is more directly comparable with the ratio used for cheeses, is usually about 1.4

Angle of wind

This may be defined as the angle θ between the direction of the yarn lay on the package surface and any plane perpendicular to the package axis *(Figure 17.2(a))* where AC is the instantaneous direction of winding at A and AB and BC are respectively perpendicular to and parallel to the package axis.

If an imaginary surface layer were peeled off and laid out flat, it would appear as in *Figure 17.2(b)*. If it is assumed that the linear speed of yarn traverse is constant even at the points of reversal:

$$\text{Tan } \theta = \frac{V}{2\pi r N}$$

where V = linear traverse speed in the direction of BC (m/min), r = package radius (m), and N = package rotational speed (rev/min).

The total yarn speed is the resultant of the traverse speed and the linear surface speed of the package:

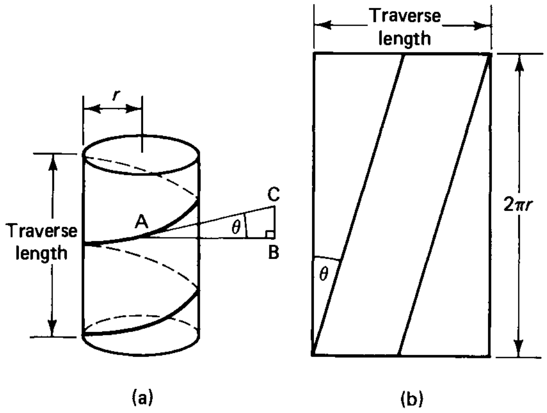


Figure17.2 Angle of wind(a) Instantaneous direction of winding AC on package surface. (b) Outer layer of package surface opened out flat.

$$\text{Total yarn speed} = \frac{\text{package linear surface speed}}{\cos \theta}$$

As a general rule, the greater the angle of wind, the better the package. However there is a maximum angle that can be wound without yarn slippage at the traverse reversals.

With a reciprocating traverse yarn guide, the power consumption increases with the cube of the winding angle.

Wind and traverse ratio

The wind is the number of coils of yarn wound on per single traverse from one end of the package to the other.

The traverse ratio is the number of coils wound on per complete traverse cycle, therefore it is twice the wind.

Traverse displacement

Without this arrangement, because yarn reversal at the traverse ends cannot be instantaneous, the relative amount of yarn wound in the proximity of the package ends would be greater than that on the rest of the package. Consequently hard package ends would be formed which would lead to poor package formation and would be particularly detrimental in packages for dyeing. By displacing the over-all traverse laterally by 3 to 5 mm, uniform package density can be arranged at the package ends.

There are two main types of winding machines: precision winders, and drum winders.

Precision winders

These machines have a positive drive to the spindle on which the package is mounted, and usually machines have a reciprocating yarn guide traverse driven from a cam shaft. This arrangement permits a precise ratio between the spindle speed and the traverse speed. Thus the angle of wind decreases as the package radius increases, but at the same time the wind remains constant and therefore can be selected to give the best conditions for a given yarn; patterning (or ribboning), described later, does not arise with a precision winder.

The speed of a conventional precision winder is limited by the reciprocating speed of the traversing yarn guide; high speeds entail intensive maintenance schedules which may be unacceptable in practice. It follows, therefore, that a higher traverse ratio permits faster angular velocity of the package, and a larger package former gives a higher initial yarn speed, and therefore a higher mean yarn speed.

Conventional precision winders are more versatile than drum winders in that just a few manual adjustments can convert a machine to wind a different type of tube, the slope of the package ends can be modified easily, and the length of the package can be varied over a wide range.

The speed limitations of the conventional precision winder can be overcome by using a grooved traverse roller instead of a reciprocating guide; mean yarn speeds in excess of 1500 m/min have been achieved by this method with the penalty of loss of versatility in choice of package formation.

Continuous filament yarns are usually precision wound because a surface contact drive might damage individual filaments; in this case mean yarn speeds from about 550 to 900 m/min may be used.

Precision wound cones also may be used as a weft supply for shuttle-less looms where the high yarn acceleration rate makes it an advantage to have no ribboning or even close-wound coils after a knot.

Precision winders are also used for sewing threads with cross-wound packages without flanges or on a tube with a conical base at one end for over-end withdrawal, similar to the pirn shown in *Figure 9.1(c)*; alternatively parallel-wound bobbins with two flanges may be used.

Some precision winders permit the choice of:

(1) constant spindle speed
(2) constant surface speed, or
(3) a combination of constant spindle speed followed by a constant surface speed.

Constant spindle speed

With this arrangement there is a variable yarn speed which may cause increasing yarn tension and increased package density in the outer layers unless there is some method of tension-compensation provided. The increased speed as the package size increases is advantageous in terms of the production rate.

Constant surface speed

This necessitates a progressive decrease of spindle speed at a rate influenced by the yarn count.

Combination yarn speed

With this arrangement initially the package is rotated at a constant spindle speed until the yarn speed increases to the required optimum; thereafter the yarn speed remains constant. This arrangement maximizes the production rate without using excessive spindle speeds or excessive yarn speed.

Most precision winding machines have attachments for yarn lubrication and provision to produce different cone shapes. Some are equipped with yarn overfeed devices to produce soft packages when required.

Drum winding machines

Because these machines drive the package by surface contact against a cylindrical drum running at a constant surface speed, frequently in excess of 1000 m/min, the mean yarn speed is approximately constant. Theoretically this makes easier the uniform application of additives such as lubricant. Machines usually incorporate a device to control package/drum pressure so that squashing out of the inner layers is avoided as the package size increases.

With drum winding the mean traverse speed remains constant, but as the package circumference increases its angular velocity decreases and hence the wind continuously decreases, but the angle of wind remains constant. One consequence of this is that if precautionary measures were not taken, then at various stages of the package build, ribboning or patterning would occur. That is, the yarn would return to exactly the same starting point and the next set of coils would be laid on top of the previous ones, thereby preventing the formation of a satisfactory package. To take a specific example: suppose the traverse ratio were 2.5 as shown in *Figure 17.3* which represents the surace layer of the package. In one traverse cycle the package would rotate 2.5 revolutions, forming the yarn path represented by the solid line 1 2 3 4 5. During the second traverse cycle the package would rotate a further 2.5 revolutions to lay the yarn on the path represented by the broken line 5 6 7 8 9. However, points 1 and 9 represent the same actual position on the package, hence at this particular package circumference ribboning would occur.

In the example shown in *Figure 17.3* there are 2.5 'diamonds' lengthways and 2 diamonds circumferentially.

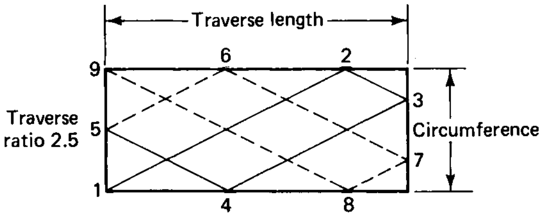


Figure 17.3 An example of ribboning

In general terms, when the traverse ratio = X/Y where *X* and *Y* are integers having no common factor, a full pattern repeat is completed in *Y* complete traverse cycles. The number of diamonds lengthways = X/2, and the number of diamonds circumferentially = *Y*.

In order to permit the formation of a satisfactory package, an anti-ribboning device must be incorporated on drum winding machines; the principles of the different types employed are described later.

It is important that if there is not an individual drive to each winding drum, the package should be lifted clear of the rotating drum when the supply yarn terminates or when the cone is full in order to avoid scuffing and sloughing of the outer layers; a better arrangement is to have the individual winding drum stopped so that after a knot has been tied, both the package and the drum will accelerate together giving a good yarn traverse immediately after the knot; such an arrangement minimizes yarn breaks during subsequent unwinding.

There are two main sub-divisions of drum type winders: the grooved drum winders, and the finger traverse winder.

Grooved drum winding machines

These are the most widely used winders for spun yarns. With this arrangement, the drum which rotates the package also traverses the yarn across the package.

The package-driving drum on modern machines has a continuous spiral groove around its circumference in which the yarn runs as it passes on to the package. The yarn is retained in the correct groove at the intersections by varying the depth of groove at these places, hence the yarn is traversed across the package without the limitations of speed and power arising from the inertia of a finger type traverse, permitting high winding speeds up to about 1200 m/min, lower power consumption, reduced maintenance costs, and reduced relative velocity between the yarn and the guide. There appears to be a maximum speed limitation imposed by centrifugal force. At very high speeds a shortening of the package length occurs which makes winding no longer possible.

The large contact area in the groove can cause twist displacement which could be a problem if it were periodic, therefore machines are usually designed to have a 'scrambling' effect on the twist displacement to avoid periodicity. With the grooved drum winder the package may be lifted clear of the winding drum at intervals of time to provide a package-speed variation which serves as an anti-ribboning device.

Finger-traverse drum winding machines

In this case the yarn passes through a finger guide which is carried across the face of the package by a traverse motion independent of the driving drum speed; this arrangement allows rapid alteration of the traverse ratio to cater for different yarns. The traverse speed is made to fluctuate in order to serve as an anti-ribboning device. The finger guide does not cause any appreciable twist displacement, but the traverse speed of a guide is limited by inertia considerations.

This limitation may be overcome by having two separately-mounted guides moving in opposite directions with the yarn being transferred alternately from one to the other.

Cone winding

Although it may not always be necessary to wind yarn after some processes such as open-end spinning, two-stage, or two-for-one yarn folding, conventionally-spun packages are usually wound on to cones for one or more of the following reasons:

(1) Cones are unwound over-end without package rotation, hence they give a low and relatively uniform unwinding tension at high speeds, sometimes up to about 1400 m/min depending on yarn properties. The over-end withdrawal of yarn from a stationary package causes one turn of twist to be inserted in the yarn for each revolution of yarn withdrawn, but this is only important in low-twist yarns such as continuous filament.

(2) Cones form a stable package which can be handled without the yarn sloughing off.

(3) A cone may have a longer length of yarn on it than a conventionally-spun package; this increases the productive efficiency of subsequent machines, releases spinning tubes for re-use, and

provides a standard package size for the yarn user regardless of the spinning package dimensions or the yarn count. Cones for apparel yarns are often made with a traverse of 150 mm and package mass of about 2 kg, but sometimes traverses of 200 mm with a package mass of about 5 kg are used; even larger packages may be used for thick carpet yarns, and can be expected for other yarns in the future.

(4) The opportunity is taken to remove faults from the single yarn, to be replaced by knots; this improves the end-product quality.

(5) Yarn additives such as lubrication and moisture can be applied under controlled conditions.

(6) Assembly-winding for folding or cabling may be needed; that is winding the required number of component threads alongside each other on to one package.

(7) Different coloured formers may be used to identify different yarn lots.

Cone taper

The taper of a cone is usually expressed in terms of the semi-vertical angle, i.e. between the cone axis and its sloping face.

A number of different cone angles have been developed such as narrow angled cones intended for high-speed unwinding where balloon formation takes place; these include 2° for shuttle-less weaving, 3°30' for continuous filament yarn pineapple cones and plain cones, and warp cones with an angle of 4°20'. These cones are made with a constant angle of taper as the package fills and they are not suitable for use in knitting where the relatively slow unwinding speed would not cause a balloon to form with the result that the yarn would rub on the package surface giving high and irregular yarn tensions. The hosiery cone is usually wound on a former with an angle of about 9°15' or 9°30'; by accelerating the traverse towards the nose of the cone the taper is made to increase up to about 14° or 16° on a full package. The curved yarn base so formed reduces the risk of yarn being trapped underneath, and unwinding tension variations are minimized by the graduated angle of taper, provided that the yarn guide is in line with the axis of the cone and at a suitable distance from the nose of the cone.

During winding, the surface speed of a rotating cone is less at the nose than at the base, hence when it is in surface contact with a cylindrical driving drum the nose must have a slower surface speed, and the base a higher surface speed, than the drum. This effect may be reduced to some extent either by using a conical driving drum, or by having the package axis not quite parallel to the axis of the driving drum so that the driven part of the package near the centre of the package length is in contact with the drum; the problem does not arise with a precision cone winder.

A hosiery cone with a traverse width of 150 mm has a maximum winding diameter/minimum winding diameter ratio of about 2.25 when empty with a 9°15' taper, and about 1.90 with a 16° taper when full. Consequently if yarn tension is insufficient there is the danger of a soft nose, formed when the cone is almost empty, being pushed out as the cone fills. A further point is that because there is proportionately less yarn deceleration at the nose of a full cone, the mean yarn speed increases as the cone fills.

Cones with a smaller semi-vertical angle suffer from this effect to a reduced extent; nevertheless the hosiery cone is now used for many purposes besides machine knitting.

Yarn tensioning

When yarn is unwound over-end from spinning cops there is a fluctuation of yarn tension with peaks occurring when unwinding from the nose, and minima when winding from the shoulder. As more of the empty tube is exposed there is a significant increase in mean tension and in tension variation. With parallel roving build there is a gradual increase in peak tensions and mean tension.

Tension fluctuations at source make it difficult to wind yarn at a constant yarn tension because the coefficient of yarn friction varies with pressure changes caused by tension variations.

Although gate tensioning devices may be used in winding, they are usually used when processing continuous filament yarns. The most commonly used tensioning method for spun yarn winding is disc tensioning in which the yarn is drawn between two discs which have either adjustable spring loading, or dead-weight loading to apply the required tension to the yarn. There is very little difference between their performance, except that the compression spring type can usually apply higher loads if required, and because thicker yarn increases the spring compression, it is more sensitive to count variations than the dead-weighted type. Because the yarn/guide coefficient of friction is influenced by yarn speed and yarn tension a change of either may necessitate an alteration to the load applied to the tension unit, as may a change from one type of fibre to another; accurate tension measurement is essential in order to be able to produce satisfactory packages. Some machines incorporate self-compensating constant tension devices and may incorporate a diminishing tension unit which operates in conjunction with the package diameter.

Winding tension may cause weak places in the yarn to break, facilitating their removal and thereby reducing stoppages in subsequent processes; winding tension should be about 10% of the mean yarn breaking load in order to satisfy this requirement. With natural fibres this means that thin places will be removed, but with strong synthetics and blends this does not necessarily follow.

Yarn tension also makes an important contribution towards package stability, but too high a winding tension may permanently impair the elastic properties of a yarn and cause fabric faults such as stripiness, barriness, or streakiness. With some fibres, high yarn tension combined with excessively high regain can cause local yarn stretching which causes short tight picks — called fiddlestrings or shiners — when the fabric is finished but normal regain variations at moderate tensions have little influence and so a humidified atmosphere is not essential for the process.

Package stability and density

The hardness of successive layers must gradually decrease from the inside to the outside of a package, otherwise bulging may occur, i.e. the soft inner layers may be squashed out at the ends of the package.

Package density depends on three factors: yarn tension, applied package/drum pressure, and angle of wind.

In the case of precision winders, yarn tension is the main means of controlling the package density although machines may have a presser roller which applies reducing pressure to the package surface as its diameter increases. With drum winders package hardness is controlled mainly by the pressure between the package and the drum.

Yarns with a higher elasticity need a lower yarn tension/drum pressure ratio in order to avoid subsequent yarn retraction causing increased pressure to develop on the inner layers. On the other hand too low a yarn tension/drum pressure ratio may permit the yarn to slough-off. These considerations are of greater importance with continuous filament yarns.

Cob-webbing (or cross-threading) is a fault which can arise by using a traverse ratio which is too high. It consists of yarn at the end of the package taking a short-cut from one point on the circumference to a point further round, instead of following the curved circumferential path. Such a fault can cause tension peaks or end-breakages during unwinding.

Yarn clearing

It has been estimated that of the faults present in a yarn as spun, 10% will cause stoppages in warping, 20% will cause stoppages in weaving, and in worsted fabrics, 70% may require burling and mending. Burling and mending is uneconomic in cotton-spun materials, and technically impractical in most knitted fabrics.

It is apparent, therefore, that fault removal is economically desirable either to reduce burling and mending costs, or to avoid rejects and seconds, and to increase the efficiency of subsequent processes. When faults are removed they are usually replaced by a knot. In most fabrics a knot may be acceptable, but in some fabrics, such as fine cotton-spun poplin shirtings, a knot is still regarded as an unacceptable fault. As an alternative, yarn jointing by adhesive has been used for very thick yarns; a more recent development is yarn splicing, which is increasing rapidly in popularity.

A major problem which arises in yarn clearing is that two requirements need to be satisfied at the same time. On the one hand yarn faults which are tolerable should be allowed to remain in the yarn, but on the other hand all unacceptable faults should be removed. Failure to resolve this problem results in either faulty fabrics or a reduced winding efficiency; the practical solution involves a compromise between yarn quality and winding efficiency. Excessive fault removal may result in a yarn so full of knots that it resembles barbed wire; this may be more objectionable than some of the faults such as neps, which may have been removed.

Yarn faults vary in length and in thickness; as a general rule the frequency of faults is approximately inversely proportional to their size, i.e. small faults are frequent whereas large faults are relatively seldom. Faults which may be unacceptable in one fabric may be passable in another, hence there is no absolute scale of fault tolerability.

The performance of yarn clearers can be assessed in a number of ways:

Yarn clearing efficiency factor (E)

$$= \frac{\text{number of faults removed}}{\text{total number of objectionable faults}}$$

Such a measure on its own is of doubtful value because it does not take account of different fault types. For example, a clearer with an efficiency factor of 0.99 may remove 99 slubs, and leave in one length of spinning double, but the length of spinning double might prove to be as expensive as the 99 slubs would have been; in this example the weighted efficiency factor would be only 0.5.

A further method of assessment is the knot factor:

Knot factor (K)

$$= \frac{\text{total number of clearer breaks}}{\text{number of objectionable faults removed}}$$

This measure takes account of spurious breaks which may be defined as the number of tolerable faults which have been removed: the nearer the knot factor is to unity, the more successful is the clearing method as far as winding efficiency is concerned.

From the efficiency factor and the knot factor it is possible to calculate the total number of breaks actually arising:

Total number of breaks = $E \times K \times n$

where n = the number of objectionalble faults.

There are two main groups of yarn clearers: mechanical, and electronic. The yarn clearing efficiency factor is usually about 0.5 to 0.6 for mechanical clearers, and usually in excess of 0.9 for electronic ones.

Mechanical clearers

Although a wide variety of mechanical clearers has been used, they form two main types: blade clearers, and comb clearers. With a blade clearer the yarn passes between two smooth sharp-edged plates placed close together; if a thick fault cannot pass between them then it becomes trapped and is broken or cut. Too close a setting can cause yarn abrasion which impairs the yarn quality. Comb clearers must be set further apart than blade ones in order to avoid surface fibres actuating the comb. A fault which is too thick catches into the comb teeth, causing the comb to pivot against a stop thereby trapping and breaking the yarn. It is difficult to clear single worsted yarn with a comb clearer without causing surface fibre disturbance which spoils the yarn appearance. Constant yarn tension is required to prevent the yarn from jumping and catching into the comb.

Mechanical clearers may efficiently remove thick slubs, but they cannot adequately detect long faults, such as spinnner's double, which are only twice the normal yarn count, or thin yarn places. They also cause a substantial increase in yarn tension before the yarn breaks at the fault.

Electronic clearers

An important feature of modern electronic clearers is that they can be designed to descriminate between fault length and fault thickness, including thin places, which is particularly advantageous with strong synthetic yarns and blends; they also can provide information to a centralized monitoring system which can present statistics relating to winding efficiency, reasons for stoppages, etc.

Compared with mechanical clearers the greater degree of yarn clearing obtained with electronic clearers means that they are not such an economic proposition on non-automatic winding machines.

Clearly electronic clearers offer the possibility of being able to select which length and thickness groups of faults shall be removed, and although sophisticated clearers are more expensive, the use of higher winding speeds makes them an economic proposition.

Electronic clearers consist of a number of basic sections which include the power supply, measuring head, amplifier and evaluation unit, and a yarn cutter which is electromagnetically actuated to sever the yarn when an unacceptable fault is detected. Care must be taken to keep clearers clean, particularly the measuring head and the cutter; more frequent and thorough cleaning is required when oil-combed worsted yarns are processed compared with dry-combed.

Clearers are frequently classified into two groups according to the method of measurement: photoelectric, and capacitance.

Photoelectric clearers

The basic requirements for this system are a light source and a photoelectric cell between which is interposed the yarn to be cleared so that the amount of light received by the photocell is determined by the yarn thickness. Hence the output voltage of the photocell varies approximately as a function of the yarn diameter.

This method has the outstanding advantage of being only slightly influenced by even large differences of regain; consequently it may be preferred for clearing acrylic yarns immediately following the bulking process.

On the other hand, since the yarn diameter is proportional to $\sqrt{(\text{count})}$, the diameter differences between faulty and normal yarn sections are smaller than are the mass differences, therefore the limits of response must be very accurately maintained.

The main disadvantages include that yarns of the same count may differ considerably in diameter if they are made from different fibre blends, or with different twists and this influences the measurement of a photoelectric clearer. Therefore it is not possible to to set the clearer solely according to the yarn count; the shape of a fault may also influence its detection, and ageing of the photocell and light source may influence the clearer sensitivity.

Pulses of invisible infra-red radiation can be used instead of visible light to give improved long-term stability of the light source and also to avoid any interference from variations in room lighting as well as minimizing the influence of differences in yarn colour, although the latter still has some influence on the measurement.

Capacitance clearers

The measuring system is based on the same principle as the Uster levelness tester, i.e. the variation in capacitance produced by a change of dielectric in a high-frequency circuit; the variation in capacitance is proportional to the mass of the short length of moving yarn between the plates of the capacitor.

The sensitivity of this type of clearer can be adjusted by setting a knob calibrated directly in yarn count, or a proportional scale, without it being necessary to run any preliminary trial runs, but different fibre types may require different settings to obtain the same level of clearing for a given yarn count. Large differences in the mean regain of the yarn can alter the actual level of fault detection unless the clearer setting is altered accordingly. consequently it is preferable to ensure uniform conditions in order to maintain constant levels of clearing. An even greater effect can be caused by short-term variations of regain within a given yarn, hence clearing should be delayed until there is an even distribution of moisture in a yarn; changes of relative humidity during winding and clearing can influence which faults are removed by a capacitance clearer.

Nevertheless industrial experience with capacitance clearers has shown that problems associated with variations in moisture can be overcome and that reliable performance can be obtained over a long working period.

Control of yarn fault content

The control of yarn fault content has been aided by the development of yarn fault analysers. For example, the Uster Classimat is a six-head winding machine equipped to count faults with respect to 16 classes ranging from A1 to D4, based on four length groups A to D, and four thickness groups 1 to 4 (*Figure 17.4*). The results, normally based on winding at least 100 km of yarn, give a quick assessment of the number of yarn faults in each group and enable decisions to be made regarding the degree of clearing to be used.

A given electronic clearer has a particular basic 'clearing line', the shape of which may be adjusted to some extent, and which may differ from the clearing lines of other types of clearers. Provision is made to alter the over-all position of the clearing line to give different degrees of yarn clearing: the broken lines X, Y, and Z in *Figure 17.4* represent hypothetical clearing lines corresponding to different degrees of fault removal. Line X would give the most severe yarn clearing, and line Z the least; all faults above the line and to the right-hand side would be removed.

The decision as to which line would be most appropriate in a particular case would depend on consideration of the following factors:

(1) Which faults would be objectionable in the particular yarn application.
(2) Whether it would be cheaper to clear during winding, or to mend the faulty fabric.
(3) Whether single knots, or spliced yarn joints, would be acceptable for the particular end-use.

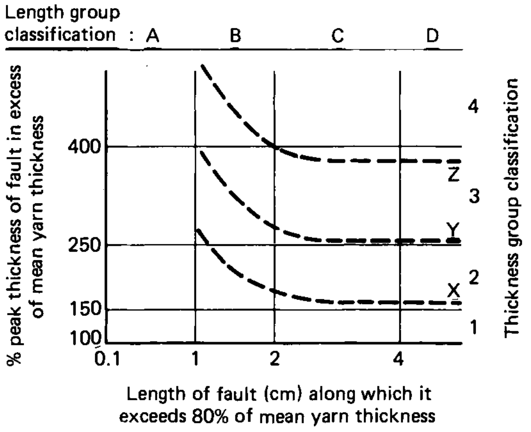


Figure 17.4 Uster classimat yarn fault classification

Knots

Mechanical knotters are used, either hand operated on manual winding machines, or automatically operated on automatic winding machines; more frequent cleaning and maintenance is required when oil-combed worsted yarns are processed compared with dry-combed.

Of the many knots available the most commonly used are dog knots, and fisherman's (or back-to-back) knots, and weaver's knots (*Figure 17.5*).

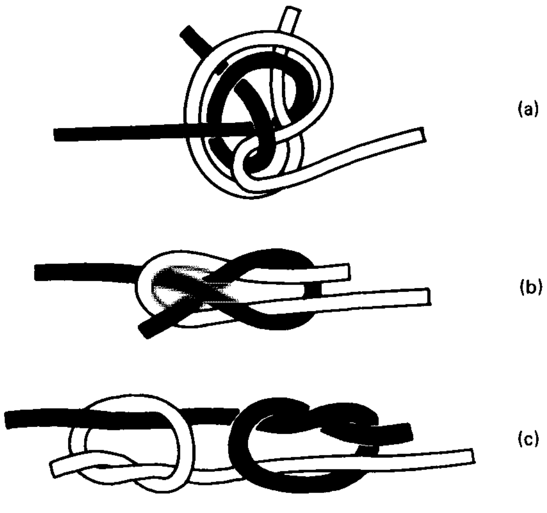


Figure 17.5 Some commonly used knots: (a) dog knot; (b) weaver's knot; (c) back-to-back or fisherman's knot

The tying of dog knots is simple and quick, but because the knot is bulky it is really only suitable for creeling where the knots will not be incorporated into the fabric. Fisherman's knots are popular for cottons, woollens, worsteds, and blends; some yarn slippage occurs when the knot is subjected to repeated tensioning, but provided the knot is correctly tied it is unlikely to fail in a warp yarn during weaving.

Weaver's knots are most popular in the cotton section of the industry, although they are also used to some extent in the worsted section.

Yarn splicing

A development which is bound to increase in popularity at the expense of automatic knotters is the automatic splicer.

The general principle of operation is that the two yarns to be joined are held and cut at the splicing point. The two cut ends are inserted either into a mechanical device which tapers them and intermingles the fibres, or into an air vortex tube which untwists them and extracts the loose fibres thereby forming two tapered yarn ends. The two ends are then drawn back until only the correct length for splicing is exposed; turbulent air then intertwines the fibres from the two yarn ends to form a splice. The joined yarn is then withdrawn and some twist enters the splice by rotation from the adjacent yarn so that a typical splice strength is at least 75% of mean yarn strength.

The advent of splicing alters the degree of fault removal as compared with knotted yarn; smaller faults can be removed economically because normally a splice is not easily visible in the final product.

Compared with knotters, splicers are more reliable; there are fewer moving parts and therefore, apart from the cutter, less maintenance is required.

Different nozzles may be needed for different yarn types; the only other adjustments needed are for air pressure and splice length.

Spliced yarns permit fewer yarn breaks in subsequent processes such as knitting, weaving, and tufting, giving increased productive efficiency and a lower product fault rate.

Yarn conditioning

Most winding machines are equipped with a plastic roller which is part-immersed in water and driven in the direction opposite to that of the yarn which contacts the upper surface. An increased roller speed increases the amount of moisture picked up by the yarn, provided that there is a constant yarn speed, arc of contact, and level of solution.

In addition to water the solution may contain additives such as rust inhibitor, anti-mildew compound, and a wetting agent.

Yarn waxing

Because knitted fabric dimensions are critically dependent on kinetic yarn friction, paraffin wax with a suitable melting point is usually added to machine knitting yarns in order to provide a low uniform yarn tension. For worsted yarns the wax melting point should be from 52 °C to 63 °C, but for acrylic yarns which have higher frictional properties than most other yarns even when well-lubricated, the best results are obtained with a melting point of 60 °C to 66 °C; the wax should be capable of removal by normal fabric finishing processes.

As the amount of wax added to an unwaxed yarn is increased, the yarn friction reaches a minimum in the region of from 0.3 μg/cm up to 0.8 μg/cm regardless of yarn count, after which further increases of wax cause a yarn friction increase; the friction of a waxed yarn is almost independent of the yarn friction before waxing. Yarn should be used in knitting within three months of having the wax applied.

Less difficulty is usually encountered when lubricating spun yarns than with continuous filament yarns made of the same polymer.

Yarn waxing confers the following benefits:

(1) Fewer yarn breaks during knitting,
(2) A more uniform and reproducible fabric, and
(3) Less fly waste at the knitting process.

Four main methods of adding wax which are in common use are briefly described here:

Free-running gravity units

The yarn passes either beneath a horizontal wax ring, usually about 38 mm diameter and 16 mm thick, with a vertical central hole about 12 mm diameter, and above a horizontal stainless steel disc with a vertical peg on which is located the wax ring, or else between a vertical wax ring and a vertical stainless steel disc with a horizontal peg and a weight-and-lever loading device.

The disc and ring are free to rotate at a high speed as the yarn is drawn between them. Inadequate wax application can be caused either by too high a load on the ring causing the yarn to be thrown outwards due to the high rotational speed, or by bouncing or binding of the ring due to accumulated fly waste.

With the horizontal ring the best performance is obtained by having two wax rings, one above the other; when the lower one is worn away, another one is placed on top.

Because the wax on a running yarn is rapidly re-distributed by wax being deposited on yarn guides from which it is later removed as it becomes molten due to the yarn/guide frictional heating, local variation in the applied wax distribution does not give rise to yarn friction variations of any significance, provided that an adequate amount of wax has been applied.

Free-running gravity waxing units are the simplest and cheapest type; provided that they are correctly maintained and operated they are as satisfactory as any of the more complicated types.

Power-driven waxing units

The yarn passes between a wax ring and a metal washer, or between two wax rings which are keyed to a positively driven horizontal shaft, usually with a slow surface motion in the direction opposite to that of the yarn. Pressure is usually controlled by a weight-and-lever system.

With this arrangement the pressure does not cause the yarn to come out from between the rings, and it remains virtually constant as the wax wears down, hence a uniform waxing is achieved provided that the device is properly maintained.

Emulsion lubrication units

With this arrangement an emulsion is added by using a conditioning roller as described previously. This method is not suitable for adjacent yarns containing different fibre types or colours, or for yarns where an increased moisture content is undesirable.

It used to be claimed that this method laid-in fibres and reduced the amount of fly waste in knitting, but trials at Hatra (the Hosiery and Allied Trades Research Association) indicated that wax is marginally better in this respect.

Molten waxing units

A thermostatically-controlled constant-level reservoir supplies molten wax to a porous tube over which the yarn runs to pick up the wax. Because oxidation of plain paraffin wax may occur, synthetic waxes may be recommended.

Yarn length measurement

Accurate measurement can reduce waste in processes such as warping, knitting, and tufting. Methods of length measurement include:

(1) Counting the revolutions of the driving drum on the winding machine. The inaccuracy of this method is in excess of about ± 2.5% between different spindles.

(2) Counting the number of revolutions of the package. Again differences of yarn tension between spindles will give rise to length variations.

(3) Measurement of the package diameter; once more difference will arise due to yarn tension differences between spindles.

(4) A mini-radar system in which the change of frequency on reflection from a moving target is measured; this method is not likely to be adopted for small 'target areas' such as yarns, except in inaccessible places or at high speeds such as in continuous filament yarn processes. An accuracy of ± 2% has been achieved at 3000 m/min.

(5) Electrostatic yarn length measurement (the Hatra system). This is a direct measurement method using an electrostatic charge mark at equal length intervals along the yarn, giving an accuracy within ± 1%.

(6) A contact wheel rotated by the passing yarn. This method can be arranged so that the contact wheel is mounted on a freely-running shaft which carries a small permanent magnet. Because inertia is almost eliminated a contact angle of 120° or more ensures the virtual elimination of yarn slippage. It can be arranged so that the electrical amplification which normally actuates a counting device is stopped instantaneously if an end breaks. This method only increases the yarn tension by about 20 mN and can give an accuracy of ± 0.5% if it is calibrated for different yarn counts, compared with ± 3.7% obtained with a contact wheel and directly-mounted mechanical counter.

Automatic yarn winding

The development of automatic winding has greatly reduced the labour requirements of the winding process and along with the developement of electronic yarn clearers has been a major factor leading to the almost universal adoption of single yarn winding and clearing except for self-twist yarns which can only be cleared in the twofold state. This is in spite of the fact that the hairiness of both conventional cotton and worsted, as well as OE yarns is increased by winding.

On the other hand capital costs are higher and a better standard of maintenance is required, but these are off-set by the much higher productivity so that, for example, the total cost per kilogramme for automatic winding of 15 tex yarn may be about half the cost of manual winding.

Bunch knots tied in the folding operation are never fully satisfactory because of the irregularities of tension and twist which they cause. Single yarn clearing virtually eliminates them and this is advantageous for most products, particularly for sewing threads. Broken ends are automatically re-tied* provided that sufficient yarn is left on the supply package.

Automatic winding has also enabled a degree of yarn clearing to be used without a great loss of winding efficiency, and which would be uneconomic with manual winding, without causing undue surface fibre disturbance even when a keen clearer setting is used.

Winding efficiency may be defined as the actual production rate expressed as a percentage of that which would be obtained if there were no stoppages.

The degree of automation on automatic winders can vary considerably from machines which require manual doffing and creeling including removal of underwinding coils on spinning cops, to machines which orientate and creel supply packages and machines which incorporate automatic doffing. There are three main types of automatic winding machines:

(1) Machines with one automatic knotter* per winding head,
(2) Machines with a traversing knotter* to serve a number of spindles, and
(3) Carousel machines in which the winding heads circulate past a fixed control unit incorporating a magazine and knotter*.

There is a higher winding efficiency obtained with type 1 particularly when winding thick counts where frequent knotting* is required. Lower winding efficiencies are obtained with winders having a larger number of spindles per knotter*, but as the capital cost of such a machine is lower it may be advantageous to use such a machine for fine count yarns where the differences between winding efficiencies of the different machine types is less significant.

Machines with one knotter per winding head*

This type of machine has the highest winding efficiency and the highest capital cost. Fewer demands are made on each knotter* therefore the likelihood of knotter* failure is reduced and in the event of failure only one spindle is affected. If the number of breaks per four supply bobbins went up from 1 to 8, the loss of winding efficiency would be in the region of only about 5%.

*Machines with a traversing knotter**

These machines usually have each section of about 10 spindles served by one traversing knotter* which is usually set to make three attempts to tie-in* the supply yarn if difficulty arises; knotters* are usually successful in about 85% of all first attempts, and more so in subsequent attempts. Failure at the third attempt illuminates a lamp to attract operative attention.

Carousel winding machines

Machines of this type have the winding heads moving past a stationary control panel (*Plate 33*).

The more recent versions have from 10 to 24 winding heads, with 4 to 6 machines per operative, depending on yarn count, package size, etc. The operative may doff full packages, place supply packages in the magazine and deal with yarn breaks with which the automatic knotter* cannot cope. With these machines each winding head passes the control panel at intervals of about only 15 to 30 seconds thereby minimizing waiting time before knot* tying when an end breaks.

* or alternatively splicer/splicing

Yarn steaming and storage

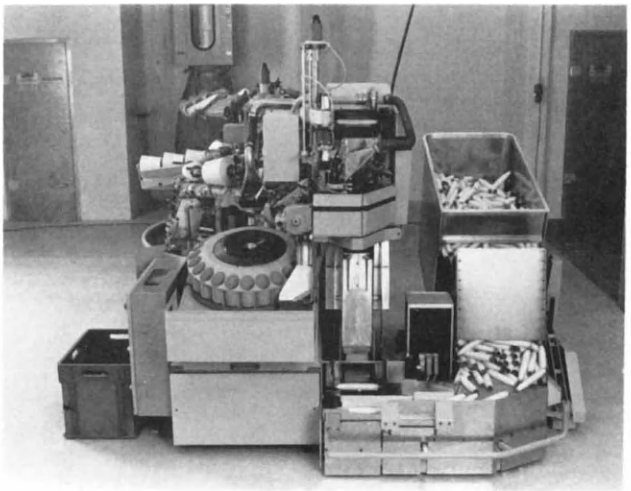
Freshly-spun single yarns show a tendency to snarl which may cause difficulty in later processes and/or lead to yarn fault formation.

In more leisurely days, yarns used to have moisture added during winding before being stored in a cellar to permit the decay of stresses inserted in the fibres during spinning and folding; in a standard atmosphere it takes from 10 to 20 days for relaxation to be complete.

Local concentrations of moisture in excess of about 9% regain for cotton or 24% regain for wool, and atmospheric moisture in excess of about 70% R.H. are conducive to the development of microbiological attacks, such as mildew, which may cause discolouration and loss of strength. The presence of impurities such as size on cotton, or oils, fats, and nitrogenous substances on wool, or sized paper package formers, may aid such an attack; jute is more susceptible to such attacks because of its chemical composition. Consequently adequate control of yarn conditioning during winding, and atmospheric relative humidity during storage is important.

Yarn steaming can relax the fibres very rapidly so that subsequent cellaring is not worthwhile. Vacuum steaming with an autoclave which provides an alternating cycle of vacuum/steam at about 98 °C for wool and 120 °C for synthetics ensures rapid uniform treatment so that if subsequent dyeing is required it will be evenly applied; condensation on the fibres must be avoided.

The removal of yarn from storage to a drier atmosphere would lead to a gradual change of



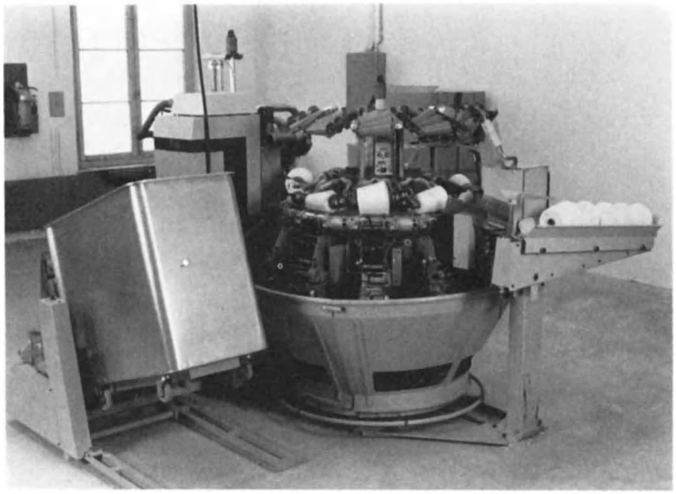


Plate 33. Fully automatic winding machine. This is a carousel type of machine in which the 10 winding heads traverse past a stationary control unit. As shown in view (a) the spinner cops are aligned and loaded automatically into the magazine the correct way up, with the yarn end located and the underwinding coils removed. The control unit splices (or knots) the yarn as required. When packages contain the required yarn length (within ± 0.3%) the full package is doffed automatically, as shown in view (b), and an empty cone tube is fed in for winding to re-commence. Naturally, facilities for automatic yarn clearing and waxing, etc, are provided. Courtesy of Schweiter Engineering Works Ltd.

regain which might cause changes in fabric dimensions. Steaming of ST yarns before knitting is essential.

Yarn mercerizing and the Prograde process

The mercerization of cotton in yarn and other forms is a well known process which has been in use for many years primarily to increase the yarn strength and lustre; it also increases dyeability. It is usually associated with high strength/high modulus products such as sewing threads and industrial yarns, but other developments include knitting yarns, for example.

The process basically consists of immersing the yarn in either hank or warp form in a solution containing sodium hydroxide and a wetting agent, followed by rinsing, neutralizing, and drying. The factors of alkali concentration, temperature, time of treatment, yarn tension, and yarn twist all influence the end-product characteristics.

Mercerizing in the absence of tension causes shrinkage in excess of 30% and the yarn then exhibits greater elasticity and a higher elongation at break. If lustre is to be developed, tension is applied to a low-twist yarn to prevent shrinkage and the elastic properties are then almost unchanged. Conventional fabric strength is usually increased by about 15%, but twistless yarn fabric strength is increased by about 40% by mercerizing.

A more recent development which produces a similar type of effect is the Prograde process in which fewer knots are introduced compared with mercerizing. The Prograde process basically consists of a winding process at about 200 m/min in which the yarn is immersed in liquid ammonia followed by stretching in hot water and then by hot air drying before package formation; bleaching or dyeing may then follow.

Compared with untreated cotton yarn, the characteristics conferred on the yarn by this process include:

(1) An increase of 50 to 100% in tenacity,
(2) A reduction of about 33% in elongation at break,
(3) A small increase in loop strength and knot strength,
(4) Dimensional stability to bleaching and dyeing processes.
(5) Increased yarn lustre, and
(6) Increased dye affinity.

Yarn singeing

This process, sometimes called gassing, consists of passing the yarn through a heater at speeds varying from 200 to 800 m/min; there is an optimum speed depending on the type of fibre.

The heat may be provided either by gas flame or electrically; 20 to 30% higher speeds can be used with gas. The yarn is delivered on cones usually weighing from 1.5 to 3.0 kg.

Singeing is used to remove surface fibres from man-made fibres, blends, spun silk, cotton, and wool yarns where smoothness and lustre are important, an example being some sewing threads.

Variations in singeing conditions can introduce shade variation in subsequently dyed yarn.

Yarn sizing

This process usually forms part of the warping process although it may also incorporate dyeing. It consists of applying size to the yarn with the object of minimizing damage to warp yarn during weaving by temporarily increasing the yarn tenacity and abrasion resistance, and reducing the yarn hairiness; the size is removed during subsequent processing.

A typical size frequently contains a starch adhesive such as potato or sago or sodium carboxy-methyl cellulose with the possible addition of tallow to act as a lubricant to minimize abrasion.

As the percentage of size added to the yarn is increased there is at first a rapid yarn strength increase, followed by a slow increase up to a maximum beyond which further additions to size make little difference.

The abrasion resistance of sized cotton yarn is significantly influenced by yarn twist and its variation.

Sizing is commonly used on cotton-spun single warp yarns and to a lesser extent on single worsted-spun warp yarns; it is more usual for worsted warps to be made from two-fold yarns; for OE yarns it is possible to use lower concentrations of size mixture and to omit the squeeze rollers because of the greater absorption properties of OE yarns.

Yarn polishing

This consists of passing an already-singed cotton-spun yarn in contact with burnishing surfaces or brushes. It is usually carried out in conjunction with another process such as drying after sizing, and wax may be added.

The object is to lay-in the surface fibres to promote yarn smoothness and reduce friction in processes such as sewing.

Yarn reeling

Reeling basically consists of winding yarn on to a rotating swift from which the yarn may be removed in the form of a hank after having the ends tied together.

Yarn may be reeled into hanks for scouring, mercerizing, dyeing, bleaching, bulking, occasionally for retail sale as hand knitting yarn, and for export because of the saving of space and tare weight, and the reduced possibility of mildew formation when winding tubes are not present. Care must be taken to avoid the formation of periodic shade variations when yarn is processed in hank form.

There are two types of reeling which may be employed:

(1) Lea reeling

The hanks are built up in parellel-wound sections; a leasing band is inserted to facilitate unwinding.

(2) Cross-reeling

This consists of repeatedly traversing the yarn across the full width of the hank so that adjacent yarn coils cross each other at an angle; this minimizes yarn entanglement during wet processing. A band is inserted through the completed hank to facilitate handling. Machines usually offer a choice of traverse ratios, and hanks of 2.5 to 5.0 kg may be reeled.

The swift usually consists of six light-weight alloy staves supported equidistantly around the central driving shaft; the maximum stave length is usually about 4 m to minimize distortion. Swift speeds range from about 250 to 550 rev/min, depending on the type of yarn to be reeled and on the supply package. Usually the swift stave support arms are made telescopic to enable different hank girths to be produced and to enable the swift to be collapsed for easy removal of the full hanks. Swifts are made either with a retractable bearing or with a cantilever bearing which permits hanks to be slid from the end of the swift.

Modern reels are available in two versions: change reels, and double reels.

Change reeling machines

Essentially these consist of two swifts 4 m long supported in a single pivoted frame. Each swift may be brought alternately into the running and then the doffing position so that while at one side of the machine hanks are being reeled under the supervision of one operative, at the other side tying and doffing can be carried out by a second operative. Alternatively groups of machines may be shared by a group of operatives; the method of deployment of operatives depends on the reeling time, which is influenced by swift speed, yarn count, and hank length required. When reeling time is more than five minutes or so, change reeling offers the highest form of productivity.

Double reeling machines

This type of machine, which has two swifts each 2 m long supported in cantilever fashion from the central headstock, may be preferred for reeling when hanks take less than about five minutes reeling time. Each swift is provided with independent driving, controlling, and measuring equipment.

Bundling

For convenience in handling and transport, hanks may be combined together to form bunches and a number of bunches may then be put together to form a bundle of about 5 kg. A hydraulic press is used to form a compact bundle which is tied by bands before the pressure is released.

Yarn balling

The commonest form of delivery for hand knitting yarn is now 25, 50, or 100 gramme balls.

Frequently after hank dyeing the large hanks are unwound into cans and the cans are then used in the creel of the balling machine.

Basically the machine consists of up to 16 vertical spindles, each of which carry a collapsible 'umbrella' former around which the yarn is traversed by a flyer rotating at about 950 rev/min in a vertical plane parallel to the spindle axis.

Hank-to-cone winding

After dyeing and/or bulking it may be necessary to transfer yarn from hank to cone. Such a process is not entirely satisfactory because yarn entanglements on the hank can cause snatching, tension peaks, and sometimes yarn breaks.

The machine is basically similar to cone winding machines already described except that an adjustable-girth-swift creel is provided for the hanks. Electronic controls may be provided to prevent over-running of the hanks, to actuate creel and winding-head stop motions in the event of entanglement or end-breakage, and automatically to re-start in the event of self-disentanglement.

To isolate the winding head from the supply tension fluctuations, feed rollers draw yarn from the hank to provide a positively controlled winding tension. Winding may take place from hanks of up to 2 kg at speeds of up to about 600 m/min.

Pineapple cones

The pineapple cone is used for continuous filament yarns wound on a former of 3°30′ with a profile as shown in *Figure 17.6*.

The precision wound package has little risk of the coils slipping down and catching underneath the

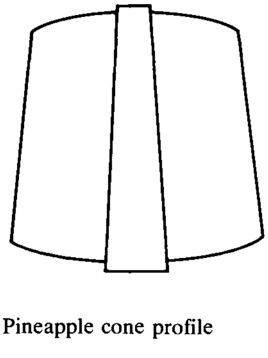


Figure 17.6 Pineapple cone profile

base because of the curvature which allows the yarn to slip back up easily. As a result a greater wind can be used and therefore a higher spindle speed can be employed.

Knots can be placed on the taper at the upper end where they do not interfere with the yarn delivery. The package is ideal for supplying knitting machines.

18

STATIC ELECTRIFICATION AND ATMOSPHERIC CONTROL

Since better understanding and control of static electricity has been developed efforts have been made for its use in applications such as fibre separation, transport, alignment, and in fabric finishing, but prior to these developments, static was mainly known for its nuisance effects.

Static electricification

Even before man-made fibres became widely used the problem of static electrification of fibres during processing was considered to be of such importance that it was the subject of the first technical publication of the World's first Textile Research Association: the precursor of Wira (the Wool Industries Research Association).

With wool, an atmosphere of 72% R.H. at 16° to 21°C reduces static problems such as high end-breakage rates in spinning, and roller and fly waste in drawing (which may be the cause of slubs) very effectively. On the other hand excessive humidity causes fibres to lick around (i.e. adhere to) rollers because of the formation of a film of moisture on the rollers.

In recent years the increased use of the comparatively hydrophobic synthetic man-made fibres in conjuction with warmer and drier indoor environments has led to greater problems than those encountered with the generally hygroscopic natural fibres. This can lead to difficulties in processing, annoying electric shocks for workers, discomfort in wear, the soiling of textiles, and in some circumstances, the danger of explosion due to static discharge.

In yarn manufacturing processes difficulties arise because the fibres are all charged with the same polarity and therefore repel each other while being attracted to any conductor and in particular to the processing machinery.

It is now thought that charged particles, not necessarily electrons, migrate from one surface to the other when separation takes place, and that relatively few ions need to migrate in order to produce the charges observed in practice; there is no mass-flow of ions and therefore static elimination involves equalizing a relatively small excess of positive or negative ions. Static formation cannot easily be avoided, therefore the removal of the excess charge is the most practicable remedy.

In general, most textile fibres are positive to substances with which they come into contact although PVC fibres generate a negative charge which, it is claimed, alleviates the symptoms of rheumatism and similar complaints.

It seems that there are two mechanisms involved in the formation of static:

(1) When surfaces of different substances are separated, static is apparent if the surfaces retain their charges. Further separation reduces their mutual capacitance and results in an increase of the potential difference; this may be called the mechanism of charge separation.
(2) When heat is generated by the rubbing together of identical surfaces, charged particles tend to migrate from hot to cold regions; this may be called the thermal effect.

This theory accounts for the anomalies of some research in which reversal of polarity may have been observed. When dissimilar materials are rubbed together static may be formed simultaneously by both causes, but the polarity of charge separation may be opposite to that of the thermal effect, hence a change of rubbing intensity could lead to a reversal of sign of the resultant static charge. Such reversals have been observed on textile yarns when changes of speed and pressure have been made.

The rollers, rather than inter-fibre friction seem to be responsible for most of the static produced in drawing, spinning, and other similar processes wherever material is withdrawn from machinery or other bodies against which it has become electrified by contact.

The dissipation of electrostatic charges during processing

Static dissipation may take place in one or more of the following forms:

(1) Gaseous discharge
(2) Fibre conduction, or
(3) Anti-static conduction.

Gaseous discharge

This may take place between the emerging material and the machine rollers if electrification has been heavy; it takes place spontaneously across the air gap while the surfaces are still in very close proximity at the commencement of separation and it has the effect of limiting the maximum charge density.

A further reduction of charge can be obtained by holding a suitable conductor close to the moving web or sliver of fibres thereby causing a local concentration of field which then initiates gaseous discharge.

The earthing of a machine does not reduce the problem of static on the fibres being processed even though it may be desirable from the safety point of view because it allows the charge to leak rapidly from the machine; passing the material in contact with an earthed bar of any thickness is more likely to increase the formation of static.

Static eliminators operate by forming ionized air containing both positive and negative charges which pass on to the charged surface to balance the excess charge. To be successful they need to be placed 40 to 150 mm from the charged textile and there should be no conducting surface in contact with the charged textile, or earthed metal parts between the charge to be neutralized and the eliminator. Static eliminators may be used in warping, winding, and sizing, but the operating speeds must allow the yarn to dwell in the eliminator field for a sufficient length of time.

Fibre conduction

Conduction through the fibres towards the point of contact with the machine may take place if the fibres themselves are good conductors. Hygroscopic natural fibres have an advantage in this respect, and wool for example, readily absorbs and retains electrolytes so that static is dissipated rapidly by conduction at a relative humidity of 55 to 65%. There is an inverse linear relationship between the log of the electrical resistance of a natural fibre and the log of its moisture content, hence humidification may be of assistance in this respect. The inclusion of natural fibre in a blend with synthetics may improve the fabric performance regarding static.

Anti-static conduction

If a suitable anti-static solution (antistat) has been applied, surface tension droplets just beyond the point of charge formation may serve to act as a liquid 'bridge' to allow virtually immediate dissipation of the charge at source.

An anti-static is a substance which provides ions, and so long as a suitable relative humidity is maintained it retains moisture so that the ions can move along its surface. A surface-spreading antistat may have a hydrocarbon layer in contact with the fibre and an adsorbed layer of moisture on the outside; the effectiveness of many antistats deteriorates after storage for a period of, say, a month after application to the fibres.

For most antistats there is an optimum concentration in the region of 0.2 to 0.5% on fibre mass; small additions give poor static control, and greater additions cost more with little improvement.

The complete elimination of static at the spinning process can lead to a greater incidence of spinning double, described on p. 218 although the provision of adequate pneumatic underclearers reduces the likelihood of this.

The dissipation of electrostatic charges for the consumer

A simple and adequate rating of the anti-static properties of a fabric is chararacterized by the measurement of its surface conductivity.

With the widespread use of central heating and synthetic-pile carpets, consumers soon became aware that unpleasant electric shocks could arise under normal domestic conditions. This was at first countered by making the carpet backing conductive and by spraying an anti-static on to the pile. However subsequent shampooing could render such a treatment ineffective; anti-static treatment of products for the benefit of the consumer should be reasonably durable as regards time and wear.

The development of electrically conductive fibres was an obvious line to follow in order to confer permanent static control regardless of atmospheric conditions. In clothing such fibres may be of advantage in situations such as explosives manufacture, powder technology, hospital operating theatres, or oxygen-enriched atmospheres where explosion might be a hazard and in sensitive situations where personnel are working in areas of high electromagnetic fields.

On such product described in 1957 was a viscose yarn incorporating 30% of acetylene carbon black. A further development along these lines was the introduction in 1973 of continuous filament and staple fibre nylon and polyester in which were embedded fine particles of carbon; such products have been named 'epitropic'. For safety clothing up to 5% by mass of the fibre may be necessary, but for comfort in clothing up to 0.5% may be sufficient, and in carpets about 1% should be adequate. An obvious disadvantage is that these fibres are black, which makes them unacceptable for pale shades.

The addition of metal fibres such as stainless steel may cost 3.5 to 9 times as much as an anti-static additive but they are very durable.

Stainless steel fibres in 7 ktex slivers with mean fibre lengths up to 150 mm are available in 8, 12, and 25 μm diameters which respectively correspond to about 4, 9, and 39 dtex, with a density of 7.88 g/cm^3. Additions of 0.3% by mass have given adequate static control in carpets in conjunction with a suitably conductive backing, but greater percentages would be required in finer yarns for clothing to obtain sufficient electrostatic continuity.

Sliver blending is used at the gill box for worsted-spun yarns, and at the drawframe for cotton-spun yarns; for woollen-spun yarns the stainless steel fibres are introduced into the intermediate feed sliver during carding subsequent to any crushing rollers.

Stainless steel is also available in continuous filament twistless tow and in twisted yarn form; the latter may be used to form a core yarn with a staple fibre sheath.

Decorative metallic continuous filament yarns also confer protection against static.

Atmospheric control

Moisture has a profound influence on the properties of textile fibres and on their behaviour in processing.

Too high a humidity may cause licking of fibres on rollers and other machine parts as well as general condensation on machines, windows, and walls; too low a relative humidity may also cause difficulties due to static.

In practice atmospheric control can vary from a simple temperature control and 'humidifier' to a full air conditioning plant. The addition of moisture in the form of a fine spray in the workroom may give rise to local areas of excessive humidity in order to obtain the required hygrometer indication and this can sometimes cause problems in processing.

A complete air conditioning plant involves the use of air washing and filtering, room temperature control by warming or cooling, air movement through ducting controlled by automatic mixing dampers, and the control of relative humidity; the movement of air is particularly important from the point of view of human comfort for which 20°C at 65% R.H. seems to be the optimum.

The re-circulation of air conserves the heat and moisture already in the atmosphere and may be linked with automatic waste separation and filtration for handling bulk wastes from textile processes. The final stage of filtration may include an electrostatic precipitator to remove fine dust particles so that the re-circulated air does not provide a health hazard. Electrostatic filtration may be advantageous where white yarns, particularly synthetic, are produced, but in less severe conditions a cheaper type of filter may be adequate.

Besides re-circulation, it is necessary to bring in outside air at such a rate as to dilute the room air to maintain the required temperature and humidity. The volume of air circulation needed for any given cooling load is dependent on the temperature difference between the air being supplied and the required room temperature. The magnitude of air currents may be of the same order as those set up by moving machinery such as ring spindles; the use of underfloor air removal reduces the danger of fly waste contamination which may be caused by the increased movement of air.

In tropical and sub-tropical climates there are often prolonged spells of heat accompanied by either high humidity or dryness which makes full air conditioning necessary, including refrigeration; in some cases it may be possible to operate without refrigeration for part of the year. Refrigeration is used to lower the air temperature so that moisture is lost by condensation. The air is then re-heated to give the required temperature and relative humidity before being passed into the working environment; the addition of refrigeration more than doubles the capital cost of an air conditioning plant. The need for refrigeration is also increased by the requirement of a lower relative humidity. The recommendations for relative humidity during spinning have been reduced in some cases and there is a growing tendency for some spinning rooms to operate at 40% R.H. or even lower.

In the temperate zones the problem is not acute and although discomfort may be experienced during hot summer weather, difficult uncontrolled indoor processing conditions usually only arise in dry frosty weather. In the U.K. outdoor humidity may range from 35 to 100% R.H. and uncontrolled factory atmospheric conditions may be 15°C to 27°C with 30 to 80% R.H.; frequently partial air treatment by humidifying and warming may be satisfactory.

Side-effects of atmospheric control

The object of atmospheric control in yarn manufacture is mainly to improve the control of static, but a number of subsidiary aspects are also worth noting:

(1) Fewer changes of draft are made because of the more uniform regain of the fibres.
(2) Less wear of spinning rings occurs at lower relative humidities, although traveller wear seems to be unaffected.
(3) The coefficient of friction of fibres may vary with changes of relative humidity in a manner which is influenced by the type of fibre lubricant employed. In general the coefficient of friction of yarns is increased as relative humidity increases.
(4) A safe maximum humidity for storing textile materials approaching equilibrium regain from the dry side appears to be about 70% R.H. if the development of mildew is to be avoided.

Recommended processing conditions

For both worsted carding and combing an initial fibre regain of about 22% is recommended with a relative humidity of 68% to 80%. For worsted drawing an initial regain of 17 to 19% with 65 to 70% R.H. at 21°C for oil-combed processing and 70 to 80% R.H. for drawing dry-combed wools gives the best results. Spinning in an atmosphere of 60% R.H. or less gives the best overall results, taking into account rubber waste, fly-waste, and end-breakage rates; the regain of the spun yarn depends almost entirely on the relative humidity of the spinning room.

On the woollen system a relative humidity below 50% usually gives rise to problems with static in the carding process and the best conditions are in the region of 15°C to 21°C with 60 to 70% R.H. The recommended humidity for spinning is 50 to 60% R.H.

In general, because of the cellulose fibres develop much smaller static charges than the protein fibres, a lower atmospheric humidity may be used when processing them.

For cotton opening processes 20°C to 25°C with 50 to 55% R.H. is normally used, whereas for carding, combing, and drawing 50 to 60% R.H. is recommended. The end-breakage rate in cotton ring spinning is at a minimum in an atmosphere of 21°C to 25°C and about 40% R.H.

The control of atmospheric conditions is important when spinning polyester and blends; recommended values for short staple processing are: 22°C to 24.5°C with 50 to 54% R.H. for the cardroom, and 24.5°C to 26.7°C at 38 to 42% R. H. for ring spinning — if fibre fusing occurs in high speed ring spinning it may be necessary to reduce the temperature to 18°C to 21°C in spinning.

Variations of relative humidity have negligible influence on the OE spinning process, but 60 to 65% R.H. for cotton, and 40 to 45% R.H. for viscose develops maximum yarn strength and maximum fibre extent although the conditions inside the rotor differ from those in the spinning room, and depend to some extent on the type of fibre being processed.

In flax processing in general optimum processing conditions are obtain with 18°C to 24°C at 60 to 65% R.H. for the preparatory processes, and 60 to 70% R.H. for the spinning process.

In general the conditions recommended for man-made fibre processing fall within the limits of 50 to 65% R.H. at 21°C to 27°C, with nylons at the lower end of the R.H. scale, acrylics in the middle, and polyester at the higher end.

Travelling cleaners

In order to minimize the likelihood of faults being caused by stray fibres, travelling cleaners may be employed. These are usually suspended from an overhead monorail support as shown in *Plate 21* and consist of the combination of high velocity blowing nozzles which keep the frames and ceilings clean, and suction nozzles which pick up the waste from the floor and collect it in storage chambers for periodic emptying.

Cleaners of this type, providing about 20 to 40 air changes per hour, are advantageous with any kind of frame spinning; for the ring spinning of polyester and blends they are essential.

Further reading

MORTON, W. E. and HEARLE, J. W. S. *Physical Properties of Textile Fibres (2 ed)* Textile Institute/Butterworths (1975)

PATEL, S. P. and SUBRAHMANYAM, K. *Air Conditioning in* Textiles Mills A.T.I.R.A., Ahmedabad, India (1974)

19

YARN PROPERTIES

The assessment of yarn properties has been the subject of a considerable amount of work. There are many characteristics which combine to give an individual yarn its own distinctive properties. The main characteristics are dealt with in this chapter.

Irregularity

Yarns can vary in properties such as strength and twist, and although it has been argued that fabric irregularity is closely correlated with the apparent variation of yarn diameter nevertheless the unqualified term 'yarn irregularity' is usually taken to mean the variation of mass per unit length or a closely analogous characteristic; similar forms of irregularity may be found in laps, slivers, and rovings. Variations in twist, strength, and diameter are to a large extent secondary or tertiary effects of the variations in mass per unit length.

It is important to appreciate that all spun yarns are to some extent irregular; it is the *degree* of irregularity which determines whether it is acceptable or not for a particular end-use.

Because the appearance of many fabrics is influenced by yarn irregularity this is frequently regarded as one of the most important yarn characteristics although in some end-uses such as industrial fabrics, interlinings, pile fabrics, and carpets, it may be relatively less important, but long-term count variation may be important in order to control total pile mass per unit area.

Although the general principles of yarn irregularity apply to yarns made from all fibres, the detailed irregularity may differ depending on fibre dimensions: yarns produced from very short fibres may contain short variations in thickness caused by fairly abrupt changes from thick to thin and vice-versa, whereas longer fibres will bring about a more gradual change; fibres with a greater variation of their diameter will form more irregular yarns than similar length fibres which have less variation of fibre diameter.

Fibre length and diameter are by far the most important properties which determine the spinning behaviour of fibres; there is a strong correlation between mean fibre length and yarn irregularity. There is also a strong correlation between increased yarn irregularity and the combined increase of the mean fibre length and its coefficient of variation.

Gross variations in yarn thickness such as neps and slubs are usually described as 'yarn faults' and are regarded separately from irregularity.

Yarn irregularity becomes apparent in fabric form and a simple visual assessment can be made on a rapidly produced knitted sample; this method does not necessarily indicate whether a yarn would be acceptable under other conditions.

Yarn irregularity may be assessed visually by wrapping the yarn round a board and although this test may seem to be useful for comparative purposes, it is subjective and the assessment is difficult to describe; furthermore a single yarn boarding is an inadequate sample.

In fabric the visual appearance of short-term yarn irregularity can be influenced by the fabric design — for example widely spaced stripes may appear more irregular than closer ones of the same yarn.

The basic method of testing yarn mass irregularity consists of cutting and weighing yarn lengths in a standard testing atmosphere and calculating the mean and coefficient of variation. This is *the* fundamental method, and it formed the basis for calibration of other methods. Because it is slow, tedious, and labour intensive, it is not used in modern routine work.

Electronic capacitance testers are now firmly established as a convenient and reliable method of testing irregularity; other methods are rarely used. The material under test is drawn between the plates of a condenser. There is a close correlation between yarn count and the capacitance tester reading; the changes of capacitance brought about by alteration of the total fibre cross-sectional area between the plates enables the automatic indication of the mean and mean deviation (U%) or coefficient of variation (C.V.%).

The ratio C.V.%/U% is 1.25 for a normal distribution, and 1.11 for sinusoidal variation in yarns.

Because variations in yarn moisture content can influence the results obtained, tests could be carried out under constant humidity conditions with the instrument at a stable equilibrium temperature.

The Uster levelness tester permits the testing of different material thicknesses at various speeds and additional apparatus such as the spectrogram and imperfection indicator (which counts thick and thin places and neps) can also be used.

There is a significant correlation between fabric appearance and Uster C.V.% although the capacitance type test tends to underestimate visual variations; a thick low-twisted place in the yarn could give a similar value to an apparently thin place with a high twist content. In general up to a point increased twist in a given yarn causes an apparent decrease of yarn irregularity when measured by the capacitance method.

The main factors involved in the formation of short-term irregularity already have been described in Chapter 5. These are: limit irregularity due to random fibre arrangement; imperfect fibre control which in roller drafting leads to drafting waves varying in amplitude and length; and mechanical defects. The form of relationship found between actual irregularity and limit irregularity in worsted slivers is shown in *Figure 19.1*. It can be seen that the two lines are approximately parallel: in other words the additional amount of irregularity due to lack of fibre control and mechanical defects is approximately constant for the different sliver counts.

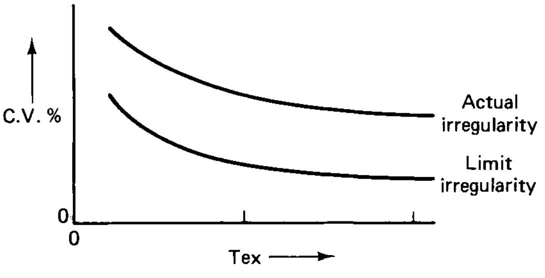


Figure 19.1 Relationship between actual and limit irregularity

The coefficient of variation of a folded yarn can be estimated from the given single component yarn coefficient of variation:

$$\text{C.V.\%}_f = \frac{\text{C.V.\%}_s}{\sqrt{C}}$$

where $\text{C.V.\%}_f$ = folded yarn coefficient of variation,

$\text{C.V.\%}_s$ = single component yarn coefficient of variation, and

C = the number of single components in the folded yarn.

The pattern of irregularity in a drawn and spun yarn is a complex combination of wavelengths introduced at each stage of drawing and in spinning. The most prominent wave is the one with the shortest wavelength — introduced at the spinning frame (except for open-end spun yarns in which the doubling of fibres inside the rotor reduces the influence of drafting waves).

In the yarn the wave introduced at roving has a longer wavelength because it has been drafted; waves originating further back from spinning have longer wavelengths still, but because doublings are used they have lower amplitudes in the resultant yarn. An example to illustrate this is shown in *Table 19.1*, where it has been assumed that the average wavelength of the drafting waves introduced at each process in a cotton drawing set is 60 mm.

It is important to appreciate that although long-term count variation may be influenced by the number of doublings used during drawing and spinning, the short-term irregularity is hardly influenced by this factor or by the conventional use of auto-levelling at or before the beginning of a drawing set, and that there is no single number which can describe fully the irregularity characteristics of a yarn.

This may be illustrated by references to two hypothetical yarns A and B for which the continuous records of mass per unit length are represented in *Figures 19.2(a)* and *(b)*. Although the two charts clearly indicate that the yarns are very different, the coefficients of variation within 10 m lengths are the same.

The difference between the yarns can be demonstrated by measuring the coefficients of variation

Table 19.1 *Origins of drafting wavelengths in a cotton-spun yarn*

Origin of wave	*Draft*	*Mean wavelength in yarn (m)*
spinning frame	36	0.06
roving	6	2.16
second drawframe	10	12.96
first drawframe	7	129.60

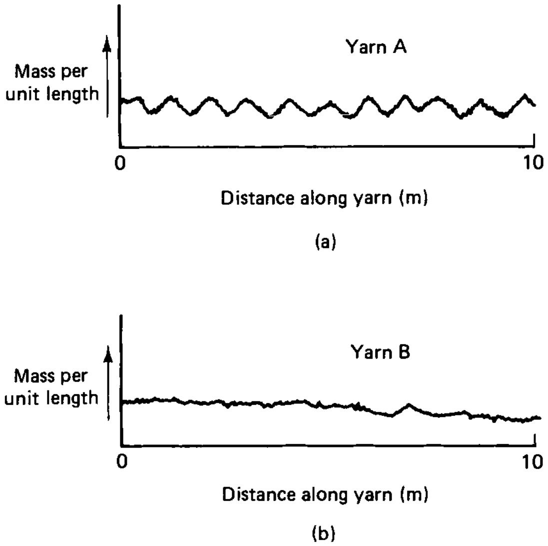


Figure 19.2 Charts of two yarns with the same C.V. (10 m)

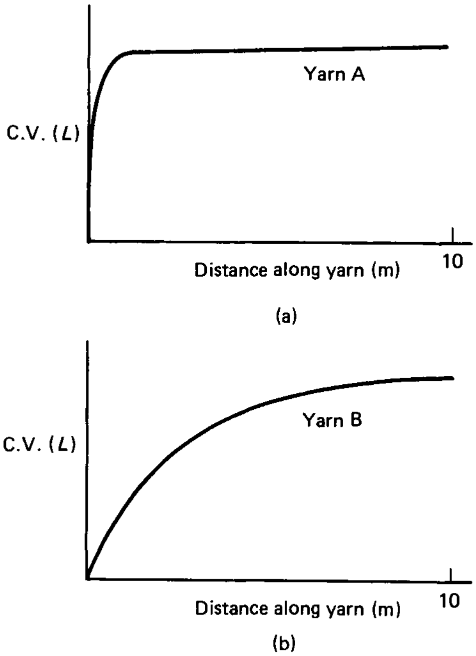


Figure 19.3 Comparison of C.V.(L) curves for yarns with same C.V. (10 m)

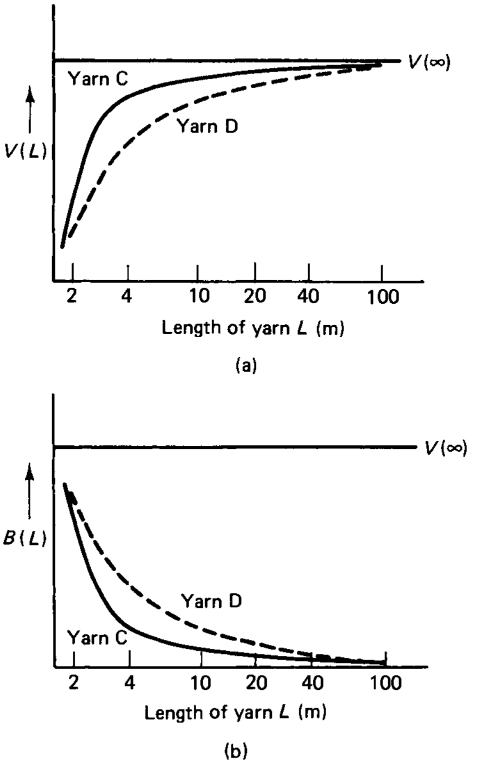


Figure 19.4 Comparison of V(L) and B(L) curves for two yarns with the Same V (∞)

within different lengths such as 1 m, 2 m, 6 m, 10 m, . . . and plotting these results against the length measured. The curve plotted for each yarn, called the *CV*(*L*) curve, meaning the C.V. within length *L* of the yarn is shown for yarns A and B in *Figure19.3(a)* and *(b)*, respectively. It can be seen that yarn A reaches the limiting value within the first metre whereas yarn B increases more gradually until it reaches the maximum *CV*(10 m) at 10 metres. If 20 metres were tested, a higher maximum would be reached — *CV*(20 m), and if all the yarn were tested the total irregularity — *CV*(∞) would be reached.

Alternatively the C.V.% *between* lengths of yarn could be ascertained, for example the C.V.% between one hundred 100 m hanks, one hundred 50 m hanks, and so on. By plotting the C.V.% against the sample length the *CB*(*L*) curve is obtained, that is the C.V.% *between* lengths L.

Because of the additive property of variance it follows for any specified length *L* that

$$(CV(L))^2 + (CB(L))^2 = (CV(\infty))^2$$

provided that all measurements are made on independent random samples from the bulk of the yarn. The square of the coefficient of variation is normally known as the 'relative variance' or 'mean standardized variance', and the above relationship is more usually written

$$V(L) + B(L) = V(\infty).$$

Hence it follows that the variance-length curve (V(L) is the mirror image of the *B*(*L*) curve as shown in *Figure 19.4(a)* and *(b)*. It is clear that when *L* is very small, $B(L)$ approaches $V(\infty)$, and $V(L)$ approaches zero.

Comparing the two yarns C and D it can be seen that although $V(\infty)$ may be the same for both of them, $V(5\text{ m})$ would indicate that D is better than C as regards short-term irregularity, that is, C would appear to be streakier than D. On the other hand $B(80\text{ m})$ would indicate that C is better than D as far as long-term irregularity is concerned, thus D might form weft bars in woven fabric or greater knitted garment weight variations than C.

These comparisons are not contradictory; they reflect differences which might show up in fabrics. This example illustrates that no single measure of yarn irregularity is sufficient for making a meaningful comparison of the irregularities of different yarns.

Although the variance-length curve is a very useful tool is it not suitable for revealing periodic variations.

Index of irregularity

Index of irregularity (I)

$$= \frac{\text{actual yarn irregularity C.V.\%}}{\text{limit irregularity C.V.\%}}$$

This provides a convenient expression to indicate how nearly a yarn approaches the 'ideal' irregularity; it is usual for I to decrease as material passes through the drawing and spinning processes.

Typical average values of I range from 1.2 to 1.4 for worsted yarn, 2.3 to 3.3 for carded short staple yarns, and 1.5 to 2.2 for combed short staple yarns, whereas at the beginning of the drawing set values of 10.0, 8.0, and 5.5, respectively, may be regarded as quite normal.

Correlograms

The analysis of irregularity which is known to contain a random component and may contain a periodic component may be carried out by calculating the 'correlation periodogram' or serial 'correlogram'. This is the degree of correlation between the local yarn mass at cross-sections of the yarn separated by different length intervals. When this technique is used for roving and yarn investigations it shows that sliver and yarn irregularity is an amalgam of complex waveforms arising at different machines during processing, with the amplitude reduced by subsequent doubling and the wavelength increased by subsequent drafting, it also reveals the diffence in character between different yarn types.

Two hypothetical correlograms are shown in *Figure 19.5(a)* and *(b)*. The yarn represented at (a) has maxima at points 1, 2, 3, . . . which indicate a maximum positive correlation between points which are L, $2L$, $3L$, . . . apart. It these correlations were unity they would indicate a strictly periodic motion of wavelength L. Normally they are much less than unity and no strict periodicity exists. The yarn represented at (b) shows a maximum negative correlation between points $0.5L$ apart, and no correlation between points L, $2L$, $3L$, . . . apart. This indicates a tendency for the chart to oscillate with wavelength L but each wavelength is so heavily damped that it does not complete one cycle and furthermore there is no constant phase relationship between successive tendencies towards periodicity. Damped waveforms have been found in normal cotton processing and in highly irregular worsted yarn, although normal worsted yarns may not show this tendency.

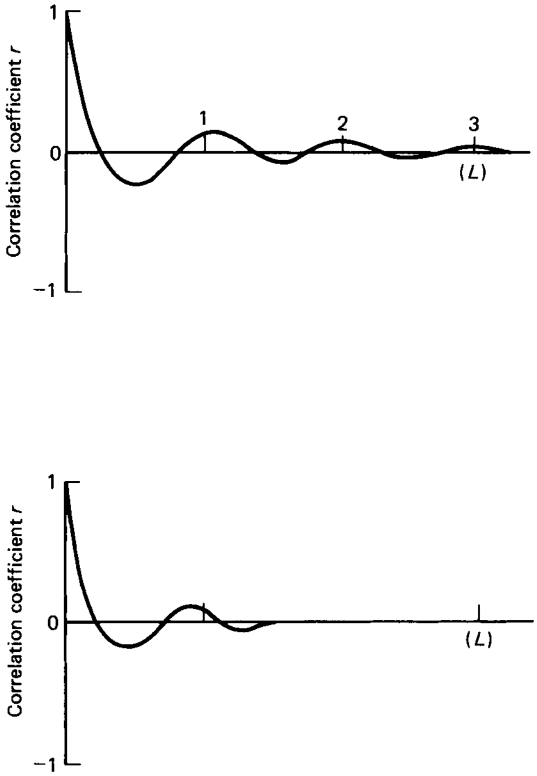


Figure 19.5 Correlograms: (a) some positive correlation at points 1, 2 and 3; (b) virtually no correlation

Periodicity

Irregularities introduced by faulty machinery are frequently periodic or intermittently periodic and can be expected to give rise to large peaks in the correlogram. Periodic yarn faults easily give rise to diamond barriness in fabrics; the cloth width:

wavelength ratio required to conceal a periodic fault is critical. Periodicity of shade variation may correspond to the package dimensions used in dyeing or some other process.

The coefficient of variation of short-term irregularity is not a sensitive measure as far as periodic yarn faults are concerned. The reason for this can be illustrated as follows:
With a sinusoidal variation,

$$\text{C.V.} = \frac{\text{percentage amplitude}}{\sqrt{2}}$$

Suppose a machine inserts a periodic variation with an amplitude of 10% into a yarn which otherwise would have a C.V. of 20%, then:

$$\text{C.V.}_{\text{p}}\% = \sqrt{\left\{20^2 + \left[\frac{10}{\sqrt{2}}\right]^2\right\}} = 21.2\%$$

where C.V.$_{\text{p}}$% = C.V.% of the periodic yarn. Hence the periodic yarn C.V. of 21.2% is not much different from a normal yarn of 20% C.V. and yet the periodic fault would probably cause an objectionable fabric appearance.

Spectrograms

A useful device for analysing yarn periodicity is the Uster Spectogram which performs a harmonic analysis of the periodic irregularities in a yarn and displays them in the form of a spectrum, the ordinates representing the proportions of irregularity associated with the wavelength represented by the abscissa on a logarithmic scale.

A typical spectrogram chart for a normal yarn is shown in *Figure 19.6(a)* and that of a yarn containing a prominent periodic fault in *Figure 19.6(b)*.

In general when the exposed 'chimney' height $P \geqslant 1/3H$ where H is the total 'chimney' height, the fabric may be downgraded, depending on the end-use of the yarn.

Long-term count variation

This is usually expressed in terms of the coefficient of variation between hank lengths such as 100 m or 50 m.

In the case of drawn-and-spun yarns, long term irregularity arises from variations either between groups, between bobbins, or within bobbins.

Between group variation represents the differences between spinning frames, frame sides, and times of spinning (days, shifts, and doffs), whereas between and within bobbin variations represent the count variation within bobbins if more than one hank is reeled from a bobbin, and between bobbin variation arises between hanks taken from different bobbins which were spun in the same doff.

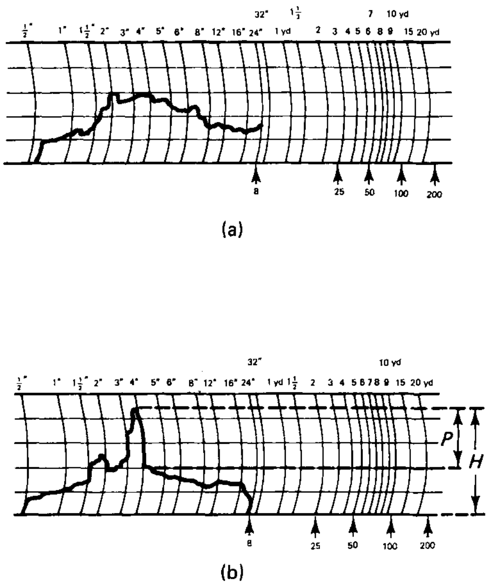


Figure 19.6 Uster spectrograms: (a) normal yarn; (b) periodic yarn

In condenser-spun yarns the draft in spinning which is usually less than 2, leads to a change in fibre alignment rather than in a true drafting action. Consequently the pattern of yarn irregularity is almost entirely governed by the carding operation; the condensed slubbing irregularity characteristics are basically the same as the subsequent yarn irregularity characteristics unless a faulty spinning process is used.

The irregularities in condensed slubbing can be divided into:
(1) variation along the slubbing, and (2) variation between the slubbings.

Long-term variations along the slubbing can be due to variations of hopper weighings, missed hopper weighs, or the influence of fibre retention in the card clothing after fettling. Variations of this type can be reduced considerably by using a Wira autocount.

In addition to variations between slubbings which represent differences between cards, between condenser heights, and between times of carding, variations between yarns also include variations between spinning frames, frame sides, and times of spinning (days, shifts, doffs).

Variation between the slubbings can be considerable — a range of 10 to 20% in count between 80 metre hanks of simultaneously produced ends is quite common. Differences between slubbings tend to be persistent over a period of a few days — light ends remain light, and heavy ends remain heavy even though long-term variations are superimposed;

the pattern may vary over the course of a few months.

The variation across can be broken down into four components:

(1) trends in mean web thickness across the card,
(2) small random variations,
(3) differences between different condenser bobbins, and
(4) inter-tape differences.

The greatest part of the variation between slubbings is due to components (3) and (4); there is a close correlation between tape tension and count variation across the condenser.

The side ends from the condenser are usually widely different from the correct count and therefore they are discarded, being fed back to the hopper.

In general the count variation of woollen yarns is greater than that of drawn-and-spun yarns; generally the woollen yarns are coarser, and the end-use is frequently less critical, especially for fabrics with a milled finish.

Tensile properties

Tensile tests on yarns are popularly used as a general index of quality because the results are influenced by a combination of factors such as fibre strength, fibre cohesion, yarn twist and its variation, and yarn irregularity.

A number of different types of strength tests are used on yarns, depending on the information required, these include: individual thread tests; hank tests; constant-tension winding tests; and ballistic tests — all of which should be conducted in a standard testing atmosphere.

Individual thread strength tests

When strength tests are carried out on one individual strand of yarn at a time the test is frequently called the single thread strength test, but as it may be carried out on folded yarns as well as single yarns it is better named the individual thread strength test in order to avoid confusion.

The strength of a specimen is that of its weakest element; consequently different speciment lengths give different apparent mean strength test results — a lower mean strength is obtained with a longer specimen length because of yarn irregularity.

Faster rates of loading give an apparent increase in yarn strength consequently for normal routine individual thread strength testing a standard specimen length of 500 mm is broken in 20 ± 3 seconds. A minimum of 50 specimens should be tested; frequently more tests are made when an automatic testing machine is available.

Disadvantages of the individual thread test include the relatively short total length of yarn tested, and the length of time involved, but on the other hand it gives a useful measure of short-term strength variation, and it is also possible to record extension at break.

Hank strength tests

An alternative test is the lea (or hank) strength test in which a hank of yarn, which has the yarn ends tied together, is broken instead of only one strand at a time. This test is used in some sections of the industry because it is rapid and uses a relatively large specimen which can also be used for count testing afterwards. Hank tests give a lower strength C.V.% than that obtained between individual thread tests and this may account for the popularity of this test where yarn strength is very variable — as in some woollen yarns.

Hank breakage is a complex combination of individual thread breakages and yarn slippage which can be influenced by the individual thread load-extension characteristics, the placing of the yarn on the pegs, the friction of the yarn on the pegs, and by irregular tension when the hank was reeled.

The hank strength is largely determined by the strength of the thinnest places in the yarn and because of twist distribution (described on pp. 60 and 107) these develop their maximum strength at a lower mean twist than is required for the thick places, hence a lower mean yarn twist will give maximum yarn strength with the hank test as compared with the individual thread test. The mean tenacity of hank tests is about 20 to 30% lower than the mean of individual thread tests.

For these reasons the results are not directly comparable with individual thread tests or with yarn breakages under normal processing conditions.

There is a linear relationship between the number of wraps of yarn and the hank strength for a given skein girth; a shorter girth usually gives a higher apparent strength; and with hanks shorter than 110 m a higher C.V.% between hank strengths is obtained.

Constant tension winding tests

Increased short-term yarn irregularity increases strength variation although changes in the former generally result in proportionately smaller changes in the latter largely because of the displacement of twist. Consequently for some purposes it may be considered desirable to conduct a test in which a long length of yarn is wound at a constant tension and the number of yarn breaks recorded; this test has the advantage of using a large yarn sample and yet the test is conducted on an individual thread to determine points of weakness below a specified threshold.

The test does not give a measure of the over-all yarn strength and it is possible, for example, that two yarns might show similar breakage rates when tested at one tension, but may behave differently at another tension. Nevertheless the constant tension winding test gives results better related to warp end-breakage rates in weaving than do tests to determine the mean breaking load.

Ballistic strength tests

These tests involve breaking the yarn by sudden impact and they can be used to measure the work of rupture. Ballistic hank tests give a ratio of (work of rupture)/(yarn count) which unlike other strength tests, remains approximately constant for a range of counts spun from a given fibre, but the value obtained with individual thread ballistic tests decreases as the count becomes finer; this test has been claimed to give a useful guide to the spinning limit of a fibre.

Rapid longitudinal impact loading tests have shown that a specimen impacted at a velocity greater than its limiting breaking velocity will always be broken. This is of interest for safety belts, lines and harnesses.

Yarn breakage

A normal spun yarn does not usually break by fibre slippage alone; in fact a considerable proportion of the fibres are actually broken, but not simultaneously.

A fibre in a helix near the surface has a greater path length than one near the centre and when tension is applied to the yarn, greater radial pressures are applied on the central fibres. Hence fibre slippage at the centre is less likely and yet at the same time fibre extension at the centre will be greater. Consequently the centre fibres break first before the outer fibres have made their full contribution to yarn strength. Fibre slippage is likely to be confined to fibre ends and to the outer fibres; at high twist, slippage may be negligible.

Fibre blends

When fibres with different breaking extensions are blended, then the fibres of the least extensible type break before the others are able to contribute fully to the yarn strength, but the broken portions of fibre may still contribute to the yarn strength and may be broken more than once. When a range of yarns is made, with each yarn containing different percentages of two components and the yarn strength is plotted on the ordinate against the percentage of one of the components on the abscissa, the relationship obtained is either linear, or, more commonly, curved convex towards the abscissa where it may show a minimum value of strength. It follows, therefore that most blended yarns are weaker than would be a yarn made from one of the components in 100% form.

The curved relationship occurs because the least-extensible fibre breaks before the other fibre has reached its breaking load. Whether a minimum-strength curve is formed depends on the load-extension curves of the component fibres.

If one component has a long final low-modulus region in which the stress is near the breaking stress, it will contribute most of its strength in a blend with any fibre having a breaking extension in that region, and in such a case there will be an almost linear relationship between the yarn strengths and the blend percentages.

Yarn tenacity and strength realization

Yarn tenacity is normally calculated by dividing the mean breaking load by the yarn count and it is expressed in mN/tex. Fibre tenacity is calculated in a similar manner from data relating to single fibre tests.

Fibre strength realization may be stated as:

$$\text{Strength realization} = \frac{\text{mean yarn tenacity}}{\text{mean fibre tenacity}} \times 100.$$

This is a measure of how effectively the fibre tenacity is utilized in the yarn. Strength realization percentages from individual thread strength tests range from: 30 to 60% for cotton; 30 to 64% for short staple man-made fibre; 40 to 50% for worsted; 32 to 58% for worsted-spun wool/man-made fibre blends; and 25% to 70% for jute.

Reasons accounting for the failure to achieve 100% include the effects of differences between the strength tests for yarns and those for fibres, variation in the breaking extension of fibres appearing in a common yarn cross-section, various forms of irregularity in the yarn, frictional, torsional, and blending effects, fibre disposition, leading to uneven stressing of fibres and slippage of fibres in the outer layers, wild fibres (i.e. protruding fibres), and the fact that short fibres and fibre ends do not bear a load equal to their strength; it follows that strength realization is a function of the entire fibre length distribution. In essence, some fibres add to the yarn mass without contributing greatly to the yarn strength.

On the other hand weak places in individual fibres may be supported by neighbouring fibres; although in single fibre tests each fibre can break at its weakest place, in a yarn the break must occur close to a particular point along the length of the yarn.

In general, strength realization is influenced by changes in fibre dimensions and yarn count in the same way as yarn tenacity; it is increased by increased mean fibre length, or by using a finer mean fibre thickness, which increases the number of fibres in the yarn cross-section.

The general relationship between single spun yarn tenacity and count is shown in *Figure 19.7* where it can be seen that tenacity increases with thicker yarn count, but this trend is not as great with O.E. yarns, and is less obvious with woollen yarns.

Fibres in the outer layer of a single yarn under tension tend to slip; they are known as the 'ineffective' outer layer. Hence:

Yarn strength $\propto \pi(R - \mathrm{d}R)^2 T$

where R = yarn radius, $\mathrm{d}R$ = thickness of the ineffective outer layer, and T = fibre tenacity per unit cross-section.

This accounts for the decreased tenacity of finer yarns because they have a greater proportion of outer fibres, it also accounts for the fact that the use of finer fibres minimizes the effect. As yarn count is increased, the rate of change of the proportion of 'ineffective' fibres decreases and so the yarn tenacity becomes almost constant for small changes in count above a certain yarn thickness.

The coefficient of variation of tenacity generally decreases with increased yarn count, decreased fibre diameter, and increased fibre length.

Yarn initial modulus

This is the ratio of yarn stress to yarn strain during the initial stages of yarn extension; it may be indicated in units of mN/tex.

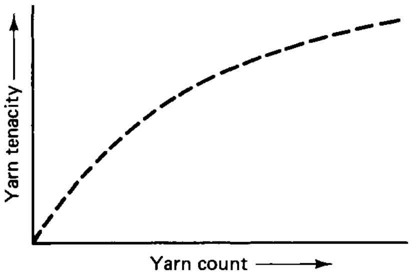


Figure 19.7 Relationship between tenacity and count of single spun yarns

When a single yarn is subjected to longitudinal tension, the fibres nearest to the yarn core are under the greatest stress and strain, assuming complete uniformity of fibre properties; in fact portions of fibres following straight paths along the yarn axis must have an extension approximately equal to the yarn extension, and they could be expected to be the first fibres to break if yarn extension were increased to a level not less than that of the fibre breaking extension in situ. An increase of yarn twist leads to a lower initial modulus.

Twist

When testing yarn for twist it is important to distinguish the purpose of the test. If twist variation is to be determined, then a large number of tests on short specimen lengths should be made, whereas if the purpose is to measure the mean twist in order to ensure the correct actual twist in a folded yarn before large scale production continues, then a small number of tests on a long speciment, in the region of 2.5 m, will give adequate results very quickly if an electrically driven twist tester is used.

The C.V.% of twist is most greatly influenced by specimen length; for two-fold worsted yarns the following relationship is typical:

Specimen length (mm):	25	50	250	500	1000
C.V.% of twist (approx.)	21	18	9	8	6

Yarn hairiness

Yarn hairiness has been observed subjectively and assessed for many years and in the spun silk and cotton trades, yarns may be singed (or gassed) to remove protruding fibres in order to produce a smoother yarn with added lustre, and in some worsted and mohair yarns, hairiness may be a nuisance.

Various methods of objectively measuring yarn hairness have been developed, including a television camera method which automatically presents three parameters: number; length; and diameter of the protruding fibres.

Various combinations of these (and other) parameters have been used to provide a composite expression of yarn hairiness, of which the product $N\,L$ is easily understood, where N = number of protruding fibre ends per unit length of yarn, and L = mean length of protruding ends. This expression is closely correlated with subjectively assessed yarn hairiness.

Hairiness is inversely proportional to fibre length and proportional to the number of fibres in the yarn cross-section and to the yarn count as well as being positively correlated with fibre torsional rigidity flexural rigidity, and diameter. When yarn twist is increased, the over-all effect is a reduction of hairiness.

Static electrification increases yarn hairiness, as does re-winding, and increased spindle speed may increase yarn hairiness.

Woollen yarns tend to have more, but shorter, protruding fibres than worsted yarns; mule-spun yarns are less hairy than ring-spun woollen yarns.

Thickness and compressibility

Yarn thickness cannot be measured simply because (1) the yarn does not remain circular in cross-section when a transverse load is applied, and (2) the extent of deformation is largely determined by the compressive force applied.

Attempts have been made to avoid this difficulty by expressing 'diameter' in terms of the mass per unit length ratio of the yarn but such 'diameters' were really yarn count numbers transcribed, and they ignored the influence of factors such as fibre density, length, diameter, crimp, cross-sectional shape, and yarn twist.

Various methods of measuring yarn thickness have been devised. A method involving the compression of yarn between parallel steel plates under known loads provides well-defined and reproducible results which enables the yarn Thickness Index, and in addition its Compression Index, to be obtained (described on p. 5).

The thickness of a yarn is obviously influenced by fibre density, but the influence of fibre diameter variation can also be considerable in influencing fibre packing density which may vary from yarn to yarn.

For a range of yarns processed from the same stock of fibres on the same machinery, yarn thickness $\propto \sqrt{(\text{count})}$. On the other hand, yarns of the same count can differ considerably in thickness and compressibility as may be seen from *Table 19.2*.

For a given yarn count, the spinning twist is the most important factor influencing yarn thickness and compressibility. Increased spinning twist decreases the 'free' (i.e. uncompressed) yarn thickness because of the increased fibre-packing density caused by the applied longitudinal tension, but it has little influence when thickness is measured mechanically under a very low transverse load, and it increases the measured thickness appreciably when measured under a high load; hence increased twist decreases the yarn compressibility.

This is clearly demonstrated by the results obtained by mechanical measurement between parallel plates as shown in *Table 19.3*.

Table 19.3 *37 tex yarns spun from 64's quality wool on the worsted system*

Twist (t/m)	*Thickness index (μm)*	*Compression index*
523	293	0.204
500	313	0.236
417	311	0.240
358	295	0.253
315	314	0.276

Fibre crimp is the next most influential factor — higher crimp increases yarn thickness and compressibility under all measuring loads; the thickness of low-twist yarns under a low load is markedly increased by high crimp as shown in *Table 19.2*.

The effect of increasing two-fold twist is similar to the effect of twist in single yarns: the compressibility is reduced without greatly affecting the thickness measured under a low load. The thickness of yarns measured between parallel plates is greater than that of single yarn of the same resultant count.

For the same count, woollen yarns are about 1.3 to 1.4 times thicker than worsted yarns.

Pilling

Pilling is a fabric surface fault which consists of small 'pills' (or 'balls') of entangled fibres clinging to the surface of the cloth, and causing an unsightly garment appearance; the pills are formed during wear and laundering by the entanglement of loose fibres protruding from the fabric surface which remain attached to the cloth by a few unbroken fibres.

For many years pilling was associated with knitted

Table 19.2 *Thickness and compressibility measurements made on 37 tex worsted-spun yarns*

Thickness index (μm)	*Compression index*	*Yarn composition*
224	0.220	low-crimp nylon
266	0.193	merino wool
370	0.267	high-crimp nylon
530	0.265	bulked acrylic

wool fabrics made from soft-twisted yarn and in more recent times pilling of woven fabrics became a problem when strong synthetic fibres were used, because the strong fibres firmly anchor the pills to the fabric unlike the weaker natural fibres which allow the pills to break away more easily. This effect has been minimized by the introduction of low-pill synthetic fibres which have a tenacity about 40% lower than that of the standard fibres originally produced, and a lower abrasion resistance.

The effect of pilling can be minimized by using increased yarn twist. Less twist is needed for low-pill synthetics compared with the standard fibres and this gives a softer fabric handle. Pilling can also be reduced by using a thicker diameter fibre, but at the cost of harsher fabric handle.

Pilling can be reduced by using folded yarns instead of the same resultant count single yarn and it is influenced by the fibre length and processing system. In comparative tests the silk and worsted systems give the least pilling, the cotton process gives more, and the woollen system gives the most pilling. A reduction of fibre length can be expected to increase the amount of pilling.

In fabric form pilling may be decreased by using denser fabric construction, singeing or cropping, suitable finishing agents, or the addition of adhesive on the reverse side of the fabric.

Bending rigidity

In practice the normal low-twist single yarns there is considerable freedom of fibre movement when bending takes place so that flexural rigidity is approximately proportional to yarn count, whereas for homogeneous isotropic fibres, for each single fibre it would be proportional to (fibre count)^2.

In the case of folded yarn there is less freedom of fibre movement than in single yarn, but nevertheless there is still a considerable freedom of fibre movement, with flexural rigidity being approximately proportional to (yarn count)$^{1.2}$.

An increase of spinning twist to about 70% more than normal increases fibre cohesion to such an extent that the yarn flexural rigidity increases by about 50%, but small variations of twist have negligible influence on flexural rigidity. This would seem to be due to the increased flexural rigidity associated with an increased fibre helix angle being cancelled out by the increased fibre cohesion which in itself would cause an increased flexural rigidity.

ST and STT yarn properties

Because of uni-directional twist of STT yarn varies approximately sinusoidally about its mean, twist test results for STT yarns must be obtained by using a specimen length of 210 mm which, allowing for length contraction due to twist, is equal to one cycle length. The quadrant twist tester is recommended using the untwist-twist method. The C.V.% of twist is usually found to be from 7 to 12%, which is comparable with that of a conventional two-fold yarn.

A comparison of the load-elongation curves of STT yarns with conventional two-fold yarns containing folding twist equal in amount to the STT added twist shows that the initial moduli are similar but STT yarns have a greater extention, particularly in the yield region; the magnitude of the difference depends on the amount of self-twist in the original ST yarn.

The breaking load of STT yarn is similar to that of the equivalent conventional yarn.

When tested on the Uster apparatus, ST yarn irregularity tends to be higher than equivalent conventional yarn, but STT yarns are similar to equivalent conventional yarns.

The weavability of STT yarns, judged by warp end-breakage rates, appears to be at least as good as an equivalent conventional two-fold yarn.

Fabrics produced from STT yarns have been found to have acceptable handle, better stability to washing, slightly higher tensile strength, and greater extension at break, and better abrasion resistance than equivalent conventional woven fabrics.

The appearance of STT yarns in woven fabrics is satisfactory provided that a suitable level of added twist has been used. Insufficient twist gives rise to an appearance of periodic patterning, and too much causes streakiness.

When ST yarns are used for knitting, care must be taken to select suitable processing conditions if excessive yarn breakages and press-offs (i.e. yarn breakages at the knitting needles) are to be avoided.

Selfil yarn properties

Compared with ring-spun single worsted yarns, Selfil yarns are non-torque, stronger, and more extensible, but they have a lower recovery from excessive strain. Excessive loads may cause partial drafting of the staple fibre strand which is then unable to recover to the same extent as the continuous filament nylon components; this results in the yarn structure and appearance becoming unsatisfactory. They also have a much greater potential relaxation shrinkage depending on the continuous filament yarns used and their previous strain history, but it is usually 5 to 8%.

Because the continuous filament component has an approximately constant contribution to yarn strength, fine yarns have a higher tenacity than coarse ones. Tenacity is not greatly influenced by the amount of twist although there is a region of maximum strength combined with minimum variation of strength.

Yarn irregularity and fault content is generally lower than conventional yarns and yarn friction after waxing is substantially the same.

Twistless yarn properties

Twistless yarns have a flat ribbon-like cross-section providing more lustre and greater cover than conventional yarns; they are more flexible in one plane than are conventional yarns. They have an even appearance because of the lack of twist and a lower elasticity than conventional yarns.

Increased starch content improves yarn strength, yarn wear resistance, and yarn rigidity; warp yarn may contain about 12% starch compared with about 8% for weft.

Cotton twistless yarn strength and extensibility is about 0.5 to 0.67 times that of conventional; yarn tenacity is approximately proportional to (effective fibre length)/(fibre count). Man-made fibre yarn strength is highly dependent on the type of adhesive used.

Fabric strength depends on fabric structure — higher strengths are obtained with closer yarn packing; greater fibre strength realization is achieved in fabrics made from twistless yarns than conventional, and in suitable structures significantly greater fabric strength than conventional can be achieved. Twistless-yarn fabrics are ideal for coated and laminated fabrics giving good strength and tear resistance.

Fabric launderability is satisfactory because even though loss of fabric strength may be greater than conventional, the greater initial strength of a suitably constructed twistless-yarn fabric can compensate for this. For a given fabric mass per unit area, twistless-yarn fabrics have lower air and water permeability and higher tearing and tensile strength, which suggests suitability for use as tent canvas.

Bobtex yarn properties

The surface appearance of ICS yarn is based on the staple fibre component, but yarns with a lower polymer content are more flexible. The properties of flexibility, tenacity, and elongation at break are influenced both by the type of polymer used and the staple fibre; the matrix and embedded fibres have a combined effect which gives a much higher tenacity than might be expected from consideration of the individual components.

Better yarns levelness than conventional spun yarn is claimed for ICS yarns as well as an abrasion resistance three or four times greater. The use of low-density polymer is claimed to give better fabric cover than conventional yarn.

One of the advantages claimed for this system is the cheapness of the product if a polyethylene matrix is used, but fabric containing such yarn would be very heat-sensitive, with a melting point of only about 124°C.

Although yarns finer than 60 tex have been produced on the ICS system, development has been concentrated on household and industrial markets, with only some apparel applications; it seems probable that these yarns generally will be restricted to heavy count applications.

Open-end yarn properties

The OE method of spinning is so radically different from conventional that it is not surprising that the yarn produced differs significantly from conventional ring-spun yarn. Rotor-spun yarns do not show the twist formation normally associated with ring-spun yarns; the fibres are matted together rather than twisted in a well-defined helical structure and the packing density of fibres in an OE yarn is variable across the cross-section compared with the more uniform and higher packing density of ring-spun yarns. This effect is largely associated with the different spinning tensions of the two systems.

Consequently in many instances it is natural to compare OE yarns with conventional yarns and thereby appreciate that there are end-uses for which at present OE yarns are not considered to be acceptable; it is also important to realize that they may become regarded as acceptable for some of those end-uses at some time in the future.

The properties of an individual OE yarn are determined by the type of machine used and on the speeds and settings employed, but the following indicates the general characteristics of OE yarns as a group:

Rotor spun cotton yarns are usually better than conventional carded cotton yarns as far as short term irregularity up to a wavelength of 0.5 to 1.0 m is concerned; the ratio (average short staple OE yarn U%)/(conventional carded cotton yarn U%) = 0.9 or even lower, although individual yarns may not always achieve this levelness and short staple man-made fibre yarn levelness may be only as good in rotor yarns as in ring-spun yarns. A similar general relationship exists with long staple rotor-spun carpet yarns, which have about 0.9 times the U% of semi-worsted carpet yarns.

Even so, OE yarns can have the visual appearance of greater irregularity than conventional yarn because of the influence of wrapper fibres. Periodic irregularities in rotor-spun yarns can arise from impurities or damage to the rotor collecting surface and from damage to the opening roller surface.

The medium and long-term variations are unaffected by the 'doubling' inside the rotor, hence at longer wavelengths it is possible to find a correlation with the feed sliver irregularity; the $B(L)$ curves of OE yarns generally have a less steep slope than do conventional yarns. The tendency towards greater medium and long-term irregularity in OE yarns is due to the reduced number of operations required to produce the feed sliver, and hence the fewer doublings, compared with those required for conventional rovings.

OE yarns also have greater freedom from knots, thick places, thin places, and neps than conventional yarns provided that rotor cleanliness is adequately maintained — otherwise yarn faults and periodic yarn may be formed. OE yarns nearly always have considerably fewer yarn faults than ring-spun yarns although individual exceptions to this rule can arise.

According to the Uster Statistics these benefits are greatest with yarn finer than 40 tex, when the ratio for an average yarn of (number of faults in OE yarn)/(number of faults in carded cotton yarn) does not exceed 0.44 for thin place, 0.17 for thick places, and 0.;77 for nep. In yarns from 40 ex to 80 tex, the ratios rise to a maximum of 0.85, 0.38, and 1.1, respectively. With yarns finer than 20 tex the number of thin places and neps approaches the level of superior quality carded ring-spun cotton yarn. Hence the decision to use the OE spinning package directly in the creel of the fabric-producing machine without winding and clearing depends on the suitability of the package shape and size, and on the end-product fault-level requirements.

OE yarns generally have: lower fibre extent; lower fibre migration; and lower packing density than conventional yarns, and this has a fundamental influence on many yarn properties. Despite the fact that they contain more twist, many short staple rotor-spun yarns have a mean yarn strength about 10 to 25% lower than conventional carded quality ring-spun yarns, and up to 40% lower than combed short staple ring-spun yarns because of the fibre configuration. The strength difference is more pronounced with fine count yarns but there may be little difference at counts of 60 tex and thicker.

The incidence of hooked fibres is greater when long fibres are processed and the lower strength of OE yarns is then more pronounced; conversely rotor yarns spuns from very short fibres (i.e. 14 mm and less) may be as strong or even stronger than ring-spun carded cotton yarns.

The use of 3.3 dtex polyester fibre instead of 1.7 dtex in a 67% polyester/33% cotton rotor-spun yarn causes a decrease of about 11% in yarn tenacity, and it has been found that more twist may be required for yarn spun from a longer fibre length in the long staple range because of the greater influence of reduced fibre extent with longer fibres compared with a ring-spun yarn.

In OE yarns which do have a lower mean strength than conventional, because the strength variation is also normally lower, there are fewer weak places and fewer end-breakages can be expected in subsequent processes such as warping and weaving, although the difference in end-breakage rates is critically dependent not only on the tension employed and the mean strength, but also on the strength variation. The strength variation of rotor yarns is greater for finer yarns and for increased twist insertion.

Rotor-spun yarns usually have a higher elongation at break than conventional so that although the mean strength may be lower, the work of rupture may be about the same as a conventional yarn. The elongation achieved is influenced by the amount of spinning twist and winding tension at the spinning frame as well as by yarn count; finer yarns tend to have a lower elongation at break and the use of higher rotor speeds gives a lower elongation at break. They also usually have a lower initial modulus, a higher bending modulus, which may make woven fabrics stiffer, and a higher coefficient of friction than conventional; hence for knitting, lubrication is essential, combined with low uniform tensions; the reduced amount of fly waste and knots is an advantage in this and other applications such as warping.

Because OE yarns have a lower degree of fibre orientation than conventional, they are about 10 to 15% bulkier. Hence for a given cover it might seem that lighter fabric could be used, but in that case fabric strength might be only 0.7 to 0.8 times that of a conventional fabric; tearing strength is only about 0.65 times conventional in the same fabric structure.

In practice due to differences in fabric finishing, a similar setting of ends and picks may be needed with OE yarns to obtain a similar cover to conventional spun yarn in the finished fabric form. In fabrics with a raised finish there is a lower strength loss in finishing for OE yarns compared with ring-spun yarns. Where fabric strength is important, adjustments to the fabric structure, if this is permissible, can remedy strength deficiencies.

Yarn-to-reed-wire abrasion of OE yarns in weaving is better than conventional, and yarn-to-yarn abrasion resistance of unsized OE yarns is much better than conventional.

In general OE fabrics have slightly better abrasion resistance than conventional although this depends largely on fabric construction. There is no significant difference between the abrasion resistance of OE and conventional yarns in man-made fibre carpet pile applications.

For cotton yarns of a given count, rotor yarns are less hairy than conventional because a greater proportion of the projecting surface fibre ends not only are shorter than 3 mm, but also they are less numerous, thus even though the number of looped fibres is greater, the OE yarns appear less hairy. The variation of hairiness between bobbins of OE yarns is greater than conventional. The reduced hairiness can improve weaving efficiency considerably under certain circumstances. Fabrics containing rotor yarns tend to pill more easily than conventional but they also shed the pills more easily.

The higher twist content of OE yarns makes them less suited than conventional for end-uses in which a soft handle is required.

Better printed fabric clarity is achieved with OE yarns because of their reduced wicking tendency compared with conventional.

Sewing threads

Unlike most yarns, sewing threads are usually sold by length; furthermore, the application of the tex system does not apply to sewing threads, for which special count systems are recognised by producers and customers.

British Standards 3418 and 4134 refer to spun yarns and smooth continuous filament yarns, respectively. For cotton and linen yarns sold retail for domestic use the ticket number is approximately equal to three times the resultant English cotton count of the thread, e.g. ticket number 36 $\simeq$ 12's cotton count, i.e. there are approximately 12 × 840 yards with a mass of 1 lb. For industrial cotton yarns the cotton count may be given, e.g. 3/36, which has a resultant of 12's cotton count.

For synthetic yarns the ticket number is based on three times the resultant metric count, e.g. ticket number 60 indicates 20's resultant metric count, i.e. 20 000 metres have a mass of 1 kilogramme. Hence the same ticket number may be used for two-fold, three-fold, or cabled yarns if they all have the same resultant count.

A synthetic yarn with a ticket number of 60 is equivalent in count to a cotton domestic 36 or industrial 3/36 — they are all approximately equivalent to a resultant count of 50 tex.

Sewing threads may be smooth or textured continuous filament, staple fibre, core yarn, or tow-to-yarn 'direct spun' which is intended to be similar to a staple fibre yarn. In general, spun yarns give a higher loop strength and seam strength than equivalent continuous filament yarns.

The sewing thread is of considerable importance even though it usually represents much less than 1% by mass of a garment. The demands made on sewing threads are frequently very exacting, both during the sewing process itself, and during the subsequent life of the end-product.

Needle threads must pass freely through the small eye of the needle; consequently they must be uniform, knot-free, non-torque, and fault-free. They must be strong: a modern sewing machine may subject the yarn to alternating accelerations and decelerations of about 6000 times that of gravity at a rate of about 100 stitches per second.

At such high speeds, the yarn must be able to withstand the high temperatures arising from needle heating as well as the abrasion caused by the rapid sliding back and forth of the yarn through the eye of the needle perhaps 50 to 80 times before it finally enters the seam.

Lubrication of the sewing thread with mixtures of wax, emulsions with synthetic resins, and silicone-based products, may minimize heat generation, and the fibrous surface of spun yarns may be an advantage in that a thin layer of the surrounding air will move with the thread and promote needle cooling.

The elasticity of a sewing thread must be uniform along its length in order to enable equal length stitches to be formed, and it must closely match the elasticity of the fabric being sewn; otherwise either seam thread fracture, or tearing of the adjacent fabric may arise during garment use. Clearly the requirements of woven and knitted fabrics will be different. High-tenacity spun polyester yarn may be suitable for woven fabrics, whereas when knitted seams are joined by linking, for example, a tow-to-yarn direct-spun nylon thread, which has a greater extensibility, is recommended.

The final direction of twist insertion may be important to enable the stitch-forming mechanism of the sewing machine to perform correctly; most sewing machines require Z twist, but there are a few exceptions where performance is better with S twist.

The sewing thread must withstand the effects of processes such as hot pressing and dry cleaning, both from the colour fastness point of view, and to avoid seam puckering, and its shade normally must be matched accurately to the garment.

Cotton is still used for sewing threads, with three-fold yarn in which the folding twist is in the opposite direction to spinning twist being the most widely used form. In the case of cotton sewing threads, wet folding is usually used on the ring system to lay-in the surface fibres and thereby obtain a stronger, smoother, and more compact yarn than could be obtained by dry processing; the single cotton yarns are passed over the surface of a rotating conditioning roller on the folding machine before they are combined together with twist insertion. Cabled yarns may be used with various twist combinations. Frequently three two-fold yarns are cabled together with Z cabling twist following S spinning twist and S folding twist, or vice-versa, with folding twist approximately 1.5 × spinning twist, cabling twist about

2.25 × spinning twist if compactness is important, or cabling twist about 1.3 × spinning twist if a balanced twist yarn is required. Spinning twist has only a minor influence on the cabled yarn properties; the cabling twist has a major influence on cabled yarn strength, extension, torque, and yarn length contraction during cabling. The proportion of cabled yarn used in sewing has decreased largely because of its higher cost and because strong folded synthetic yarns are now available; nevertheless cabled yarns may still be required for applications such as button-holes and for decorative top-stitching. Cotton sewing threads normally are mercerised or treated with liquid ammonia (the Prograde process) to improve tenacity and yarn appearance.

Some cotton yarns are supplied as glacé or polished sewing threads; these are often used when severe conditions are encountered during sewing and in use, such as with heavy fabrics, and for decorative stitching. The yarn has a mixture of size and lubricants added to it before being polished by high speed rotating brushes while under tension. The surface finish is not permanent and is removed by subsequent wet treatment.

The high strength of synthetic fibres makes them attractive for use in sewing threads, and these, frequently polyester, are used widely in spun staple fibre yarns to obtain the benefit of the cooling effect of the surrounding air mentioned previously.

Air jet textured yarns may be used sometimes as a needle thread.

Core yarns with a multifilament core of polyester and an outer sheath of cotton or polyester staple fibres, folded to form two-fold or three-fold yarns provide excellent performance, with strength provided by the core, and the heat resistance of the sheath permitting high sewing speeds. The disadvantages are the high cost, and the greater care required in dyeing.

Some sewing threads do not need to meet the stringent demands which are required of the needle thread in applications such as a lock-stitch seam; in particular the demand for heat resistance may be less, so that in appropriate cases it is possible to use synthetic yarns of a relatively simple construction. Continuous filament yarns of polyester and polyamide, which range from monofilament to single or folded multifilament yarns may be quite adequate for use in applications such as chain stitch or over-edging as well as for the looper thread in lockstitch seams, in which case the yarn is usually supplied on pre-wound spools; in some cases textured yarns may provide a more pleasing appearance.

Tow-to-yarn 'direct spun' sewing threads are made by feeding a continuous filament tow into a stretch-breaking zone and inserting twist into the strand of fibres so produced, with delivery on to a ring spinning package. Compared with yarns spun from staple fibre, direct-spun yarns are more uniform, more compact, strong, have a lower extension at break, a better abrasion resistance, and are free of defects such as neps. Unless high temperature setting is used on the direct-spun thread, it will have a greater relaxation in subsequent hot wet processing than an equivalent spun yarn. Because of their characteristics, direct-spun yarns may be used to advantage in some critical applications, but only when the higher cost can be justified. The tow produced for this purpose is relatively thin compared with tow produced for staple fibre production, and consequently it usually costs well over twice the cost of staple fibre; hence direct-spun yarns are relatively expensive.

Most synthetic yarns, both continuous filament and staple, are subjected to a hot stretching and setting process. This treatment slightly increases the tenacity, reduces the breaking extension, and reduces the shrinkage of the yarn when it is later subjected to high temperatures. On subsequent high-temperature dyeing, which causes a slight length contraction, there is an increase in breaking extension, and a further reduction of residual shrinkage. Alternatively hot stretching and dyeing may take place simultaneously.

Some continuous filament yarns, usually nylon, are made into bonded threads by adding a bonding agent to a low twist yarn prior to hot stretching. The bonding agent helps to protect the thread from heat damage, maintains a circular yarn cross-section, and prevents fraying at the cut ends of the yarn. This development has overcome some of the difficulties encountered in heavy duty sewing.

Although they are not widely used, some sewing threads are made from spun silk. An important feature of such yarns is the high extension at break of about 20%, along with a high breaking load. Some continuous filament silk yarns are used for button-holes and decorative stitching because of their attractive appearance and smoothness.

Sewing threads are normally wound on precision winding machines to form packages with 50, 100, or 500 metres for domestic use, and from 5000 to even 100 000 metres for industrial use.

Because of the rapid developments which take place in sewing and seaming machinery, manufacturers of sewing threads maintain close liaison with machinery makers and machinery users. This has led towards small firms of spinners withdrawing from this section of the industry.

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20

YARN FAULTS

Theoretically it should be possible to produce a yarn so fault-free that subsequent yarn clearing would be unnecessary. However under current practical conditions such a yarn would be uneconomic; hence when yarns are mass produced under normal industrial conditions it is inevitable that some faults will be formed; the skills of management, operatives, and machine designers must be deployed to minimize the number and the severity of faults produced.

The term 'yarn faults' or 'gross faults' as they are sometimes called, does not include the normal variations present in even the most perfect yarns produced by methods at present available.

Yarn faults may arise as a result of one or more of the following causes:

(1) faulty raw material;
(2) selection of unsuitable raw material;
(3) mechanical faults on machines;
(4) incorrect machine settings;
(5) lack of machine and environment cleanliness;
(6) operative faults; and
(7) bad organization.

With modern single-yarn winding and clearing facilities the major faults will be removed and replaced by a knot which, after yarn folding is usually acceptable for most end-uses although there are exceptions to this, such as: fine poplins made from short staple yarns, some clear-finish plain-weave worsteds, mohair yarns, and yarns for tufting. The developing of yarn splicing instead of knotting may take care of this problem.

An excessive fault content before yarn clearing reduces the efficiency of the winding process itself and may give rise to an unacceptably high number of knots in the delivered yarn.

Occasionally yarns are knitted or woven into fabrics for which they were never intended and this may lead to problems with factors such as colour fastness, for example. However, under such circumstances this can hardly be described as a yarn fault.

Although yarn fault dimensions form a continuous spectrum of thickness and length which for convenience have been divided into sixteen groups on the Uster Classimat system described on page 190 and illustrated in *Figure 17.4*, they can be regarded as two main groups when causes of faults are considered: short faults such as neps and slubs; and long faults.

According to extensive investigations by Zellweger Uster Ltd, approximately 25% of yarn faults shorter than 40 mm were due to processes prior to spinning and raw material faults, and about 75% were introduced at the spinning operation itself largely because of fly waste, although the exact percentages differed for different methods of yarn production.

Neps and their formation have already been described in the Chapter on carding; in combed yarns they are largely removed by the combing process. Neps can not be removed by yarn clearing; they are more prominent in fine yarns, but are less of a problem in thick carded short-staple or condenser-spun yarns. Extraction of neps and their replacement by knots would not only be uneconomic, but would also increase the yarn fault rate; electronic counting, however, does provide a measure of the degree of yarn imperfection.

Slubs are much bigger clumps of fibres — usually about 12 to 25 mm long — and unlike neps they are usually cigar-shaped rather than ball-shaped. The fibres are generally longer than those in a nep, and they are more firmly attached to the yarn. In worsted fabrics although it is usually possible to remove slubs during the mending process, they are still undesirable and add to the cost of the product. Slubs may be caused by inadequate noil removal. excessive waste accumulation, and fly waste, they may also be caused by fibres becoming doubled up by either bad sliver piecenings at any process between carding and spinning, by licking slivers from ball-type packages and careless handling of ball packages. In worsted processing slubs may be caused by damaged faller pins, by an excessive fatty matter content in merino tops, or by top dying of merino wools hence recombing is normally used after the top dyeing of merino wools.

Many slubs formed during the early stages of processing may be thrown out during yarn ballooning in conventional spinning but in ring spinning the passage of the yarn through the traveller may cause surface collections of fly waste to be pushed together.

There is a close correlation between mean fault thickness and peak fault thickness, furthermore fault severity is visually related to the percentage increase in thickness rather than the absolute value of thickness increase: hence thin slubs in a fine yarn may appear to be just as objectionable as thicker slubs in a thicker yarn.

Prior to autolevelling being introduced, up to 30% of the number of slubs in a normal worsted yarn could be caused by piecenings. The introduction of autolevelling, larger packages, and accurate delivered-length stop-motions has minimized the need for piecenings in the early stages of drawing and it is not customary to make piecenings at the later stages i.e. reducing and roving, because thick yarn lengths of about 1 m long may be caused.

The formation of short lengths of thick yarn by undrafted roving being pulled through the drating zone of the spinning frame is called 'spewing'; this can be eliminated by reducing the control applied to be fibres in the drafting zone.

The presence of infrequent extra long fibres in a roving can sometimes cause a momentary delivery roller slippage and therefore a momentary stoppage of yarn delivery which causes a short thick place; these faults are known as 'crackers'; they are not very common with modern apron-drafting equipment and usually arise when fibres have been mixed accidentally or when man-made fibres have been incorrectly cut during stapling. Crackers can be distinguished from slubs by applying increased tension until the long fibre snaps and the yarn elongates to normal thickness; they should not be confused with spun-in waste, or fly waste, which usually can be pulled off the yarn, leaving it intact.

Apart from neps and slubs, other yarn faults include the following.

Faulty piecenings causes by careless or inexperienced operatives; the usual fault is an excessive length of overlap. It is sometimes considered preferable to have bad piecenings in order to ensure that they are all removed during single yarn clearing.

Married ends or double formed in spinning, roving, or reducing, are caused by a broken end lashing across to an adjacent spindle and continuing to run, so that a long length of thick yarn is produced. The incidence of this type of fault it increased by the complete removed of static, and decreased but not necessarily eliminated, by pneumatic underclearers. Spinning double and roving double both cause the yarn to be thicker than it should be by a factor of 2, whereas reducing double causes it to be 1.5 times thicker — assuming that two doublings are used at the roving stage.

Three or four-fold instead of two-fold yarn can be formed in the folding operation by a single or a two-fold end lashing across to an adjacent spindle. A less common fault is for single yarn to be produced instead of a folded yarn when twist-on-twist yarn is being processed. In either case the fault is basically due to a machine maladjustment.

Slack (or soft) twist — i.e. a much lower than intended amount of twist — may be caused by incorrect threading permitting the supply yarns to by-pass the feed rollers, by yarn slippage in the folding operation, by a defective spindle drive, or incorrect spindle whorle diameter.

Hard twist occurs less frequently than slack twist. The basic cause is either too slow a yarn delivery, or too fast a spindle rotation. The former is most commonly caused by either incorrect threading or by waste accumulation; the latter, although possible, is extremely unlikely.

The fault of mixed lots of yarn theoretically should never occur; in practice it has been known to account for 20% or more of detected faults. It is easy to appreciate how this arises when similar counts and shades are spun, folded, or wound on adjacent machines. The fault is minimized by arranging to keep lots apart and by eternal vigilance by all operatives; this may be aided by the use of fugitive tinting for undyed and pale shades, the selective use of coloured bobbins and tickets, and the employment of operatives with sensitive colour vision where coloured yarns are produced.

Faults in woollen-spun yarns can arise from defective carding machinery, such as irregular laying of intermediate feed sliver, and intermittent or eccentric worker or doffer movement.

Colour mixtures comprising fibres of different abrasion resistance should have component colours distributed equally in the different fibre types; otherwise wear could lead to local shade variation and, perhaps, contrasting coloured pills.

Other faults which occur infrequently may be grouped together as miscellaneous, they include uneven shade mixtures, excessive yarn irregularity and count variation, incorrect twist direction, irregular twist, and faults caused by defective machinery; in delivered yarn they may also include slipping knots, faulty clearing, badly wound packages, and other rare faults. Periodic yarn is not a common fault, but particular care must be taken to avoid it being made by faulty rollers when high spinning drafts are used.

In OE spinning, operative-made piecenings are usually longer than for the same fibre when ring-spun, depending on the dexterity of the operatives, but open-end piecenings are less numerous. Fibres may collect near or on the opening roller and then enter the yarn together to form thick faults, particularly if there are burred metal machine parts, therefore care must be taken to avoid mechanical damage to components during dissembly and cleaning. Impurities or fibre tufts may accumulate at the collecting surface if cleaning is too infrequent; this can lead to a general deterioration of yarn quality. There is no opportunity in OE spinning for faults to be ejected from the yarn during ballooning. In general OE cotton yarns may contain a much smaller number of faults than an equivalent ring-spun yarn — usually less than 50% of the total and the number of neps is usually only about 30%.

Self-twist yarns which require a high standard of roving cleanliness usually have a fault rate as good as or slightly better than ring-spun yarns, with fewer thick places and more thin places. There are fewer faults arising from fly waste, and this also applies to fasciated yarns.

Continuous filament core yarns contain the faults usually associated with the sheath fibre concerned, but in addition they may have bare filament where the staple fibre is missing; this fault is called 'grinning'.

Further reading

BLEAKLEY, T., *Linen Yarn Faults, J. Text. Inst.*, **41**, p. 526 (1950)

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21

SPECIALITY YARNS

Fancy yarns

A fancy yarn is one into which deliberately produced variations are introduced.

There are many methods of making such yarns, frequently by using ingenious mechanisms designed for that particular purpose. Because of the many methods used it is not possible to describe either every mechanism or every yarn of this type. However the main methods of producing them may be classified as follows:

(1) spinning

(i) condenser-spun
(ii) drawn-and-spun

(2) folding

(i) using conventional machinery
(ii) using specialised machinery

(3) weaving

A Chenille 'yarn' is produced by weaving a fabric (on what is known as a weft loom), which is then cut into narrow warp-way strips. The 'yarn' so produced has projecting tufts formed by the original weft yarn. The Chenille 'yarn' is used as weft in the production of Chenille fabrics.

(4) dyeing

Fancy coloured yarns may be produced by techniques such as space-dyeing.

Condenser-spun yarns

A simple method of producing effect yarns is to incorporate the effect components into the blend prior to carding; for example kemps or imitation kemps can be introduced in this way.

Most fancy condenser-spun yarn effects are obtained by modifications to the carding process.

Knickerbocker woollen-yarns, otherwise known as knop, nepp, or knicker yarns, show contrasting coloured spots or nepps on the yarn surface.

One method of production is to use a feed-sheet and roller arrangement to provide a controlled flow of nepps, i.e. small balls of coloured fibres, to the latter part of the carder just prior to the condenser. With this method it is essential to use nepps made from fibres which have good cohesive properties, such as fine merino wool, or cotton.

Alternatively the balls of coloured fibres may be incorporated into the blend, in which case the blend must already be opened thoroughly, and usually only one worker on each part of the card is used to act on the material, using open settings in order to avoid the fibre balls being opened out; usually with this method a reverse direction of rotation is used for the early doffers in the card in order to prevent the fibre balls from falling out.

A similar method of production in which the nepps are partially carded can be used to form a type of slub yarn.

Compared with the production of ordinary woollen yarns, it is usual to produce the condensed slubbing nearer to the ultimate yarn count so that a low spinning draft of about 1.2 can be used in order to minimise both end-breakages and disturbance to the fancy effect.

Slub yarns can be produced in woollen carding using a method similar to that used for nepp yarn production by feeding slubs instead of nepps. These types of yarn contain a random order and a random spacing of the coloured nepps or slubs.

Flake yarns, i.e. yarns with a gradual count change — or an elongated slub, can be made by attaching a mechanism to the card which either alters the doffer speed or varies the setting distance between the last swift and doffer of the condenser section. This arrangement only produces the flake effect in the basic shade being processed and so to be effective a large flake usually is preferred. Flakes of contrasting colour and/or fibre type can be produced by having a mechanism which feeds a fleece of coloured fibres into intermittent contact with the doffer card clothing, the length and spacing of the flakes can be controlled, but regular length and spacing are usually avoided in order to avoid patterning in the fabric ultimately produced. Smaller flakes are usually appropriate when there is a contrast of colour involved.

A similar system can be used, by feeding soft condensed slubbing to each end being produced at the condenser. Three or four condenser bobbins may be used to supply different coloured condensed threads in order to add variety. The condenser bobbins are mounted on surface drums and some method is used to introduce the slubbing intermittently.

Variegated woollen yarns may be made by taking cans of different coloured slivers from the scribbler section of the card and feeding them in a controlled manner to the carder feed sheet. By using electronic controls a complete colour change in the yarn can be arranged to occupy either a minimum of about 20 metres of yarn, or 2000 metres of yarn or more.

Fancy woollen yarns which exploit these carding techniques are expensive because of the lower carding production rates involved and the increased costs of supervision and maintenance.

Slub yarns can be produced in woollen ring spinning by the slub injection technique. This involves the additional mechanism required to control and feed short lengths of slub material into the false-twist tube just prior to the nip of the drafting zone front rollers. Slub length and spacing can be varied over a repeat length of more than 2700 metres to given an apparently random effect.

Drawn-and-spun yarns

Slub yarns produced at the spinning frame are usually known as spun slubs.

Spun slubs can be produced by blending fibres of different dimensions, such as woollen slubbing with normal worsted top sliver; the imperfect fibre control during drafting provides randomly distributed slubs of varying dimensions and perhaps different colours.

Alternatively spun slubs can be produced by mechanical modification to the spinning frame so that intermittent acceleration of the rollers of the drafting zone causes alternating degrees of draft to be applied. A similar method can be used at the roving stage to produce a slubbed roving from which a slub yarn can be spun using a constant draft.

Various mechanical systems have been made which can provide this facility at the spinning frame. Examples are given here to represent their evolution and to illustrate the principles involved.

A simple method of doing this was to use a draft gear wheel, from which some teeth had been removed. This would provide intermittent stopping of the back rollers to produce a thin place. Normally nowadays this method is not used because it provided limited scope for the effect length — too long a stoppage would cause a spinning end-breakage — it also administered a considerable mechanical shock to the machine parts involved.

A development of this method was to use a pair of different diameter driving gear wheels, A and C (*Figure 21.1*). One wheel had teeth missing where the other one did not, and vice-versa. A pair of complete driven gear wheels B and D were used to gear up with A and C so that the drive was provided alternately either via A and B, or via C and D. Such an arrangement made a wider range of yarns possible; the minimum yarn count was positively controlled, and the mechanical shock was reduced. Different arrangements of tooth distribution on wheels A and B could provide a range of different slub effects.

A more sophisticated method of providing an alternating draft has been developed in which a random-impulse generator permits the production of slubs which are random in both distribution and in dimensions (*Figure 21.2*). The random impulse generator (not shown) is used to energize the magnetic particle clutch as required. When the clutch is not energized the normal drive is used via gear wheels A, B, C, and D to produce the basic yarn. When the clutch is energized, the drive via

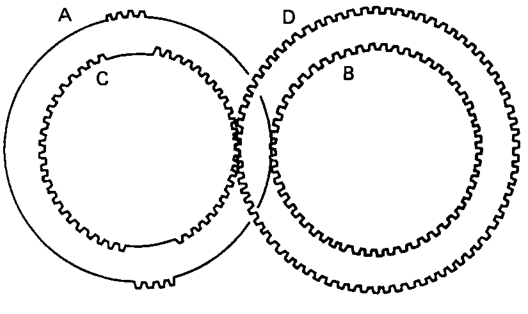


Figure 21.1 An early spun slub mechanism (Prince Smith & Son, Keighley, circa 1911)

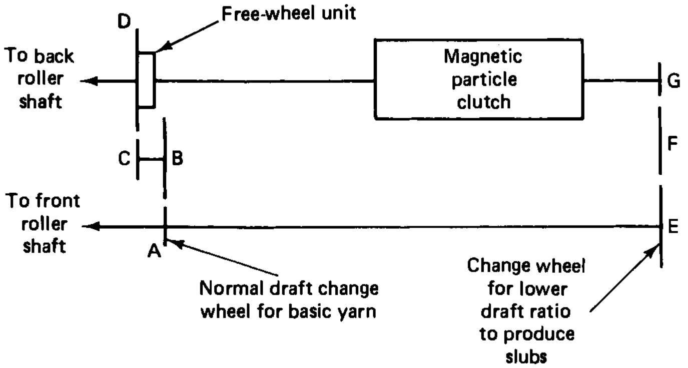


Figure 21.2 Method for producing ramdomly generated slubs

gear wheels E, F, and G is connected so that the back roller shaft rotates at a higher speed, leaving gearwheel D to freewheel and thereby reducing the draft to produce the slub.

Slubs cannot be produced by alternating the draft in condenser spinning because normally the draft is very low and the difference in yarn thickness would be negligible.

Slub injection can be used for drawn-and-spun yarns by fitting the necessary control and feed mechanism to the spinning frame; the additional slub material is fed into the drafting zone front rollers with the desired slub length and spacing being varied as required over a very long repeat length to avoid patterning effects in the subsequent fabric. Flake yarn effects — i.e. elongated slubs — can be produced by this method.

Fancy yarns produced on conventional folding/cabling machinery

A limited range of fancy yarns can be produced using conventional folding/cabling machinery.

A spiral yarn or corkscrew is a yarn in which one component spirals around the other component. If equal lengths of two or more components containing S and Z twist respectively are combined with twist, the component/s to which twist is added will contract in length, while the other/s will extend and spiral around the outside of the yarn thus formed; this is later referred to as an unbalanced-twist spiral yarn.

If equal lengths of two yarns, one coarser than the other, are folded together, the thicker one will spiral around the other.

A diamond yarn can be made by folding a thick single yarn or roving with a fine yarn of contrasting colour, possibly a continuous filament yarn, using S twist, and then cabling the product with a second similar fine yarn using Z twist. The end-product will then have two fine yarns, with an equal number of turns of opposite twist to each other, spiralling around the untwisted thick central yarn, provided that suitable amounts of S and Z twist are used. For example: 220 tex roving containing 200 t/m Z twist, folded with 400 t/m S twist, and then calbed with 200 t/m Z twist — this yarn would finally contain the untwisted roving with one fine yarn around it with 200 t/m Z and the other with 200 t/m S.

Various effect yarns can be made by producing multi-fold/cabled yarns, one example of which is given here:

> three 37 tex yarns containing 400 t/m Z twist folded together with 400 t/m Z twist, and then three such threefold yarns cabled together with S twist.

By introducing different amounts of folding twists in each of the threefold yarns, different colours of single yarns or groups, different counts, or different spirals, a wide range of interesting possibilities may be exploited.

A gimp yarn can be made by cabling an unbalanced-twist spiral yarn as described previously with a single yarn (known as the binder) using twist opposite in direction to the previous spiral folding twist. The resultant yarn consists of a twisted core with projecting semi-circular loops.

A mock Chenille yarn is made by cabling two or more unbalanced-twist spiral yarns together using a cabling twist equal and opposite in direction to the folding twist. Each of the original spirals usually contains more than two components so that the final compound yarn has single components projecting around the yarn surface.

Fancy yarns produced on specialised folding/cabling machinery

Many machines which differ from each other in detail have been designed specifically for this purpose; however, the basic principles involved are common to them all.

The general arrangement (*Figure 21.3*), is to provide facilities for feeding two or more yarns at speeds which are independently controlled, including uniform, fluctuating, or intermittent feeds as required; this is represented by rollers 1, 2 and 3, although more than three sets of rollers can be used. The yarns may be brought together, perhaps via a yarn guide (4) for twist insertion at a knopping bar (5, 6, and 7) which may be stationary or moving, and then passed through a lappet guide (8) before twist insertion and winding-on take place, usually using the ring spindle (9).

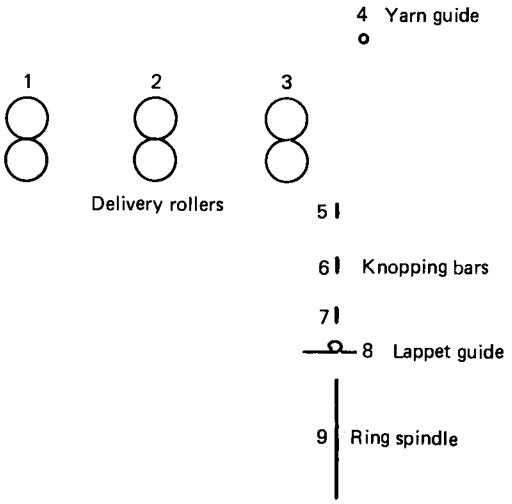


Figure 21.3 General arrangement of fancy yarn folding/cabling machine

Usually irregular time intervals can be selected for the control mechanisms to actuate the various mechanical or electro-mechanical methods which have been devised to produce the required roller or knopping bar movements. Such arrangements permit the production of an infinite variety of fancy yarns. The main groups are described here, with methods of production illustrated where appropriate.

The arrangement of threading for the production of a cloud yarn is shown in *Figure 21.4*. The two different coloured components are fed by alternating fast and slow deliveries of rollers 2 and 3 which are 180° out of phase so that each thread alternately forms the base while the other forms the cover to obscure the base from view.

A knop yarn can be made by using the threading shown in *Figure 21.4*. The foundation thread is fed intermittently by roller 2, while the knopping thread is given a continuous delivery by roller 3, forming a knop each time roller 2 stops. A knop yarn may be bound by an additional thread added at a cabling operating using the opposite twist direction to that of the folding process. This will effectively prevent the knops from accidentally sliding along the yarn during subsequent processing.

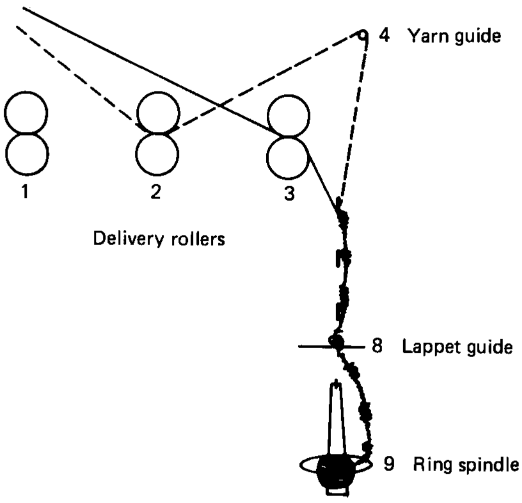


Figure 21.4 Threading which may be used for cloud yarns, knop yarns and spiral yarns

By using two additional knopping threads via roller 3, guide 4, and knopping bars 6 and 7 (as shown in *Figure 21.3*), a three-colour knop yarn may be produced.

If different sets of rollers, running at different speeds, are used for the knopping threads, then the different colours of knops can be of different sizes, and by altering the delivery speeds of the knopping threads, the sizes of knops of a given colour may be varied.

Elongated knops can be made by arranging to move the knopping bar/s upwards while the foundation thread is stationary.

A loop yarn is made by delivering two foundation threads at a constant speed, and delivering the looping thread at a faster speed. The looping thread is made from long rigid fibres which also may be lustrous, such as a mohair or a lustre wool roving, or an untwisted thick continuous filament yarn. The thick thread forms loops which become secured between the two foundation threads. A cabling process is then used in the opposite direction of twist to apply the binder thread.

A snarl yarn is made in the same way as a loop yarn except that a twist-lively yarn is used to form projecting snarls instead of loops, the twist of the snarl yarn is usually in the same direction as the folding twist; a binder is usually added at a subsequent cabling process using opposite twist to the folding process twist.

A spiral yarn can be made using the threading shown in *Fig. 21.4*, with the yarns having constant, but different, delivery speeds; the slower yarn will provide the base around which the faster yarn will spiral. A more pronounced spiral can be obtained by using a base yarn with twist in the same direction as the folding twist and the opposite twist for the spiralling component. By using a varying roller speed a fluctuating spiral can be produced.

A stripe yarn can be made with an alternating fast/slow delivery of the striping thread on to the constant slow delivery of the foundation thread. Part of the yarn appears to be a normal folded yarn but the stripe obscures the foundation thread intermittently. This type of yarn also can be made by using a moving knopping bar; a point may be reached at which it is difficult to distinguish between an elongated knop and a stripe.

Slub yarns can be produced by the plucked slub method (*Figure 21.5*). Two foundation threads are fed through rollers 3 to meet a twistless roving which is fed by the intermittent action of rollers 2. The roller 2 and 3 act as an intermittent drafting zone and so produce tufts of roving which become twisted between the two foundation threads; in general plucked slubs give a neater and cleaner appearance than spun slubs.

Additional variations can be made on the above themes by using varying roller speeds, varying knopping bar speeds, and by combining two or more effects into one yarn, such as a combined snarl and knop yarn.

An eccentric yarn is an undulating gimp yarn which can be produced by cabling a binder thread in the opposite direction of twist to that used in folding to produce the other component yarn which may be a fluctuating spiral, stripe, or slub.

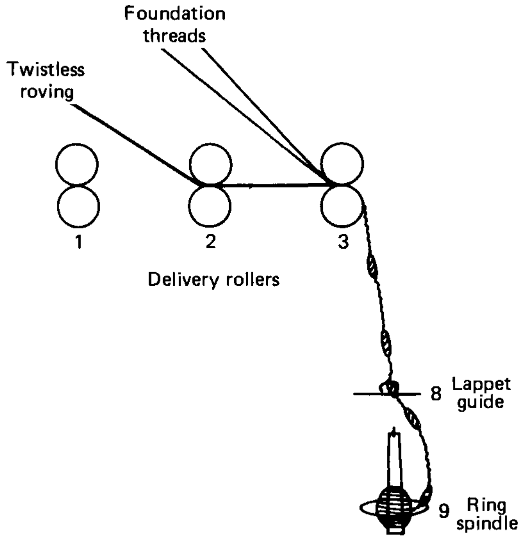


Figure 21.5 Plucked slub production

Folded Chenille type yarn can be made without the weaving process by using specially designed machinery. The 'weft' yarn is laid between two sets of yarns fed from warp beams, and is cut to form short tufts trapped between an upper and a lower warp thread. Twist is inserted into each pair of warp yarns to form a twofold yarn which contains tufts of 'weft' yarn. By using space-dyed 'weft' yarn supply packages, a random colour effect can be obtained.

When a binder thread is required to prevent slippage of the effect yarn, such as in a knop yarn or a loop yarn, instead of using a separate cabling operation as described previously, modern machines may add the binder thread by using the hollow spindle technique described on page 171.

Core yarns

Core yarns are produced by feeding an existing yarn, frequently smooth or textured continuous filament, but not necessarily so, through the nip of the front rollers of a drafting zone so that the fibres from the drafted roving surround it as twist is inserted.

For best results the filament should be introduced at the centre of the staple fibres in the spinning frame drafting zone front roller nip and should be pre-tensioned to given an extension of up to 5% for smooth continuous filament yarn, about 30% for textured yarn, and about 400% for elastomeric yarn. The amount of spinning twist may influence yarn properties such as pilling and abrasion resistance even though it may have a smaller effect on yarn strength than with a conventional spun yarn.

The core spinning technique may provide advantages at the spinning process itself by increasing the production rate and reducing end-breakages and possibly by permitting the spinning of finer yarns from a given fibre or the use of a cheaper staple fibre for a given yarn count.

Also there may be advantages in the yarn or fabric characteristics for particular applications such as: lightweight fabrics; increased mean yarn strength and decreased strength variation without loss of the desirable staple yarn properties; use in industrial fabrics; improved sewing thread performance; or improved bonding properties for coated fabrics such as PVC tarpaulins.

One disadvantage of core yarns is the possibility of staple fibre slippage along the filament core during processes such as weaving. One way of avoiding this is to fold two core yarns together; an alternative is to size the single core yarn before further processing.

A modification of the core spinning technique results in the production of a staple yarn wrapped by continuous filament yarn. By feeding the filament component under low tension to one side of the staple fibres as they emerge from the roller nip, a pronounced displacement of the filament from the core to the surface is produced; this contributes to a higher yarn strength if low spinning twist is used with short staple fibres. A similar effect is obtained if the filament is introduced *after* the delivery roller nip. Compared with spun yarns, wrapped yarns have improved strength, abrasion resistance, decreased hairiness, reduced yarn friction, and the spinning process may benefit in a manner similar to core spinning and with the added benefit of a reduction of fly waste.

A variation of this type of yarn can be produced on a false-twist tube ring frame as used in woollen spinning. The filament is introduced around the staple fibre strand by rotating the supply of continuous filament yarn mounted on the false-twist tube so that it is already twisted around the strand of staple fibres before the final twist is inserted in the usual way by the ring spindle. Such a yarn is called a 'Differential Twist Yarn' (DT yarn) and it differs from the covered yarns described above in that the twist of the continuous filament yarn is greater than that of the staple fibres.DT yarns have greater tenacity, less variation of tenacity, lower yarn irregularity, and lower extension at break than woollen yarns.

Core stretch yarns can be produced by using a stretch core of elastane. This is usually done at the spinning frame by having a purpose-built suface-roller-creel to feed the elastane into the nip of the drafting zone front rollers under positively controlled conditions of extension, usually in the region of about 400%. When the resulting yarn is allowed to relax, the core contracts and bulks the sheath fibres to form a series of loose spirals. When extended, the core will stretch until the sheath fibres become taut. Frequently a single core yarn of this type is folded with an ordinary spun yarn to produce a two-fold stretch yarn which has the general appearance of a normal staple fibre yarn; the folding process helps to prevent 'grinning' (i.e. the core showing through the sheath of staple fibres). Stretch yarns can be produced on the Repco self-twist system using elastane or textured continuous filament yarn combined with staple fibre. Hot processing of the extended yarn can modify the recovery properties of the elastane, and so yarn dyeing must normally be done under low-tension conditions such as those encountered in muff dyeing. Yarns of this type are useful in applications such as cuffs and neck openings for knitwear, and for the tops of socks. Continuous filament elastane yarn is expensive, but used in this way it only accounts for about 1 to 2% of the total yarn mass, depending on the yarn count and stretch requirements.

The principle of combining continuous filament yarns with staple fibre can be extended to the 'scaffolding thread' application, where a soluble continuous filament yarn, such as alginate, provides temporary yarn strength, but is removed chemically from the final product.

Continuous filament metallic yarns sometimes may be used in conjunction with staple fibres to produce fancy yarns.

Coloured yarn manufacture

The manufacture of speciality coloured yarns has been widely developed on the worsted system for many years, and during the twentieth century some short-staple spinners have moved into this section of the trade.

The coloured fabrics which are produced by piece dyeing and yarn dyeing usually consist of solid shades unless cross-dyeing of blends is used in which case there are limitations to the range of different colours which may be combined and only fairly simple colour-mixtures can be produced in this way.

If fibres are dyed before blending then a wide variety of colour-mixtures, or 'ingrain' blends can be produced and dyewares can be selcted to satisfy any particular requirement, such as fastness to washing, for example. In some cases, when using dyes which provide a good resistance to certain agencies, it may be difficult to produce a good 'level' shade. By dyeing the fibres in top form, any problem arising from shade variation can be eliminated by blending during subsequent yarn production processes.

When coloured fibres are mixed together to form a colour mixture or 'ingrain' blend, only a limited range of solid shades are required in the dyer's palette to provide an infinite range of colour-mixture shades.

There is no doubt that the application of colour to textile materials is one of the most important steps in the sequence of manufacture, as it is often the colour and design of a garment or fabric which appeals to the customer. The dyeing process is a specialized combination of art and science, and the dyer is a key person in the production of coloured textiles.

When oil-combed tops are dyed, the loss of oil during dyeing is very slight under normal conditions, therefore very little oil (if any) should be added in subsequent processes unless backwashing has been used after dyeing.

In a large firm which produces stock shades and repeat-shade orders, the first step in ensuring that the correct, and accurate repeat, shades can be obtained is to carry out an initial quality control check on the dyewares themselves. Most mass produced products vary slightly and in this respect dyewares are no exception. A sample is dyed from each incoming container of dye, at the same time and under identical conditions as a 'standard' of the same shade so that the new dyeing can be compared with a standard dyeing. If the strength of the dyestuff in the new container differs from the standard, the dye receipt can be suitably modified to ensure that future dyeings from the new dyeware can be the same shade as that produced by the standard. The increase (or reduction) in the amount of the new dyeware needed to produce the standard shade is expressed either fractionally or as a percentage, and usually it will be of a low order because of the accuracy to which dyewares are manufactured. For example, suppose that the amount of the new delivery of dyeware needs to be increased by 0.1% in order to produce the same shade as the standard dyeware, then in every dyeing recipe using this new delivery, 1001 grammes will be required in place of every 1000 grammes indicated on the standard recipe. The standard recipe is *not* altered; it remains unaltered as a *standard* recipe based on the *standard* dyeware. Even when such precautions have been taken there may be slight shade differences between yarn lots produced. Consequently yarn users should never mix different yarn lot numbers indiscriminately even though the lots are supposed to be identical in fibre quality, count, twist, and shade.

For example, in the production of knitted garments it would be foolish to make sleeves from one yarn lot number, and body sections from a different yarn lot number; one lot should be used up in the correct proportion of sleeves and body sections before changing to the new lot number. Similarly a weaver may 'spread' the old lot number across a warp, or alternatively use up the old lot number *continuously* in the weft until it is all used up, before commencing to use the new lot of yarn in the weft. In this way one single weft bar will be made.

The descriptions which follow apply to the well established practices and products of the worsted industry, but the same principles apply to any staple yarn manufacturing system.

Most of the yarns produced may be divided into three groups: solid shades; mixture shades; and colour twists.

Solid shade yarns contain fibres which are intended to be all the same colour, but in practice when very large lots of yarn are produced, different dyeing batches may vary from each other slightly; this can be catered for in the subsequent blending routine to be described later.

Mixture shades contain not fewer than two different colours of fibres blended together and intimately mixed. It is not intended that fibres of one colour should be bunched together or grouped in any way — such fibre arrangements form different types of yarns which are given distinctive names which will be discussed later.

Colour twists are yarns which contain different coloured single yarns folded together. The single yarns have been processed separately as far as the spinning stage — they may be solid shades or colour mixtures and can involve contrasting or harmonizing colours.

In addition to the groups mentioned above, which account for the bulk of the coloured yarns made, there are many speciality coloured yarns which have specific names; they are described later.

The methods employed for the blending and mixing of coloured fibres differ considerably, both between the different firms in the industry, and also within a single firm. These differences are largely influenced by the form in which the fibres are dyed, the fibre dimensions, the yarn count to be produced, and the intended end-use.

Yarns of similar fibre quality, shade, and count, may be destined for use in fabrics which impose vastly different degrees of critical appraisal on the yarn itself; in one case it may be essential to use a recombing operation, whereas in another case recombing might be omitted because it would be an unnecessary expense. Similar considerations may influence the decision to use Vigoureux printing (described later) rather than a colour mixture. Vigoureux printing gives a more even shade distribution, but is more expensive than a colour mixture; consequently usually it is restricted to critical end-use situations.

The production of worsted yarns spun from coloured fibres usually involves the dyeing of top slivers before the different coloured fibres are mixed together. An alternative which is rarely used on the worsted system, but which may be used sometimes on the woollen system, is to dye the material in card sliver form.

Dyeing in card sliver form

This method is rarely used on the worsted system because of the disadvantages of coloured fibres processing in combing: because the coloured noils produced would be less valuable than undyed noil.

On the woollen system, dyeing of loose fibre stock *before* carding is commonly practiced because usually all the mixing possible on the brief system of yarn manufacture is needed.

Assembly of dyed top slivers prior to gill mixing or recombing

It is usual to divide large lots of dyed tops into 'setts'. A sett may be from 60 to about 130 kg, but for a given lot of tops being processed, all the setts are of one particular quantity.

Solid shade processing

In the case of solid shade processing of large lots it is almost inevitable that different dye batches will vary slightly in shade. For example, suppose that a lot consists of 5000 kg of material dyed in ten different dye batches of 500 kg each. The ten dyeings may be divisible into, say, three main groups: one 1000 kg which is light in shade; one group of 3000 kg which is approximately on shade; and one 1000 kg group which is dark in shade. The last group may deliberately have been dyed dark to counterbalance the earlier slight off-shade dyeings which were light in shade. It should be appreciated that the terms 'light' and 'dark' are only relative and may represent only a slight shade difference in the dyeings; nevertheless even a slight shade difference which would not be noticeable in different garments would show up strongly if such yarns were knitted or woven alongside each other. In this example, the 5000 kg lot of material could be divided into 50 setts of 100 kg, with each sett made up of 20 kg light shade, 60 kg approximately correct shade, and 20 kg dark shade. Each sett is fed into the first gill box of the gill mixing set or comb preparing set of gill boxes as a separate entity: one sett is 'run out' before the next sett is fed in and so on. The length delivered per doff at each process is calculated to give the correct number of full cans to provide the required number of doublings at the following operation. When processing a very large lot it may take days to complete, but the proportions of colours fed in are maintained constant because each sett is identical. The setts will become intermingled later because of the arrangement of drafts and doublings used subsequently.

Mixture shade processing

A similar method is used when colour mixtures are processed, but in that case there is the added complication of including the correct proportions of the component colours.

There are three main aspects to the problem of ensuring a constant shade of a colour mixture product:

(i) shade variations may occur between different dyeings of components which represent a large proportion of the blend in exactly the same way as with solid shade lots;

(ii) accurate weighing of the blend components is essential, particularly for smaller blend proportions, and especially if these components are relatively strong shades. Weighing accuracy also necessitates the prior storing of components for a length of time which will ensure uniform moisture content within and between all the components;

(iii) when the proportion of a component is very small, great care must be taken to ensure that the mixing is sufficient to guarantee even distribution of that component.

The components are assembled into setts in the required ratio in much the same way as for solid shades, but in the case of complicated colour mixtures it may be preferable to use smaller setts in the region of 60 to 100 kg.

A complicated colour mixture may contain a large proportion of one or two components combined with relatively small proportions of some more distinctive colours to produce a bright sparkling mixture based on a somewhat dull background. For example, a 4000 kg lot may contain 3000 kg of one basic shade component such as slate which will form the background for the brighter components. Such a large amount of slate will probably have been dyed in, say, 8 batches, therefore the same care must be used as if a solid shade were being assembled, by ensuring that each dye batch is proportionately represented in each sett. The remaining components in the colour mixture may be much more distinctive than the background slate, being both brighter and stronger in shade. A hypothetical example of such a colour mixture is given in *Table 21.1*.

In this example, each of the brighter colours probably will have been produced as a single dye batch and so there should be no variation *within* each of those components; this simplifies the weighing-out of those components.

If, on the other hand, some of the smaller components were using up material from a previous dyeing which had been left in stock, along with a small new dyeing to make up the required component quantity, all the same precautions would have to be taken

Table 21.1 ***Proportion of components in a hypothetical colour mixture***

Component	*Component quantity (kg)*	*Quantity per sett (kg)*
background slate	3000	60.0
light blue	500	10.0
turquoise	275	5.5
green	200	4.0
bright yellow	25	0.5
total quantity: for the lot	4000	per sett 80.0

as described previously for when more than one dyeing batch is involved. The main problem with these smaller components is to ensure their constancy throughout the process of weighing out the material into sett form; for this purpose a weighing accuracy of at least 0.1% is needed.

Assuming that twelve doublings of 20ktex each are to be fed into the first mixing operation, then the length of one doubling from a sett of 80 kg must be (80 × 1000)/(20 × 12) = 333.33 m, and it will have a mass of (20 × 333.33) 1000 = 6.66 kg. It follows, therefore, that the turquoise, green, and bright yellow top slivers would be too short to form one complete doubling running throughout the sett at the first operation. In the case of the bright yellow component, the 500 g per sett would have a length of only 25 m; the turquoise would be 275 m, and the green 200 m long.

To improve colour distribution, a preliminary drafting of these minor components would be made, along with some of the main background slate, using doublings equal to draft. The total draft needed to extend the 25 m of bright yellow to the required minimum length of 333.33 m would be 333.33/25 = 13.33; this would be too much draft to apply in a single operation and so in this particular example, the bright yellow would have to pass through two preliminary gill mixing processes in sequence with equal doublings and draft in each process. The turquoise and green components would also be included in this case, but if there had not been such a small quantity of bright yellow, a single preliminary gill mixing would have been sufficient for these two components. The pre-gilled mixing is colloquially known as a 'dolly'.

The dolly will then be used as a doubling in its own right at the first operation of the mixing set proper when 12 doublings would be used in the normal way.

As stated previously, it is usual to dye the material in top sliver form when worsted yarns are to be spun from coloured fibres. The actual dyeing process usually involves the dyeing of the complete top package which remains intact during the actual dyeing process; this is known as top dyeing. Alternatively the dyeing process can take place on hanks reeled from top slivers; this is known as slubbing dyeing, a method now rarely used.

The subsequent mixing together of the different coloured top slivers may take place in one of three ways: (1) gill mixing; (2) recombing; or (3) at the commencement of the drawing process.

(1) Gill mixing

This method is rarely used for merino wools, but is commonly used for crossbreds up to about 56's or 58's wool quality. With most of these wools recombing is not necessary because the dyeing operation does not cause much fibre disturbance and so neps and slubs are not easily formed; it is sometimes necessary to recomb 58's quality, and occasionally 56's when they are to be used under exacting conditions such as in a woven colour and weave effect fabric, but for most purposes gill mixing is adequate.

Gill mixing usually consists of four operations using gill boxes; a typical arrangement of drafts and doublings is shown in *Table 21.2*,

During gill mixing, oil and/or antistatic may be added, and moisture may be added so that the tops produced will contain the correct amount of moisture when they are delivered to the spinning factory.

Table 21.2 ***Gill mixing set: input 20 ktex top slivers, output 20 ktex mixed top slivers***

Operation	*Doublings*	*Draft (approx)*	*Delivery (ktex)*
1	12	5.5	43
2	8	5.7	60
3	6	5.9	61
4	2	6.1	20

(2) Recombing

This method is mainly used for merino wools of 60's quality and finer, although it is sometimes used for 58's and occasionally for 56's. The products may be either:

(i) solid shade comb-mixed tops, or
(ii) mixture shade comb-mixed tops.

There are two schools of thought regarding these methods. Some colour matchers prefer to process solid shades through recombing and then gill mix later to obtain the required colour mixture shade. Other colour matchers prefer to mix the different coloured components prior to the actual recombing operation. The latter method benefits from the additional doublings used to mix the different colours togethers, but careful allowance has to be made if differential noil removal takes place during recombing. Differential noil removal means that the shade of the noil extracted will be a different shade from that of the tops produced because the percentage of noil removed may differ for each different coloured component present. This phenomenon has to be allowed for by including a greater percentage of the 'high-noil fibre' in the assembled blend before recombing. This can be done on the basis of previous experience, and can easily take care of the alleged disadvantage of producing mixture shades at the recombing process itself.

The dyed (and dried) slivers are passed through a recombing preparer set of gill boxes prior to the actual recombing operation, which is then followed

Table 21.3 ***Recombing preparer set to process 20 ktex top slivers prior to the rectilinear recombing operation***

Operation	*Doublings*	*Draft (approx)*	*Delivery (ktex)*
1	12	6.0	40.0
2	5	6.1	33.0
3	3	6.4	15.5

by the usual two top finishing operations. An example of a recombing preparer set is given in *Table 21.3*.

If Noble recombing were to be used, doublings would be increased and drafts decreased to deliver a sliver of about 55 to 60 ktex.

The recombing route involves more processing than just gill mixing and it also entails the extraction of noil; consequently it is more expensive. For dyed merino wools about 4% noil is extracted usually, and only exceptionally is more than 5% noil removed from dyed wools, but 5% is normal for Vigoureux printed merino wools; for fine cross bred recombing about 3% noil is usually taken out from dyed wools. The nep content of dyed recombed merino tops is usually only 25% to 50% of the original undyed top, the mean fibre length is usually about 5% longer, and the C.V.% of fibre length typically is reduced from about 48% to about 44%.

(3) Colour mixing in drawing

In effect this method is really gill mixing prior to the normal sequence of drawing processes. It involves the use of three or four additional gill boxes using drafts and doublings to obtain the required degree of mixing. This method was used quite widely by worsted spinners prior to the introduction of shortened drawing sets in the 1950s following the introduction of autolevelling and high-draft spinning. With the modern short drawing sets, many spinners prefer to buy ready-mixed tops from the recomber, but some spinners still use mixing at the drawing stage because it allows them freedom to control the shades produced and possibly permits a shorter time from receipt of order to delivery of the yarn.

Vigoureux printing

The majority of dyeing prior to drawing and spinning is intended to result in the uniform application of colour to all the fibres and all along the length of each fibre. A specialized alternative which is widely used from time to time, depending on the vagaries of fashion, is the Vigoureux printing method (otherwise known in the UK as melange printing). This method, patented by a Frenchman, Stanilas Vigoureux in 1863, was not widely used until the beginning of the twentieth century. The process involves a specially designed gill box which delivers a broad web of parallel fibres which pass between a printing roller and a felt-covered roller which is impregnated with a mixture of dyeware and other additives.

The printing roller has raised helical bars. Rollers with different bar widths and spaces between the bars provide the facility to imitate the effect of different proportions of black and white, for example. Changes in the printing roller pressure will also influence the final depth of shade obtained. The printed area is usually from 10% to 70% of the total area of material passing through.

The Vigoureux process is by no means easy to control; the slightest change of printing roller pressure may throw out the depth of shade significantly. This makes shade matching difficult and tedious because the final result is not really apparent until after the final gilling which takes place later. For this reason it may be necessary to blend in a small proportion of a different depth of Vigoureux shade in order to bring the batch on shade.

The Vigoureux process, besides being used mainly for wool and mohair, may also be used for man-made fibres provided that suitable dyewares are used.

The dyestuff placed in the colour box is usually in the form of a printing paste as an admixture with ancillary dyeing additives and a thickening agent which enables it to grip firmly on the fibres to stay in place without smudging. Other ingredients may include: glycerine — to prevent drying before the steaming process; a type of chrome; oxalic acid; sodium chlorate; and water.

The web of printed fibres is cuttled into louvred aluminium cans ready for steaming. Traditionally steaming takes a total time of about 1 to 2 hours. Care must be taken to avoid condensation falling on to the fibres during steaming because this can cause dyewares to run and spread to form short sections of continuously dyed fibres which would show up as a fabric fault.

When printing animal fibres it is important to minimise the yellowing of the unprinted fibre sections. This is ensured if there is a low oil content and low residual alkali content after scouring. The use of synthetic detergents in woolscouring can ensure a low pH.

After steaming, the fibres are re-gilled and may also be backwashed to remove surplus residues of the colour paste; there may be up to four rinse bowls used for this purpose prior to the suction drum dryer.

Because the objective of Vigoureux printing is to produce a superior mixture-like yarn it is usual for 58's and 60's wool qualities to be recombed. Normally about 1% more noil is extracted compared with ordinary dyed material when identical comb settings are used.

The cost of printed tops is higher than for a corresponding mixture shade because all the fibres must pass through the process, whereas for a 50% black, 50% white mixture, for example, only half the material has to be dyed, and for a lighter shade an even smaller proportion would be dyed.

The Vigoureux printed sliver presents much smaller units of colour than can be obtained by mixing fibres which are fully dyed along their length, and this is the reason why a much more uniform mixture effect can be obtained.

Imitation Vigoureux effects

An effect which gives a good imitation of the printed top can be obtained by judiciously blending a series of intermediate shades of fibres. For example, instead of blending 50% black and 50% white to produce a medium grey mixture, it may be decided not to include any black or any white at all, but to use a series of slate shades ranging from near-black to near-white. By doing this the streaky effect caused by fibre bunching, which is almost inevitable in a straight black/white mixture, can be avoided. This method will have a cost intermediate between Vigoureux printing and an ordinary mixture. At the same time it should be appreciated that the 'sparkle' given by the contrast of pure black and pure white in a mixture or in a printed top will not be obtained.

A similar technique may be used under circumstances where it is difficult to avoid a streaky appearance. This situation can arise when fibres of different fibre lengths are to be blended. A traditional blend which gives a good example of this is when a blend of 2/3 undyed 64's quality wool is blended with 1/3 black dyed 58's quality wool. This choice of blend arrangement has the advantage that black fibres which are coarser will not show up excessively in a blend whereas undyed coarse fibres would appear more prominently. Such a product is often referred to in the trade as a 'blended 60's quality top' because it has a mean fibre diameter and mean fibre length similar to that of a 'straight 60's quality top' (i.e. unblended). However, the other characteristics of a straight 60's top would be considerably different from the blended 60's top as may be seen from the typical details given in Table 21.4.

The straight and blended 60's may be distinguished by the differences between their coefficients of variation of fibre diameter and fibre length, respectively, and in the percentage of short fibres.

This blended type of top was traditionally used for the production of a grey mixture worsted flannel cloth. The object of blending such diverse components is that they both contribute certain desirable features to the end-product. The finer component gives good cover and handle, whereas the lower quality imparts strength, stability, and hard-wearing properties.

A problem arises in controlling the different fibre lengths in drafting to avoid streakiness caused by the tendency for fibre grouping in the two component shades. To solve this problem it is common practice to add a small proportion of Vigoureux printed top in the blend, or an intermediate shade containing both of the component qualities. By using this technique the inability adequately to control the fibre mixing is no longer visually apparent. Fabrics of this type nowadays would probably involve blending polyester and wool, but from the colour appearance point of view, similar principles can be applied.

Speciality coloured yarn terms

In addition to the solid, mixture, and Vigoureux shades mentioned previously, colour effects may be produced by combining the different shades of components at the roving, spinning, or folding operations. Standard yarns produced by such methods are identified by particular names:

Colour twist

Two-fold yarn composed of different coloured single yarns, either solid or mixture. The term grandrelle is often used in the short-staple section of the industry for this type of yarn.

Table 21.4 *Comparison of fibre dimensions in straight 60's and blended 60's tops*

	64's	*56's*	*Blend of 2/3 64's 1/3 56's*	*Straight 60's*
Fibre diameter: mean (μm)	22	29	24	24
C.V.%	23	25	29	24
Fibre length: mean (mm)	70	100	74	74
C.V.%	47	44	49	46
% fibres shorter than 30 mm	15	7	8.5	13

Single marl

A single yarn spun from a two-coloured roving. The roving is produced by feeding into the drafting zone of the roving frame two doublings which are of different colours.

Marl

A two-fold yarn composed of two identical single marls.

Half marl

A two-fold yarn made from a single marl folded with a solid or mixture single yarn of the same count and quality, but usually of the same shade as the darker shade in the single marl.

Double marl

A two-fold yarn made from single marls of different colours so that four distinct colours are present.

Single mottle

A single yarn produced by feeding into the drafting zone of the spinning frame, two half-count rovings of different colours. The contrast is greater than that produced in a single marl, but otherwise the effect is similar. Single mottles are rarely produced commerically because about three times as many roving spindles are required to produce the half-count rovings as would be needed if a single end of normal count roving were fed to the spinning frame.

When yarns are spun from three rovings of one-third of the normal count, it is essential to feed in the three different colours of roving in the same order from the creel pegs at all the spindles in order to avoid shade variations. This is because the outer fibres are incorporated into the yarn differently from those in the middle of the ribbon of fibres emerging from the front rollers of the drafting zone.

22

TOW-TO-SLIVER CONVERSION AND BULKED ACRYLIC YARN PRODUCTION

A tow-to-sliver converter is a machine which is fed by continuous filament tow, but which delivers a staple fibre sliver. For many years staple man-made fibre was supplied to yarn manufacturers to be processed on machines originally designed for natural fibres. This arrangement still generally applies in the short staple industry where bales of staple fibre are received after being cut from continuous filament tow by the man-made fibre producer before being processed into yarn at the spinning factory, processing includes opening, blending and carding, and sometimes combing, prior to drawing and spinning.

In the long staple section of the trade a similar situation existed until the 1950s. For example, in the UK staple fibre Terylene was introduced to the worsted industry in 1952 to be processed into tops at the woolcombing factory via processes including carding, combing, and top finishing, before being delivered to the spinner. However, by about 1963 approximately 85% of all Terylene tops were processed from tow by converters instead of by carding and combing.

Conversion from tow-to-sliver in one machine offers commercial and technical advantages, including fewer neps in the top produced. The tow-to-sliver conversion route is now firmly established in the worsted section of the industry and for other long staple processors. For most yarns, combing is not required, although it may be used for some purposes, such as fine count yarns and after fibre dyeing for contrasting speciality coloured yarns.

Tows are produced ranging from about 10 to 60 ktex, depending on the fibre type and on the method of processing, to give a total input to a stretch-breaking converter of from 70 ktex for polyester up to about 120 ktex for acrylic fibre, and for a cutting converter a total input up to about 200 ktex.

Tow quality is important for tow-to-sliver converters, particularly as regards uniformity of crimp wavelength and amplitude, parallel filaments, and lack of fused, broken, or entangled filaments.

There are two main methods of conversion available: the cutting method and the stretch-breaking method, each having some advantages and disadvantages.

The cutting method does not alter the fibre characteristics such as strength, extensibility, or shrinkage, and positive control may be exercised over both the mean and variation of fibre length. The cutting method is not usually regarded as successful for fibres finer than about 2 dtex, and sometimes difficulty may be experienced in separating fibres after cutting, with the consequence that some fibres may remain bunched together to form a thick place in the ultimate yarn.

The stretch-breaking method can be used for virtually any filament thickness. Compared with cutting it does not permit such close control of the fibre length properties, but it has the advantage that no bunching of fibre ends takes place. The physical properties of the fibre are modified by stretch-breaking and this feature is exploited in the production of bulked acrylic yarns.

Various machinery makers have produced machines operating on one or other of these principles in which the detailed machine construction may differ from the other machines; nevertheless, the basic principles involved remain very much the same, and so the general principles of the two methods are discussed here.

Cutting converters

The Courtaulds Greenfield converter was the first commercially used tow-to-sliver machine; it was employed from 1937 within Courtaulds' factory to produce viscose tops for sale to worsted spinners. The Pacific converter became available after World War II for use *within* the spinning factory so that spinners could be supplied with continuous filament tow. Alternatively combers used this route instead of carding and combing to produce man-made fibre tops. The Pacific converter was capable of processing all types of man-made fibre including the hard synthetic fibres. Later the Greenfield converter was modified to deal with synthetics, and now many other makes of cutting converters are available.

The features which are common to most, if not all, cutting converters include a creel, the cutting section, the sliver forming section, and stuffer-box crimping followed by can delivery.

Usually the creel is mounted over the machine and it consists of a series of stainless steel bars of about 40 mm diameter, some curved, which are intended to enable the tow to divest itself of any false-twist, and permit the filaments to spread out evenly across the required input width, with equal and uniform tension applied to each filament before the actual process of cutting takes place.

The cutting section consists of a helical blade cutting roller mounted over a smooth hard anvil roller (*Figure 22.1*). The cutting roller is the most expensive and important part of the machine, and for successful operation it must be adjusted and maintained carefully. The blade roller width is usually about 25 to 38 mm and usually a load of about 2 tonnes is applied to cause crush-cutting of the filaments by metal-to-metal contact between the cutting blade and the anvil roller.

The space between the cutting edges is lined with synthetic rubber to prevent lateral movement of the filaments during cutting — which would result in double-cuts and hence the production ofundesired short fibres.

The mean fibre length depends on the design of the cutting roller — different rollers are needed to produce different mean fibre lengths. The fibre length variation is influenced by the degree of parallelization of the tow, and on some machines the angle of tow feed can be varied sideways continuously to control the variation of fibre length.

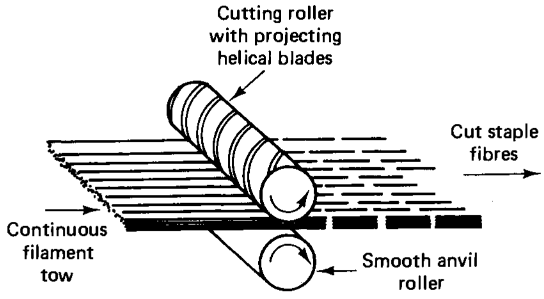


Figure 22.1 Cutting method of tow-to-sliver conversion

Badly maintained cutting rollers can cause melting instead of a clean cut so that some fibres may be twice as long as intended, with a hard bead halfway along the length; they may be called fused fibres. Even correctly maintained cutting rollers give rise to the production of a fine dust known as 'fish food' which is largely removed by suction later in the machine.

The cutting section is followed by the sliver forming section. On most makes of machines, sliver formation takes place by passing the overlapping fibres through a gill box type of fibre control unit, but on the Pacific converter a sophisticated arrangement of debonder rollers and shuffle sections is used to ensure separation of the fibre ends.

Usually the continuous sliver is then passed through a stuffer-box to crimp the fibres and thereby improve the cohesion of the fibres before they are delivered into the can under negligible tension. Normally after cutting conversion, at least two gilling processes are used to ensure adequate separation of fibre ends; these two processes may be equivalent to top finishing if tops are to be the end-product, or they may be the initial operations in a drawing set.

Stretch-breaking converters

This system is based on the principle that if a filament is held between the nips of two sets of rollers, with a faster surface speed for the delivery rollers, then under suitable conditions, the filament will be stretched and broken.

Superficially such an arrangement might be expected to produce a random distribution of breaks, but in practice, if the ratch between the two sets of rollers is not much longer than the intended fibre length, and if it is intended to break all the filaments in one single zone, then more short fibres will be produced than would be produced with a random distribution of breakage. Largely this is because the thicker mass of filaments entering the zone to some extent will be mutually supportive because of the inter-fibre friction, and therefore more breaks will take place nearer to the faster delivery rollers where there is a thinner assembly of filaments and less mutual support. In addition the tensile properties of the filaments entering the break-stretch zone vary not only between each other, but also along their length, and this contributes to a non-random distribution of breaks.

The early developments for tow-to-sliver conversion were intended for different types of end-products. The original Turbo-stapler was designed to process heavy acrylic tows, with heat-stretching and setting prior to the actual breaking zone in order to facilitate the production of bulked acrylic yarns. On the other hand the Seydel machine was originally developed to process relatively light-weight tows composed of fine filaments which were then processed into regular yarns (i.e. yarns which are not bulked) on the spun silk (schappe) system. Both these machines have been modified and have emerged in a similar form; now there are many other makes of stretch-breaking tow-to-sliver converters available. They are mainly used for the production of bulked acrylics, which have proved to be very popular.

Machines of this type consist of a series of heads, with each separate head containing a set of rollers all running at the same surface speed and arranged to avoid filament slippage. The rollers in a given head normally have a higher surface speed than those in the preceding head.

An example of the roller arrangement on a machine of this type is shown in *Figure 22.2* to which reference is made in the following description.

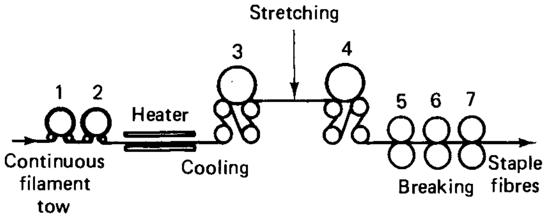


Figure 22.2 Stretch-break method of two-to-sliver conversion

The filaments are tensioned by heads of rollers 1 and 2 before being stretched by rollers 3 and simultaneously heated. It is important at this stage that filament breakage should be avoided. The objective usually is to obtain maximum stretch without filament breakage.

The actual temperature and stretch ratio i.e. (rollers 3 surface speed)/(rollers 2 surface speed) applied depend on the recommendations of the fibre producer of the particular tow being processed; it usually falls within the range of a heater setting from 120°C to 170°C with a stretch ratio from about 1.4 to 1.8. The two main control variables of temperature and stretch ratio have an important influence on the utlimate yarn properties because of their effect on both the subsequent shrinkage of the fibres and on the ultimate yarn strength. The general relationships are shown in *Figures 22.3* to *22.6*. The use of excessive temperatures causes a permanent breakdown of some molecular bonds and therefore a lower subsequent shrinkage as shown in *Figure 22.3*. Up to a point an increase of the stretch ratio leads to greater shrinkage, but beyond that point excessive stretch causes a permanent breakdown of some bonds, and hence a lower subsequent recovery from stretch as shown in *Figure 22.4*.

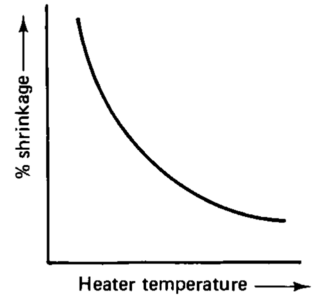


Figure 22.3 The influence of heater temperature on fibre shrinkage.

Within the normal range, the use of higher temperatures or an increased stretch ratio leads to increased yarn tenacity because of the effect on the molecular orientation, the general relationships are shown in *Figures 22.5* and *22.6*.

For a particular fibre the best conditions for producing maximum bulk are recommended by the fibre producer.

The thermostatically controlled heater plates are moved apart automatically when the machine is stopped in order to avoid 'cooking' of the tow, and

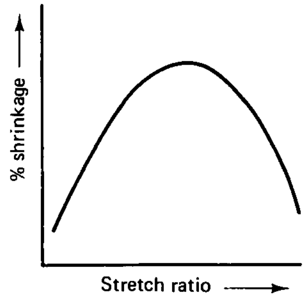


Figure 22.4 The influence of stretch ratio on fibre shrinkage.

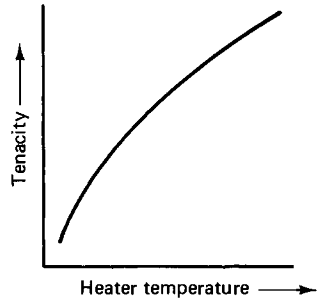


Figure 22.5 The influence of heater temperature on fibre tenacity.

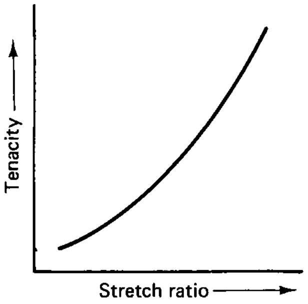


Figure 22.6 The influence of stretch ratio on fibre tenacity.

they come together again when the machine is re-started.

Immediately following the heater it is important that adequate filament cooling takes place before stretch-breaking; in addition to a cooling flow of air, water-cooled rollers are used for this purpose. The arrangement of the rollers contributes significantly to the cooling of the tow and also eliminates filament slippage. Further stretching takes place at rollers 4 before the final breaking between the three sets of rollers 5, 6, and 7, which are set at a suitable distance apart to provide the required fibre length diagram.

The sliver then passes through a stuffer-box crimper and is cooled before it is delivered into the can.

For the production of regular yarns, the heater is not used.

Bulked acrylic yarn production

General principles

A blend of pre-relaxed (i.e. relaxed prior to blending) and unrelaxed fibres is drawn and spun before being subjected to heat treatment. This causes the unrelaxed fibres to shrink so that the yarn contracts in length; at the same time the pre-relaxed fibres buckle and produce a considerable increase in yarn bulk. As shown in *Table 22.1*, a bulked acrylic yarn, after shrinking about 20%, was about twice as thick, and also more compressible, than a merino wool yarn of the same final yarn count. The meaning of the Thickness and Compression Indices was described on page 5.

If self-crimping bi-component fibres are used for the pre-relaxed proportion of fibres along with mono-component unrelaxed fibres in acrylic yarns, then even greater bulk can be developed. Such yarns give increased elasticity in knitted structures, particularly with cable and with tuck stitches, as well as an improved knitting performance.

Blend proportions

Gill box blending takes place at the beginning of the drawing set. Usually about 40–50% of unrelaxed fibres are blended with 50–60% of pre-relaxed fibres to obtain the best compromise between bulk on the one hand, and shrinkage, strength, and elongation at break on the other.

Maximum yarn bulk is obtained with about 40% unrelaxed fibre (*Figure 22.7*). With a lower percentage the unrelaxed fibres are unable to exert the power to shrink the yarn sufficiently, and with higher percentages of unrelaxed fibres there are fewer pre-relaxed fibres available to buckle and thereby provide bulk.

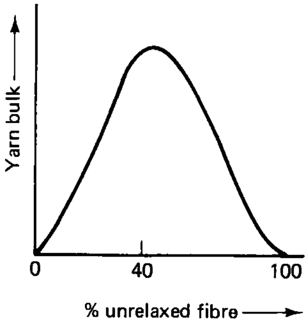


Figure 22.7 The influence of the percentage of unrelaxed fibre on yarn bulk.

Maximum yarn length shrinkage occurs when 50% or more of the fibres present are unrelaxed (*Figure 22.8*). Lower percentages of unrelaxed fibres can not exert sufficient power to effect maximum shrinkage.

Minimum yarn strength is obtained with a 50/50 blend of pre-relaxed and unrelaxed fibres (*Figure 22.9*). This is because when a load is applied to the bulked yarn only about 50% of the fibres support the load — the remaining 50% of the fibres are buckled and therefore initially remain relatively

Table 22.1 *Thickness and compressibility measurements made on 37 tex worsted-spun yarns*

Thickness index (μm)	*Compression index*	*Yarn composition*
266	0.193	merino wool
530	0.265	bulked acrylic

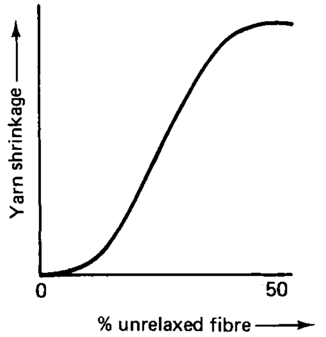


Figure 22.8 The influence of the percentage of unrelaxed fibres on yarn shrinkage.

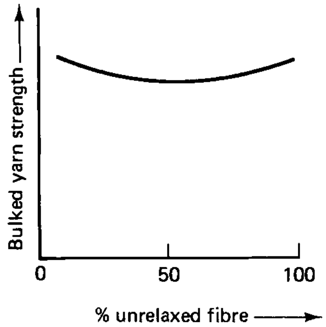


Figure 22.9 The influence of the percentage of unrelaxed fibres on bulked yarn strength.

untensioned. The result is that one group of fibres tends to be extended and broken before the other group is able to contribute fully to support the load. Consequently the load/elongation curve of a bulked acrylic yarn has an unusual outline (*Figure 22.10*). A plateau part-way along the curve corresponds to the further straightening out of the buckled fibres before they in turn are able to contribute to load-bearing.

For similar reasons the elongation at break of a bulked yarn falls to a minimum with a blend of about 50/50 (*Figure 22.11*). At the extremes, 100% pre-relaxed fibre would give a stable (or regular) yarn with maximum strength, whereas 100% unrelaxed fibre would yield a high-shrinkage yarn with maximum strength; in both cases the yarns would not have buckling properties and therefore would not bulk.

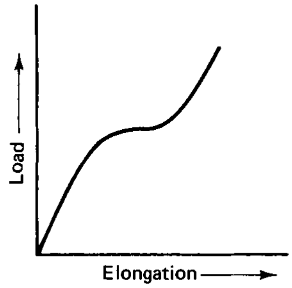


Figure 22.10 Typical load/elongation curve of a bulked acrylic yarn.

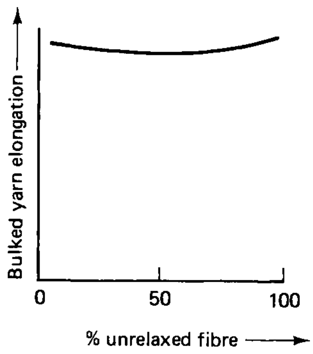


Figure 22.11 The influence of the percentage of unrelaxed fibres on bulked yarn elongation at break.

Pre-relaxation

All the fibres in the sliver leaving the stuffer box of the converter are in a state of suspended recovery from extension; the heat-stretch-cooling process has temporarily 'set' the fibres in an extended state. Later when the fibres are subjected to a suitable temperature, the fibres will contract back almost to the original unstretched length.

As explained previously, it is usual to have about 50–60% of pre-relaxed fibres to blend with 40–50% of unrelaxed fibres.

The original method of pre-relaxation (i.e. relaxation *before* blending), which is still in use, is to put the louvred aluminium cans of sliver delivered by the converter into an autoclave which provides an alternating cycle of air evacuation and steam. After this process the pre-relaxed sliver will be shorter and thicker, and this has to be allowed for when the cans of sliver are produced by the converter in the first place.

Close control of the process is essential: variations greater than about 2°C can cause differences in dye uptake which could lead to subsequent fabric faults. After pre-relaxation by this method the cans are usually allowed to stand for about four hours to cool before blending with slivers in cans which have by-passed the autoclave.

A more recent alternative to the autoclave batch process method is to have a continuous steaming unit attachment on the tow-to-sliver converter following the stuffer box crimper so that pre-relaxed fibres are delivered direct into the delivery can of the converter.

When the unrelaxed sliver is to be produced the continuous steaming unit can be by-passed by using a cooling tunnel. Compared with the batch system this arrangement offers lower production costs because of the time and energy saved in handling and the reduced energy, maintenance, and capital costs involved in the process itself. Further benefits conferred are that the accurate control system ensures uniform dye uptake, and also the dimensions and construction of the converter delivery can is not restricted — usually solid-sided circular plastic cans of 1000 mm diamater and 1200 mm height are used.

Final yarn shrinkage

After spinning and yarn folding have been completed it is usual to subject the yarn to a heat treatment which causes the unrelaxed fibres to shrink and, therefore, the bulk to develop by buckling the pre-relaxed fibres. If dyeing is required, bulking may be combined with the dyeing process provided that the yarn is free of physical constraint as it may be in hank dyeing or muff dyeing. If dyeing is not required then a continuous bulking process may be used in which the yarn is fed from a supply package into a heated chamber which contains a reserve of yarn: the yarn is drawn continuously from the top of the reserve to be wound on to the delivery package at a slower speed than the speed of yarn being continuously fed in to the bottom of the reserve. Some machines working on this principle deal with a single yarn at each heater, whereas other machines feed a number of yarns to each heater before separating them prior to forming the delivery packages.

Acrylic yarn counts

Apart from regular yarns, most acrylic yarns are delivered to the customer in the bulked state after the final yarn shrinkage process. Alternatively it is possible to carry out the bulking process in fabric form, after knitting the un-bulked yarn (or after some other fabric-forming process). To avoid confusion when quoting yarn count, it is important to describe which state the yarn was in when it was tested. It is usual to quote the count ‘as spun’ when the yarn has not yet been bulked, even if it is a folded yarn, or as ‘bulked’ if it is tested after final shrinkage.

For normal bulked acrylic yarns, yarn shrinkage after spinning is usually about 22%, but fibre which shrinks about 26% can be used to produce ‘superbulk’ yarns; such yarns exhibit a more noticeable core and sheath segregation of the unrelaxed and pre-relaxed fibres in the final yarn — this is sometimes called the ‘lotus ring effect’. Low shrinkage yarns are sometimes produced, mainly for use in full-fashioned knitwear, with a yarn shrinkage of about 16%.

APPENDIX

PROCESSING SEQUENCES

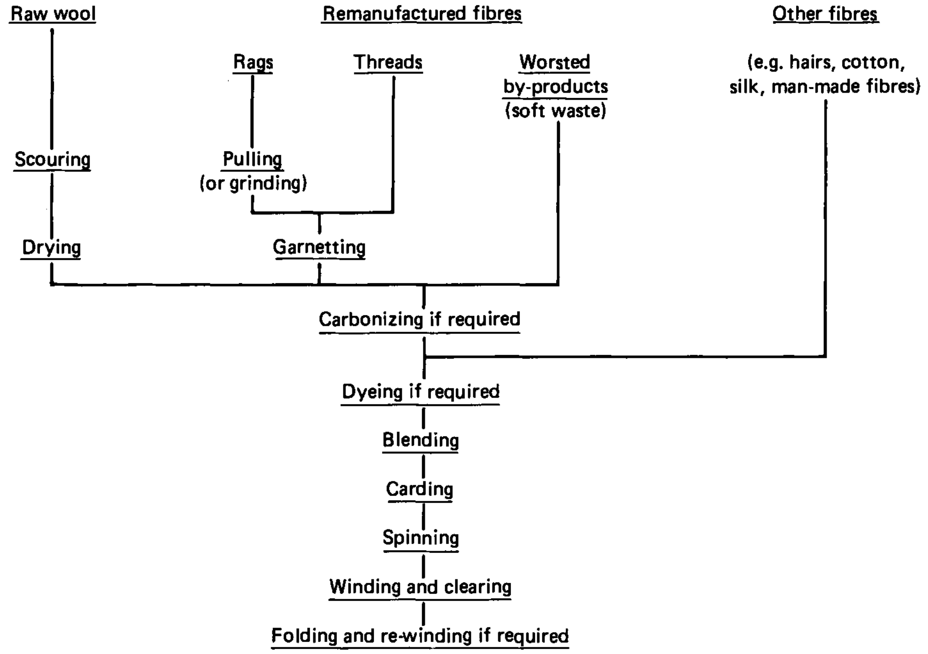
This appendix, which consists mainly of process flow-charts, is intended to integrate the earlier information so that a general indication is given of the operations through which fibres usually pass in order to be made into a yarn on a particular system, ready for delivery on cone.

Additional processes which may be used such as weft winding, hank reeling, balling, or warping, have not been indicated in these charts.

There are many exceptions to the schemes which are indicated: for example, in woollen processing rags may be carbonized before pulling, and yarn dyeing or piece dyeing may be used.

The processing of man-made fibres either in blends or 100% is common on all the systems, but this has not been emphasised in the charts which follow — the charts concentrate on the processing of the natural fibres for which the systems originally were designed.

Woollen flow chart



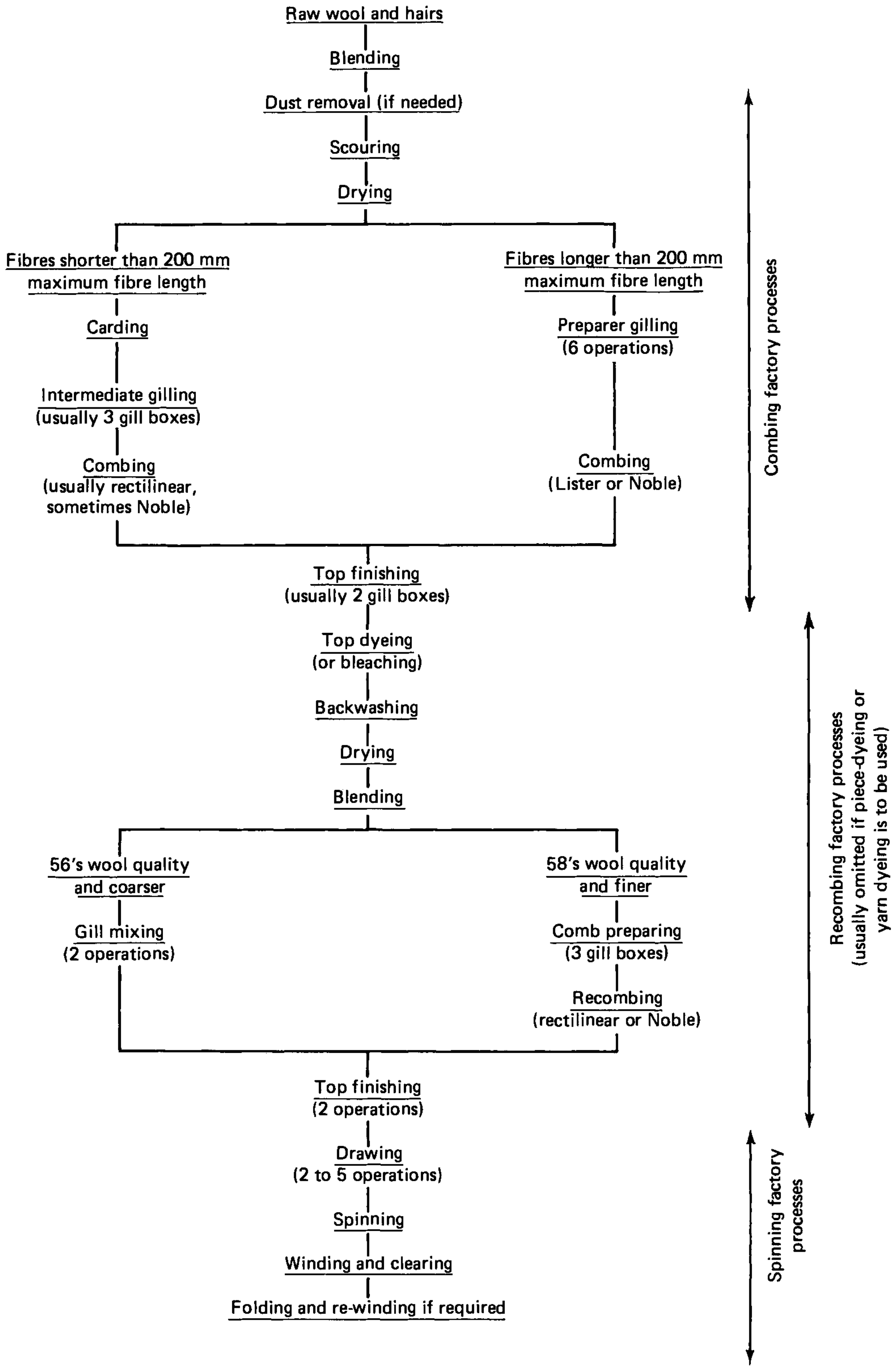
The woollen system is capable of processing wools and animal fibres of almost any fibre length distribution, some of which otherwise would be wasted. The products may range from cheap re-manufactured fibres to more luxurious fibres, such as lambswool, and expensive luxury fibres such as cashmere and vicuña.

Rates of production in carding are related to the ultimate yarn count — when fine condenser slubbings are produced, card production rates are much lower than the card could attain without the restrictions imposed by the condenser.

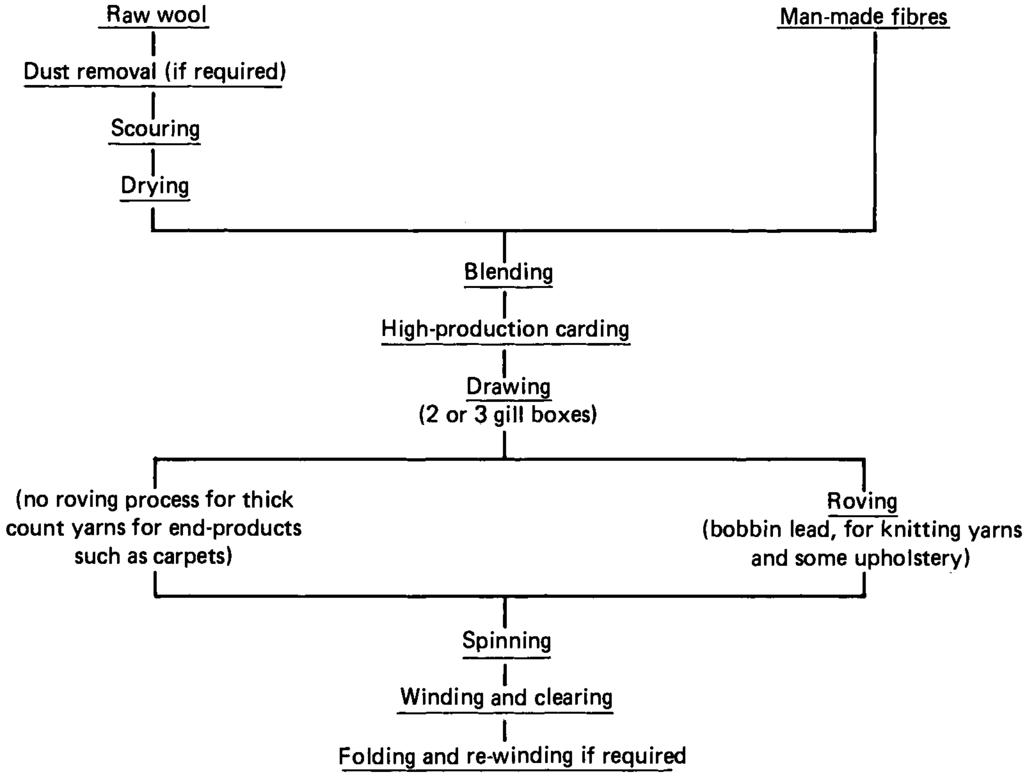
Carding is frequently carried out on dyed wool; the high oil content and flexible card clothing which may often be used makes card fetting a lengthy procedure when changing to a blend of another colour. For carpet and blanket yarn production, usually undyed fibres are processed, with yarn or piece dyeing taking place later.

Many yarns are now made from blends of wool (or hair) and man-made fibres, or from 100% man-made fibre.

Worsted flow chart



Semi-worsted flow chart



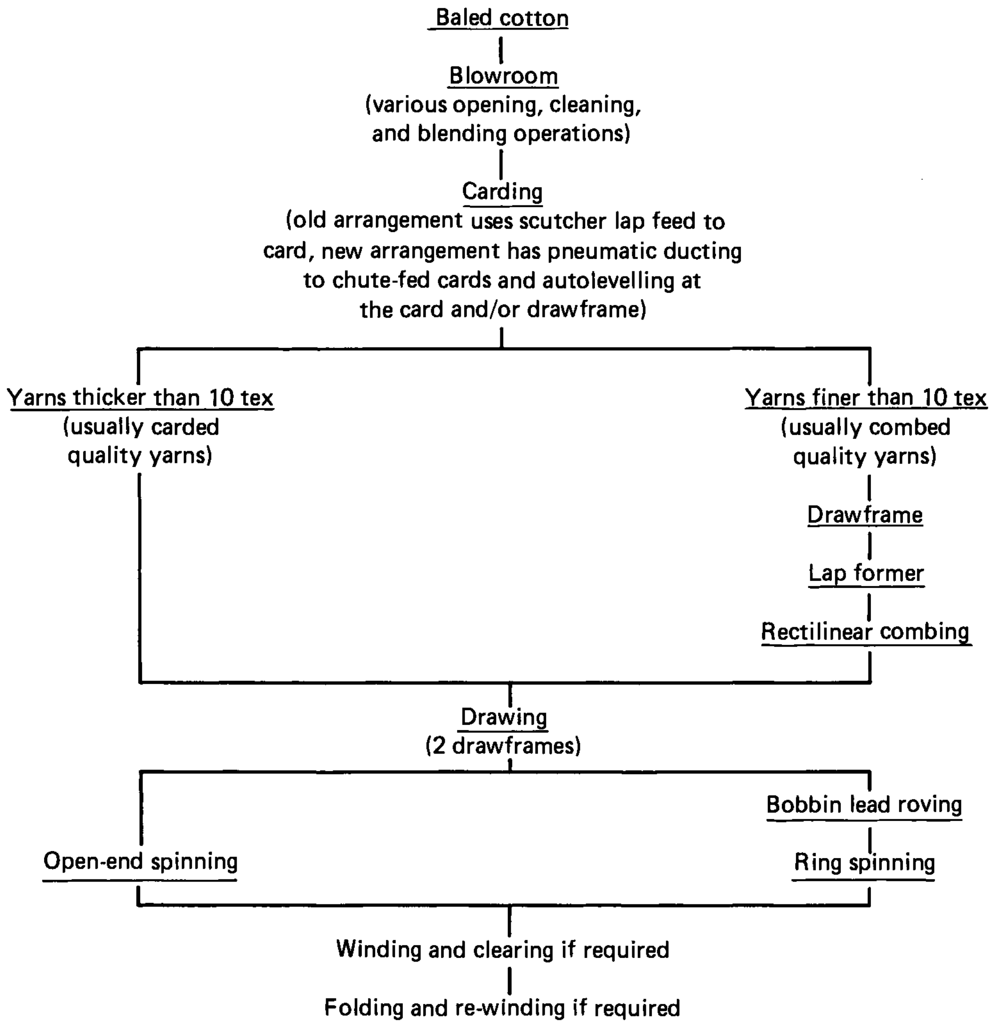
This system may be used for processing 100% wool (not very common), 100% man-made fibre, or blends, for use in products such as carpet pile, unholstery, and hand-knitting yarns, mainly in the count range from 100 tex to 300 tex or thicker. Although a modified jute card may be used for the carding process, the general principle is that worsted-type machinery is used, operating at high production rates with large packages, and hence low labour costs. *Combing is omitted.*

For the production of carpet pile yarns the semi-worsted system has developed as an alternative to the woollen system where the use of the condenser limits the card production rate. Because the yarn is generally smoother, stronger, and more uniform than woollen yarns, the semi-worsted process has increased in popularity for the production of tufted carpet pile yarns which frequently are spun from stock-dyed blends of man-made fibre.

The semi-worsted system is not widely used for 100% wool processing because of the relative shortage of suitable wools. For satisfactory processing, wools must have a good fibre length — i.e. a mean fibre length not shorter than about 64 mm, and with not more than 30% of the fibres shorter than that length; grease content must not exceed 1% in order that fettling will not be required with the rigid metallic card clothing used. The system is most frequently used for processing man-made fibres from 9 to 17 dtex, in lengths from about 100 to 150 dtex.

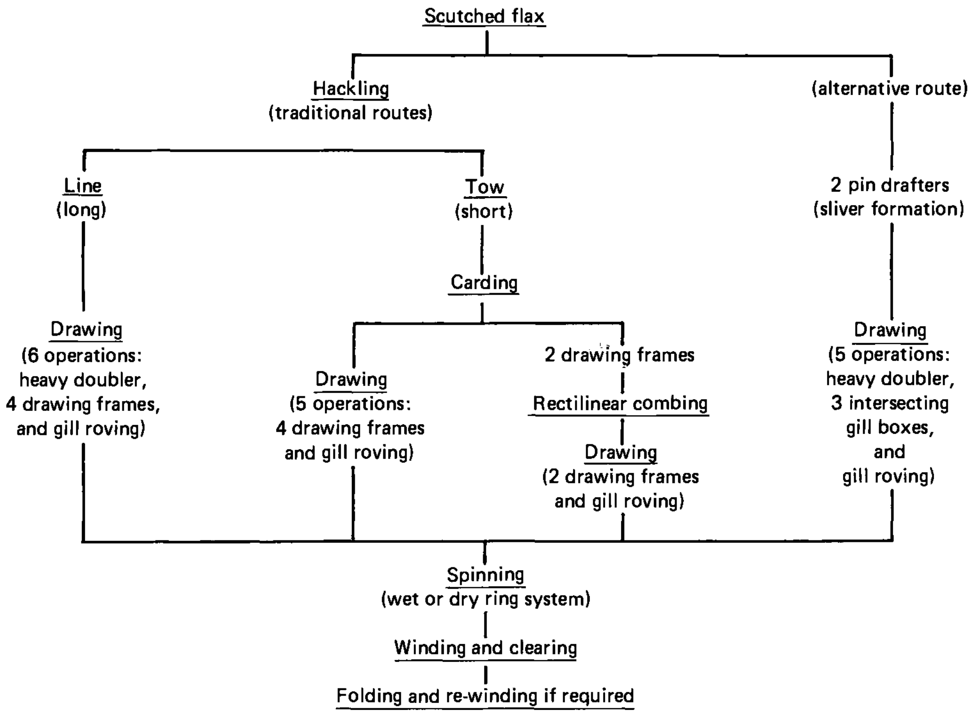
Many wools unsuitable for semi-worsted processing are still dealt with on the woollen system.

Cotton flow chart



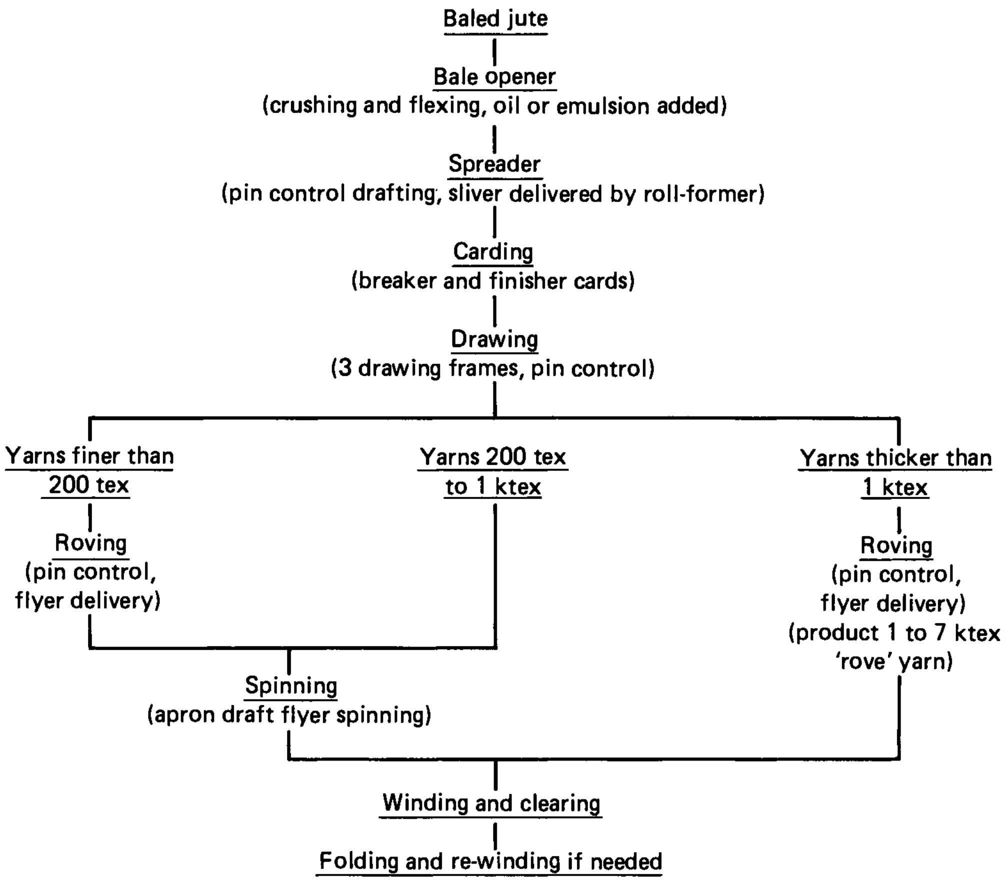
The division into carded and combed quality yarns at a count of 10 tex is somewhat arbitrary, and there may be many exceptions in practice.

Flax flow chart



Note: Heavy doublers, intersecting gill boxes, pin drafters, drawing frames, and gill roving all use pin control in drafting.

Jute flow chart



The chart above indicates, in general terms, processes which are typical of high quality and medium quality jute yarns — counts thicker than 1 ktex are in a minority.

For low quality jute fibre made into sacking warp, and root cuttings etc., which may be used for sacking weft yarns, a process called the softener may be used instead of the bale opener, followed by a teaser card instead of the spreader, prior to the breaker card.

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Note: main entries are shown in **bold** type