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WEAVING:

CONVERSION OF YARN TO FABRIC

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PREFACE

This book has been written for students of all levels and for all who are engaged in the production of woven fabrics. It covers all important aspects of the conversion of yarns into fabrics, including not only weaving itself but also winding and preparation, loom design, noise, loom developments, fabric properties and design, the interaction between yarns and fabric, management and cost optimization. Care has been taken to expose terms which may be new to the student, and these terms are defined in a glossary which is linked with an index to the text and to a list of literature references. The index is designed to provide the reader with a means of following up any topic which he wishes to study in greater depth.

Grateful acknowledgements are given to our colleagues in the School of Textiles, North Carolina State University, and, in particular, to Mrs. E. Ragland for her secretarial work and Mr. J. Baker for his library research.

1973

Second Edition

The book has been revised to express the examples in metric units as well as Imperial units. The opportunity has been taken to rewrite some sections to include newer information and to broaden the coverage.

1982

Merrow Publishing Co. Ltd.,
I.S.A. Building, Shildon,
Co. Durham, England.

Reprinted 1992

ISBN 0 900 54178 4

Printed and bound in Great Britain by
Redwood Press Limited, Melksham, Wiltshire

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AN HISTORICAL INTRODUCTION TO WEAVING

The Ancient History of Weaving

Human beings have clothed themselves with woven materials since the dawn of history, and the history of civilization is also, to some extent, the history of weaving. Aitken says, "There is evidence that the Egyptians made woven fabrics over 6000 years ago and it is believed that in prehistoric times, lake dwellers in Europe made nets from twisted threads". Old mural paintings and carvings, china and other ancient artifacts make it clear that providing himself with clothes was an important facet of man's early life. Until comparatively recent times, spinning and weaving were skills associated with domestic life, and there are references to these familiar occupations in the literature of all civilized societies. Thomas Gray, for example, wrote

> Weave the warp, and weave the woof,
> The winding-sheet of Edward's race.
> Give ample room, and verge enough
> The characters of hell to trace.

In the earliest primitive civilizations, the threads used for weaving were very coarse (probably vines or creepers). In general, therefore, the cloth produced was also crude and coarse, although there are references in even the oldest literature to fine fabrics. For example, the filaments extruded by the silkworm were used by the Chinese to make the finest of fabrics. The origins of sericulture (the culture of silkworms to produce raw silk) are so ancient that the earliest references are to be found only in legend and fable. Silk became economically important in China over 4000 years ago under Emperor Huang Ti and it is said that his Empress invented the loom. However, it is probable that the loom has been invented many times in many civilizations.

In ancient times, fine fabrics could be afforded only by the rich; the ordinary folk usually wore rough materials made from animal furs (if they were fortunate) or from animal or vegetable fibers. The more recent history of textiles is concerned with the development of methods of converting animal and vegetable fibers into fabric and, in modern times, with the development and conversion of man-made fibers into fabrics.

The Early English Woolen Industry

A great deal of textile development occurred in England and neighboring countries. The history of the English textile trade is a story which involves the complex interactions of society, economics, the emerging sciences, agriculture, and the ancient textile arts. It is salutory to find that many of today's economic difficulties are no new phenomena; they had their like in times long past.

In the ninth century A.D., Alfred the Great found himself as Comrade-in-Arms with Arnulf of Flanders in repelling persistent attempts at invasion by the Danes. This relationship was sealed by marriage and founded a lasting connection between the men of England and Flanders; the latter were well versed in the textile arts. The social organization was such that small, almost self-sufficient communities grew up around strongholds and their affairs were managed by guilds. As life became more complex, craft guilds began to appear which were concerned only with given crafts, and the first of these was the Weavers Craft Guild (1100 A.D.). In 1108, following disastrous floods in the Low Countries (i.e. Holland), many Flemings emigrated to England and Wales bringing their skills with them. Flemish textile workers provided a foundation on which much of Britain's textile trade was built. In 1362 the Staple was established in Calais;

this was a center for the export of English wool (it is probable that this is the origin of the use of the word "staple" as a textile term). At this time, England was an agricultural country, and there is evidence that many farmers found wool more profitable than corn.

William the Conqueror (who successfully invaded England in 1066) was married to a Flemish princess, as was Edward III in the fourteenth century; there was thus a continuing tie between the two peoples which helped maintain the textile tradition. This was further encouraged by subsidies which, according to Wood and Wilmore, were £6800 in 1348—a very great sum in those days. It is not surprising that the Belgian weaving trade was seriously affected.

In 1407, The Merchant Adventurers Company was chartered to operate a monopoly in the export of cloth to Continental Europe. There was, of course, no industrialization at this time; weaving was a cottage industry. Families worked in their homes to supply a clothier who rented the looms, collected the woven materials and distributed them for profit.

After his quarrels with the Pope and his loss of influence in Europe, Henry VIII devalued the coinage in 1544. This caused a boom followed by a slump and left an unstable textile industry which had many ups and downs. The situation continued for the next two hundred turbulent years, and was not eased by the growing conservatism of the craft guilds which often opposed progress. Many workers migrated from the established centers to set up new ones in the northern parts of the country to escape the tyranny of the guilds. (It is interesting to note that when the industrial revolution swept through the north in the eighteenth and nineteenth centuries, similar attitudes prevailed and the term Luddite came to have its particular meaning.)

Meanwhile Elizabeth I reformed the currency, set up a number of trading companies and made London a great international center of finance and shipping. The early Stuart dynasty did much to encourage the arts and sciences and this was to prove of great benefit in later years. However, these were very hard times for the ordinary folk; prices rose faster than wages (mainly because of profligate spending), the population continued to grow and there were terrible shortages. Religious intolerance added to life's burdens. Little wonder that some 60,000 Britons emigrated out of a population of less than 5 million; little wonder that there was civil war. The Pilgrim Fathers were among the 60,000 emigrants from Britain.

When William of Orange eventually acceded to the throne, England was brought once again into the European commercial scene and the way was paved for the age of reason and enlightened despotism of the early Hanoverians.

The Industrial Revolution

During the early Hanoverian period, attention was diverted from wars and religious intolerance with the result that there was considerable progress in other directions. The sciences, which had flourished under the patronage of the Stuarts, now developed and were exploited, particularly in the second half of the eighteenth century. This trend continued through the nineteenth century as industrialization spread and the factory system evolved to create what we now know as the industrial revolution.

Prior to this period, attitudes could seldom be described as enlightened; for example, one of the earliest attempts to control a loom from a single position dates from about 1661 in Danzig, but the authorities there were so fearful of the outcome of such an innovation that they caused the inventor to be murdered and the invention to be suppressed. Sometimes, inventions failed because the means were not available to develop them. It is not enough to have good ideas; the environment must be suitable before ideas can be translated into useful form. This environment was created during the industrial revolution, and invention and application proceeded apace. Progress in one direction stimulated progress in another; each new step forward paved the way to further advances.

The relationship between spinning and weaving was an example of such forced development. In 1733, Kay invented the fly shuttle which enabled filling (weft) to be inserted more rapidly, and this led to a shortage of yarn. An account of 1783 refers to the knavery of the spinners and continues, "The weavers in a scarcity of spinning . . . durst not complain, much less abate the spinner, lest their looms should stand unemployed; but when (spinning) jennies were introduced and the (weaver's) children could work on them, the case was altered, and many who had been insolent before were glad to be employed in carding and slubbing cotton for these engines". Thus the see-saw of advantage between spinning and weaving helped to stimulate progress. In 1745, de Vaucanson produced a loom, which was further developed by Jacquard, on which intricate patterns could be achieved by lifting the warp ends almost separately as required. This invention established a line of looms which are still known today as Jacquard looms. They did not develop as rapidly as they might have done during those early days; no doubt the environment of revolutionary France was not conducive to industrial development.

Kay's shuttle was hand operated and although it made possible considerable increases in productivity, it also opened the door to even greater advances as soon as power could be applied to the loom. A clergyman named Cartwright (1785) invented a so-called power loom which could be operated from a single point by "two strong men or a bull"; there was an obvious need for power beyond the resources of a single man. Fortunately, steam power was already becoming available; James Watt had begun making steam engines in 1776. A great deal of Watt's success stemmed from the availability of suitable iron in sufficient quality and quantity; Wilkinson's first blast furnace for making iron was in operation by about 1749. The train of events in the progression of invention and exploitation is illustrated in Fig. 1.1.

By the early 1800s, looms were made of cast iron and were driven by steam power; by 1821, there were over 5000 looms in operation in some 32 mills in the north of England. In

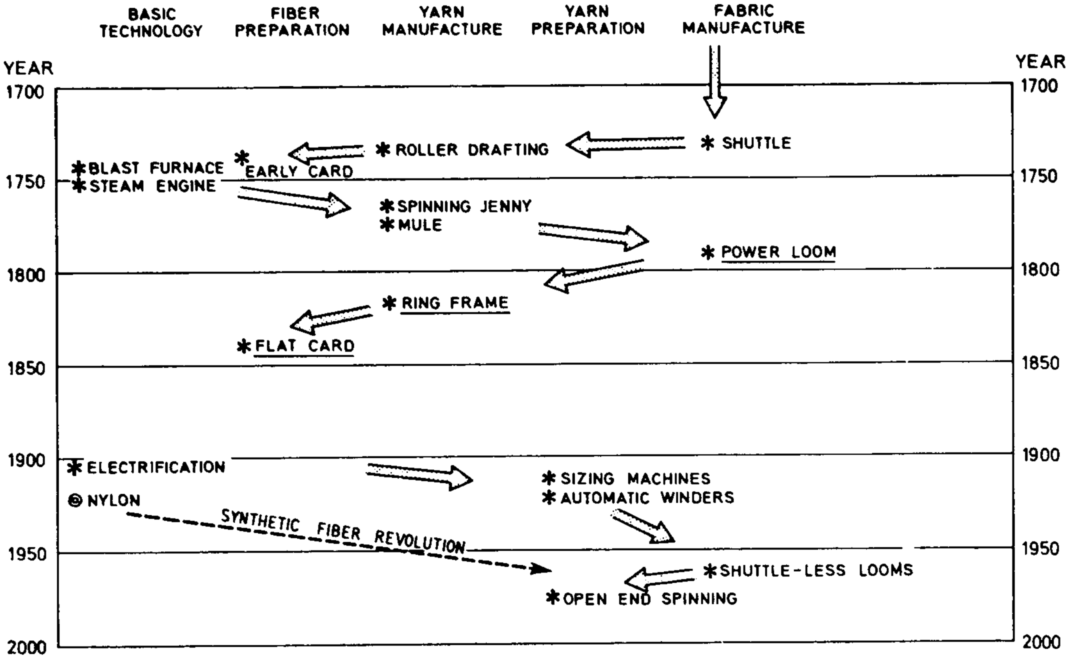


Fig. 1.1. Development of the textile processes

just over ten years from that date, the number had increased to some 100,000 and the basic loom had almost developed to the machine we know today.

Economic and Social Effects of the Industrial Revolution

The sudden surge forward during the industrial revolution brought significant social and economic changes. People left home to work in factories. When industry was centered in the home, child labor went unnoticed, but in the factory it was brought under general scrutiny. The account of 1783, mentioned above, says "spinning machines were first used by the country people on a confined scale, 12 spindles being thought a great affair at first, and the awkward posture required to spin on them was discouraging to grown-up people, while they saw with a degree of surprise, children from 9 to 12 years of age managed them with dexterity, which brought plenty into families, that were before overburthened with children". Here the use of children was seen as a boon, but in the factories, bad working conditions existed and extremely long hours were the rule. The following quotation from the Select Committee on Child Labour in Factories in 1831-2 sets the scene.

"I was 7 years of age when I began to work . . .; the employment was worsted spinning. The hours of labour at that mill were from five in the morning till eight at night, with an interval for rest and refreshment of 30 minutes at noon; we had to eat our meals as we could standing or otherwise. . . . the wages I then received was 2s. 6d. (about 50 cents) a week. In the mill there were about 50 children of about the same age as I was. There were always, perhaps half a dozen regularly that were ill because of excessive labour. There were three overlookers—and there was one man kept to grease the machines and then there was one kept on purpose to strap. Strapping was the means by which the children were kept at work. It was the main business of one of the overlookers to strap the children up to this excessive labour".

No wonder Blake wrote

> And did the Countenance Divine
> Shine forth upon our clouded hills?
> And was Jerusalem builded here
> Among these dark Satanic mills?

Lipsey and Steiner say, "In the worst days of cotton-milling in England the conditions were hardly worse than those (then) existing in the South (of the U.S.A.). Children, the tiniest and frailest of five to six years of age, rise in the morning and, like old men and women, go to the mills . . .". "Many children work all night 'in the maddening racket of the machinery, in an atmosphere insanitory and clouded with humidity and lint' ".

However, human conscience is strong; the Factories Act, passed in 1835, limited working hours and from that time conditions have improved steadily. Even today, however, many weave rooms are still excessively noisy and sometimes dirty.

The change from cottage industry to factory system was a radical one. Until the invention of the power loom, a machine could produce no more in a factory than it could in a home; a factory was difficult to finance; it was risky to employ a number of people and transport was difficult and hazardous. The power loom could not be installed in a home because many looms drew their power from a single source; also trade had improved and expanded, finance was available, transport systems developed and the factory became a good investment. Further, clothiers were finding it difficult to control their workers who became very independent, so it was thought better to concentrate them in factories to preserve quality, quantity, and delivery schedules. The demand for labor became so great that it outstripped supply, despite a population increase from 16 to 32 million in the latter half of the nineteenth century. This led to the growth of great concentrations of population around the manufacturing centers and to the development of large towns and cities. The combination of insistent demand and unchecked human greed led to the excesses previously described, but these in turn stimulated great reforms; for instance, in 1891, elementary education was made free for all and in 1897 the Workmen's Compensation Act was passed into law.

The Cotton Industry

The beginning of cotton as a textile fiber are somewhat obscure, but certainly it was used in Egypt in ancient times. It was also grown in Moorish Spain in the tenth century, but it made its way into central Europe primarily from the Far East. Columbus discovered the inhabitants of Hispaniola wearing cotton clothes, Magellan found the Brazilians sleeping in nets of cotton, and Cortez was intrigued by the cotton garments worn by early Americans.

In Europe, cotton spinning and weaving spread progressively through Italy, Germany, the Low Countries and then to Britain; cotton was imported into England in 1303, the import duty being 2d. (about 3 cents) a sack. In 1402 a bale of cotton was valued £5 (this was equivalent to at least two years wages for one man). The devastating Thirty Years War in Europe in the seventeenth century left the field clear for the Lancashire cotton industry, but even so a pamphlet entitled "The Ancient Trades Decayed and Repaired Again" published in 1678 says, "This trade (the woolen) is very much hindered by our own people, who do wear many foreign commodities instead of our own; as may be instanced in many particulars; viz. instead of green sey*, that was wont to be used for children's frocks, is now used painted and Indian-stained and striped calico—etc.". An Act of 1700 banned the import of Indian silks and printed calicos, but instead of protecting the woolen industry it caused the introduction of calico printing; a further Act of 1721 prohibited this, but printed fustian (a mixture of cotton, linen and wool) was excluded.

* Sey was a fabric.

Manchester Exchange was opened in 1729 and John Dyer says:

> Again, and oft, th'adventurous sails disperse,
> These to Iberia, others to the coast
> Of Lusitania, th'ancient Tharsis deemed
> of Solomon; fair regions, with the webs
> of Norwich pleas'd or those of Manchester;
> Light airy clothing for their vacant swains
> And visionary monks.

The use of cotton continued to grow and by the end of the eighteenth century it was well established; an Act of Parliament of 1774 legalized the manufacture of fabrics made entirely of cotton. Prior to this, it had not been possible to make adequate warps out of cotton using the spinning jenny, but Arkwright had demonstrated with his new machine that cotton could be used on an industrial scale for the manufacture of both warp and weft. However, such advances were not popular with the workers. Kay had to flee the country and many machines were broken up by the angry workers fearful for their jobs. Another artisan inventor, Samuel Crompton (a weaver), worked in secret to improve the spinning process and eventually he produced the mule (1790) which gave the mass production of yarn a considerable impetus. The production of yarn now began to outstrip the production of cloth by the loom, until in due time the development of Cartwright's power loom redressed the balance.

It is interesting to note the first British muslin in 1780 retailed at 10s. 6d. a yard (i.e. at least a week's wages for a worker) whereas in 1850 it was 2d. a yard (i.e. less than 2 per cent of its former price). Arkwright's mill at Cromford was the first of the new factories; it was capable of producing 7 tex (80s cotton) and even 6 tex (100s) yarn, a feat which many modern mills cannot match.

The establishment of the cotton manufacturing industry in Lancashire was influenced by several factors:

1. Lancashire produced a succession of artisan inventors who were able to exploit the newly emerging scientific knowledge.
2. The new technology was widely accepted (except by some fearful workers).
3. There were good ports and good transport facilities.
4. The humid air was suitable for the spinning of cotton.
5. There was ample rainfall to provide power (in the early stages) and water for wet processing.
6. The soft water of the Pennines made it easy to wash and dye the cloth.
7. Coal supplies were located nearby which made power relatively cheap.
8. The salt deposits in nearby Cheshire provided chemicals needed for bleaching and dyeing.
9. Farming was difficult and alternative employment was welcomed.
10. There was freedom from the restrictive attentions of the craft guilds.

In the late nineteenth century there was growing competition from Germany and America. In 1870 the Corn Laws were repealed which led to a flood of cheap North American wheat; this aggravated the growing unemployment brought about by a failure to keep up with technical advances. Then came the disastrous World War I which brought in its train many social and economic difficulties. Bitter trade union controversy (which led to the General Strike) combined with the American slump and the collapse of Wall Street left much of the world in a parlous condition; many millions of former factory workers were unemployed through no fault of their own.

The value and cost of labor became more vividly apparent in these times and greater attention was directed toward a deeper consideration of the economics of the entire process of textile manufacture. More consideration was given to the peripheral processes than to the development of the loom itself.

Aitken says:

"The period from 1920 to the present day has been one of immense improvement in the winding and warping of yarns of all kinds. Although actual processes remain unchanged, the machines are completely different. The development of clearing yarns of faults without abrasion, and of winding at low and constant tension for both warp and weft have improved weaving at the loom, with consequent increase in machine efficiency and the allocation of more looms to a weaver.

"During this period warp tying machines and warp drawing-in machines have not only been improved but there is now a competitive field for several makers of these machines. Much progress has also been made in tape sizing, particularly in the drying section and the size box."

Thus the main areas of progress in the early twentieth century were in the development of adequate preparation of the material for subsequent weaving. This implies a better understanding of the economics of the whole process of fabric production. No longer can weaving be considered to be merely operating a loom. All the processes including yarn production and fabric finishing have to be taken into account.

In the late 1930s prosperity seemed to be returning, but in 1939 World War II interrupted progress and upset the previously prevailing balance. Following the end of the war in 1945, a completely different structure of the textile industry began to emerge.

The strident demands of war had shown that unskilled labor working in shifts through night and day could produce amazing quantities of material. The textile industry, after some hesitation, began to adopt shift working with all its economic advantages. The hesitations arose from the reluctance of labor to work unnatural hours and of the employers to re-equip with expensive modern machines. (There is much less advantage in shift working if the machines are heavily marked down in value.)

The centers of the industry began to change because of the wide variations in the cost of labor. For example, the Lancashire industry declined and there was an upsurge of activity in the Far East. In U.S.A., there was a migration toward the South where labor was cheaper and the restrictions from the labor unions bore less severely.

Man-made Fibers

In the mid nineteenth century, there were attempts to make synthetic textile materials; in 1855, Audemars made cellulose nitrate from which the nitrocellulose method of making rayon was developed. In 1884 Chardonnet made the first artificial fiber from this material and he built the first rayon factory. Regenerated cellulosic fibers became competitive with natural fibers in the first few decades of the twentieth century, but they were suitable only for certain purposes and they came to be regarded as poor imitations of the natural materials.

In 1927, Wallace Carothers started investigating polymerization and discovered that he could make fibers from polymers such as polyesters and polyamides. By 1935, polyamide fibers were being produced on a commercial scale, and were soon to become available to the public as nylon. The first nylon hosiery was on sale in 1939.

After the war, nylon was vigorously marketed, but in the form that then existed it did not satisfy all the user requirements; in particular, its moisture absorption was low—less than half that of natural silk—and this detracted from its comfort in apparel uses. The development of texturizing provided nylon filaments in a bulkier, softer form, and opened up a wide range of new applications. The impact of texturizing has been so great that it can be règarded as one of the major advances of the twentieth century. It is not surprising that the rise of this new section of the industry has had a marked effect on weaving.

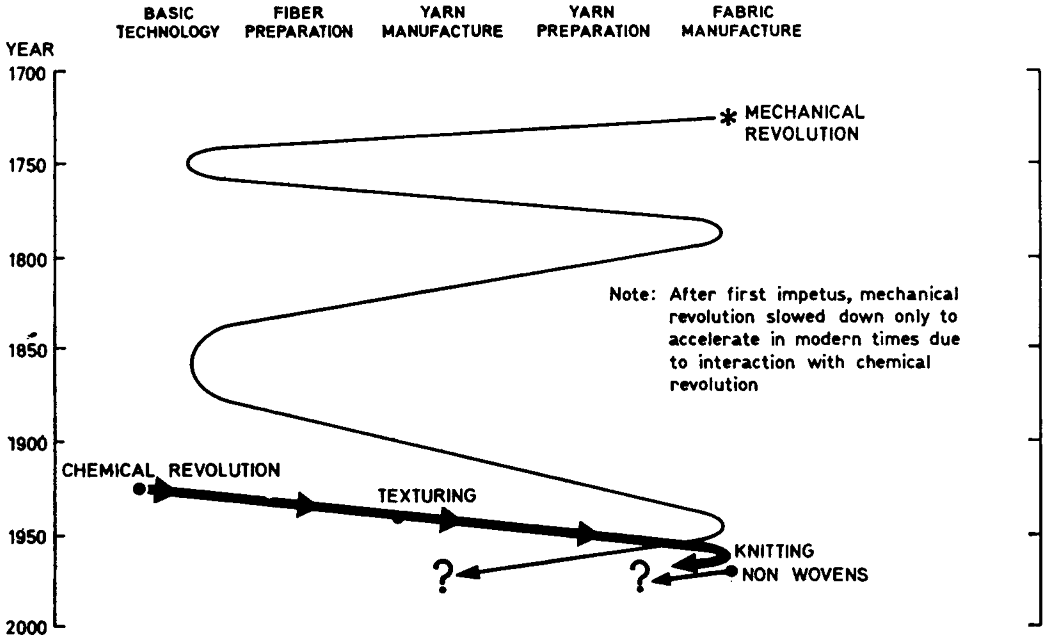
At the present time, natural fibers are losing ground generally to man-made fibers, which are making a significant contribution to the increasing market for textiles. Japan and other Far Eastern countries are playing a major role in this development. The low wage rates which prevail in many Eastern countries are making it increasingly difficult for textile manufacturers in the advanced Western industrial countries to compete. So, as the technology changes, the pattern of geographical distribution of the textile industry is changing too.

One way of combating inequalities in wage rates is to increase productivity per man to such an extent that his contribution to the cost of a unit of production is less than the cost of transport from far off places. This must be done without unduly inflating the capital cost of the equipment, and it requires a technological development beyond that which has been apparent in the first half of the twentieth century.

Knitting

Knitting has brought a new challenge to weaving in recent years. The ancient art of knitting has been mechanized, and in this form it is inherently a more rapid process than weaving.

It is not known who invented knitting but the word is said to be derived from the Anglo Saxon "cnyttan" which was in use at the end of the fifteenth century. Certainly in the following century the trade termed "hosiery" was well established and leg coverings were knitted on needles of bone and wood. The first knitting machine is attributed to William Lee in 1589. Lee failed to get a patent in England and moved to France where he was granted one in 1610. This established the basis of the modern knitting machine. For some reason, the potential of the knitting machine was not clearly recognized and it did not develop in a significant way until the latter half of the twentieth century. The nature of knitted fabric is quite different from that of woven fabric, and the early knitted fabrics made from natural fibers had only limited appeal. However, with the emergence of textured man-made yarns, the appeal of knitted fabrics has broadened to the extent that a considerable amount of the potential



Note: After first impetus, mechanical revolution slowed down only to accelerate in modern times due to interaction with chemical revolution

Fig. 1.2 Interaction of the mechanical and chemical technological revolutions market has been lost by the weaver. In fact, the successive development of man-made fibers, texturizing and knitting may be regarded as a new chemically-based industrial revolution. Certainly, this second revolution has interacted with the old Industrial Revolution and speeded up its tempo, as indicated by Fig. 1.2 (a simplified version of Fig. 1.1).

"Nonwoven" Materials

Another challenge to weaving lies in the so-called "nonwoven" materials, in which sheets of fibers with varying degrees of organization are held together by adhesives, stitching or needle punching to give a usable fabric. Again, the nature of the fabric limits its appeal but there are unmistakable signs of this appeal being widened.

Summary

The pattern of development in the textile industry has been marked by change and counter-change. To blindly resist these changes is to court extinction; survival and progress require that new ideas must be accepted and adapted to our needs. It must be remembered also that technology cannot be considered in isolation. All changes affect, and are affected by, the social, economic, and political environment.

Weaving will survive alongside its new competitors, but to do so effectively the technology of weaving must develop rapidly. This demands an understanding of the fundamental concepts of the subject, and an appreciation of the directions in which technological progress is carrying the industry forward. It is hoped that the following pages will provide this understanding and appreciation.

"The time has come" the weaver said,
"To think of many things,
Of shafts—and sheds—and sizing wax—
Of selvages—and rings
And why the warp is abraded not—
And whether shuttles have wings".

Apologies to Lewis Carroll

2

A TECHNICAL INTRODUCTION TO WEAVING

Key words: *beat-up*, *cams* (*tappets*), *cloth take-up*, *dents*, *dobby*, *fabric finishing*, *fabric structure*, *filling* (*weft*), *gripper*, *harness* (*shafts*), *heddle* (*healds*), *jacquard*, *lay* (*sley*), *lay swords* (*sley swords*), *loom*, *loom timing*, *picking cam* (*picking bowl*), *picking stick*, *quills* (*pirns*), *race board*, *rapier*, *reed*, *rocking shaft*, *slashing* (*sizing*), *warp*, *warp end* (*yarn end,*) *warp beam*, *warp let-off*, *warp shed*, *warp sheet*, *weft insertion* (*picking*), *yarn twist*, *yarn preparation*.

The Fabric and the Phases in its Production

Woven fabrics are produced by interlacing *warp* and filling yarns as shown in Fig. 2.1. The warp lies along the length of the fabric whereas the *filling* (or *weft*) lies across the width. Every warp yarn is separated from all the others; thus, the warp consists of a multitude of separate yarns fed to the weaving apparatus. On the other hand, the filling yarn is usually laid into the fabric, one length at a time.

There is a large variety of possible ways of interlacing the two sets of yarns and the manner in which this is done determines the *fabric structure*. The yarn character and the fabric structure together determine the properties of the fabric, such as appearance, handle, wear capability, etc.

A prime requirement of a textile fabric is that it should be flexible. Many thin sheet-like materials can be flexible in bending, but they usually have such a high shear stiffness (see Fig. 2.2) that they do not drape well and may look unattractive. This point may be illustrated by a simple experiment in which a sheet of paper and a piece of woven

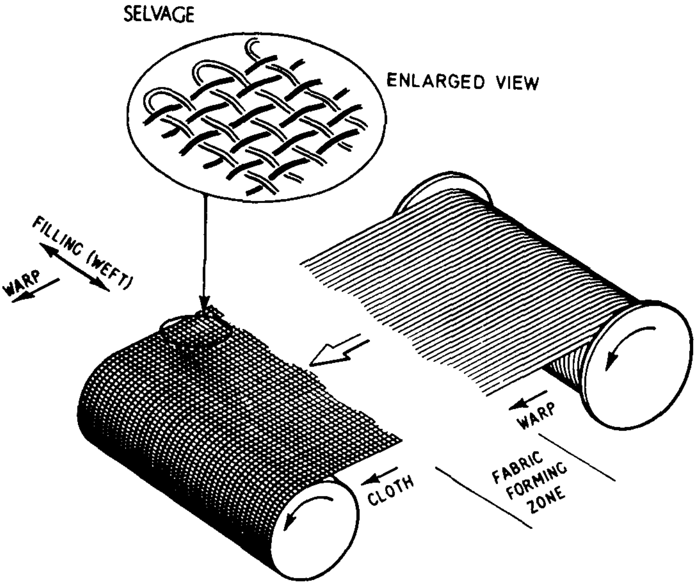


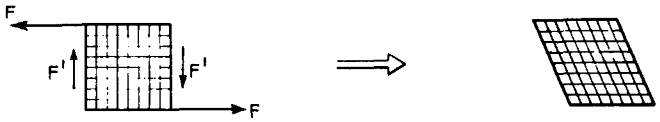
Fig. 2.1. Warp and filling (weft)

cloth of similar size are laid in turn on a child's ball (Fig. 2.2(c) and (d)).

The flexibility and drape of woven fabrics are considered further in Chapter 7.

Generally, the warp yarns undergo greater stress than the filling yarns during weaving; consequently, the yarn requirements for the two purposes are different. Warp yarns must be of a certain minimum strength, whereas the filling can be quite weak; the warp yarns usually have a relatively high *twist* but twist in the filling yarns is usually kept as low as possible. As twist costs money and excessive twist produces harsh fabrics it is generally kept as low as possible in both types of yarn.

In fabric manufacture, the sequence of operations is as follows:



(a) FORCES (b) DEFORMATION

SHEAR

(c) PAPER
(FAIRLY HIGH SHEAR STIFFNESS)

(d) FABRIC
(LOW SHEAR STIFFNESS)

Fig. 2.2. Ability of material to mold, i.e. drape

1. Yarn production.
2. Yarn preparation.
   (a) Warp.
   (b) Filling.
3. Weaving.
4. Fabric finishing.

The present book covers in detail the topics of yarn preparation and weaving, but it does not deal with yarn production or fabric finishing.

Yarn Preparation

The linear production rate of a typical spinning machine is quite different from the yarn consumption rate of a normal loom. For example, a typical yarn production rate might be up to 100 m/min (4000 inch/min) whereas in weaving, warp is consumed at perhaps 0.1 m/min and filling is consumed at up to 1000 m/min. It is clearly difficult, therefore, to operate

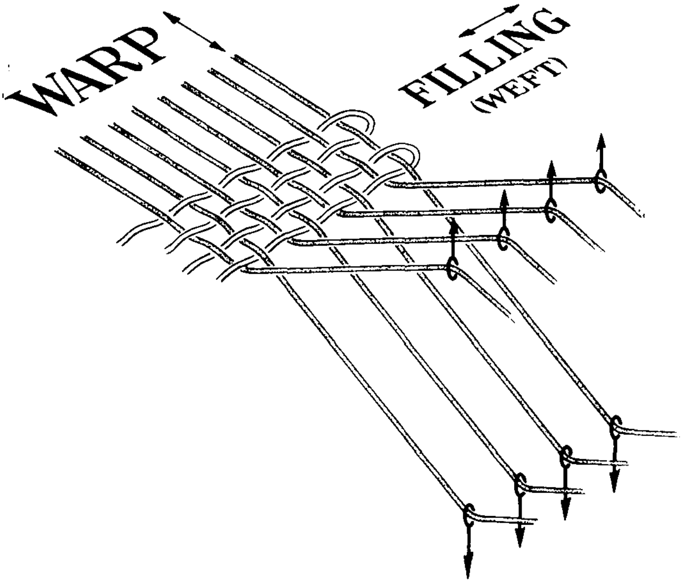


Fig. 2.3. Shedding

a continuous process involving spinning and weaving. Intermediate packaging operations are a feature of modern fabric production, and this series of operations is termed *yarn preparation*. The object of these operations is to prepare packages of a size and build best suited to a particular purpose.

As a warp consists of a multitude of separate yarns or *ends*, in making an appropriate package (known as a *beam*) the ends must lie parallel and this determines the type of yarn package that must be used. On the other hand, filling yarn needs to be continuous and the filling yarn package is wound according to the type of weaving apparatus used.

Adhesives may be used in achieving the minimum strength requirements of warp yarns. The process of weaving involves the abrasion of one warp end against its neighbors and against the adjacent machine parts. The use of adhesives and lubricants can limit the amount of damage caused by this abrasion and it is the normal practice to treat warp yarns with a solution which serves both as adhesive and lubricant. The process, known as slashing or sizing, is generally regarded as part of yarn preparation.

Looms

The apparatus used for weaving is termed a *loom**. The loom may be considered simply in terms of its various functions (which are not necessarily separate). The warp from the beam is fed to the zone where it is converted into fabric and this fabric is then "*taken-up*" on a cloth roll. This can be regarded as a flow of material along the length of the fabric and the control of this flow is one of the functions of the loom. Prior to interlacing, it is necessary to divide the warp sheet as shown in Fig. 2.3 so that the filling can be inserted to give the required interlacing as shown in Fig. 2.4. After the weft insertion, the sheet has to be rearranged before the next weft insertion so as to generate the required fabric structure. The process of dividing the warp sheet in its varying patterns (*shedding*) is the second function. The process of inserting the filling yarn (*picking*) may be regarded as the third function. A further function, called *beat-up*, involves the positioning of the filling in the fabric as illustrated in Fig. 2.5. Summarizing, these functions may be listed as follows:

1. Warpwise control.
2. Shedding.
3. Picking.
4. Beat-up.

These will be discussed in detail in subsequent chapters.

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* Strictly speaking, a loom is not a true machine as defined according to the laws of mechanics.

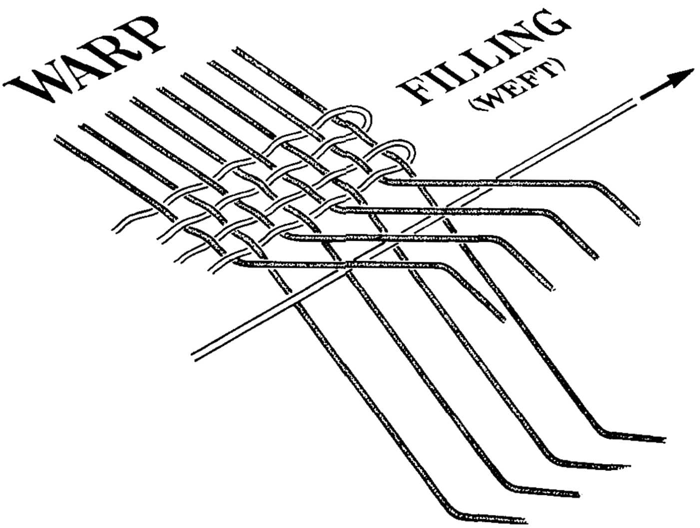


Fig. 2.4. Filling (weft) insertion.

The Development of the Loom

In early looms, the main structural components were very simple; the warp was tensioned by individual weights and the filling was inserted by a suitably shaped stick or such-like. In these primitive looms, the functions of warp control, filling insertion and beat-up are recognizable but the function of shedding is almost completely absent. Furthermore, there was no readily recognizable process which corresponded to what is today called warp preparation.

As the loom developed, the function of shedding became more apparent, presumably because a well organized shedding system made it easier to insert the filling. However, the process was still very much a discontinuous one and was limited to piece weaving, hence there was little need for yarn preparation as we know it. With the advent of Kay's shuttle, a distinct warp shed was essential to pass the shuttle; also it

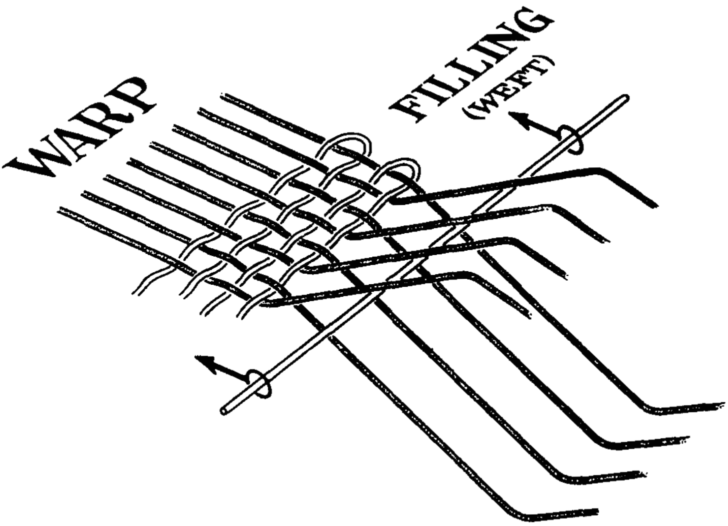


Fig. 2.5. Beat-up.

was necessary to wind *quills* or *pirns* to fit into the shuttle (see Fig. 2.6). By this time, too, rudimentary warp beams were in use and another aspect of yarn preparation was established. As the improvement in the quality of warp yarns increased, so it became technically feasible to operate the loom faster. The emergence of the power loom realized this potential and made it necessary to consider warp sizing in a much more serious light.

The idea of fortifying a poor yarn by painting it *in situ* with a cheap vegetable adhesive was not new, but with the extra stresses and abrasions suffered by the warp in power weaving, a separate sizing operation became a necessity. The first sizing machines appeared in 1803. The objects were (and still are) to give the warp yarn the necessary strength whilst retaining a sufficient elasticity, and to impart a smooth compactness which (together with lubrication) minimizes the frictional resistance.

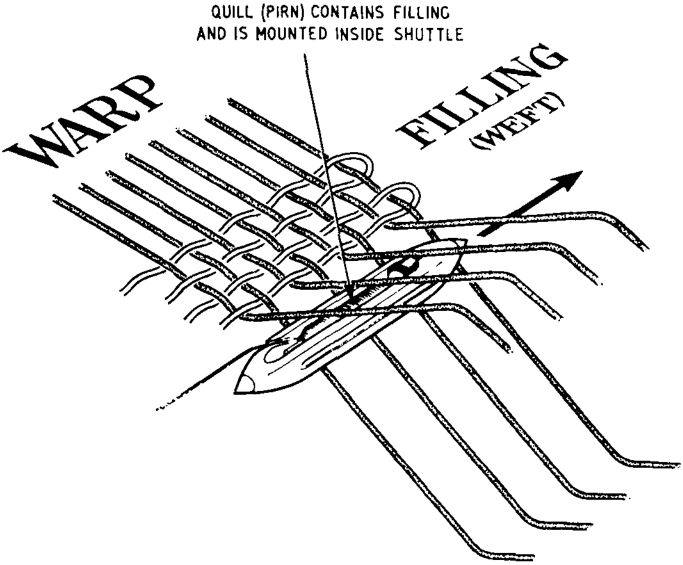


Fig. 2.6. Shuttle passes through warp shed leaving filling (weft) trailing behind.

Once the basic mechanisms were established, it was then possible to elaborate the loom in various ways. A number of protective devices were developed which stopped the loom when an end broke; this minimized the amount of defective fabric produced and protected the machine against damage. Multi-shuttle systems were produced which permitted a change of color in the filling direction without stopping the loom and this enabled fancy fabrics to be made. In 1894 Northrop devised a means for changing the empty quill in the shuttle for a full one without stopping the loom. In fact, this is essentially what is meant by an automatic loom; it is a loom in which the weft replenishment is automatic.

By using variable patterns of shedding in combination with filling of different colors, it became possible to produce a great variety of fancy cloths from these power looms which soon rivaled those produced by the ancient craft weavers.

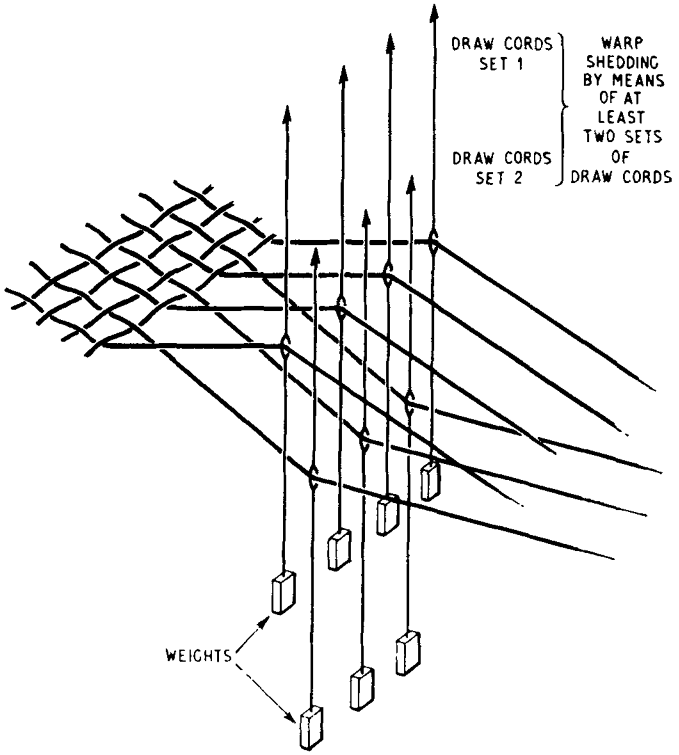


Fig. 2.7. Schematic view of shedding in draw loom.

This technique drew much from earlier experience. The traditional draw loom had permitted figuring effects to be made because the shedding of each warp end was controlled by a separate string which was tensioned by its own dead-weight, as shown in Fig. 2.7. The strings were connected in groups to neck cords which could be lifted in certain sequences to give the desired pattern. The bunches of strings were pulled in turn by a draw-boy while the weaver attended to the weft insertion. In 1725 Bouchon used a punched tape to control the strings and in 1728 Falcon invented what was,

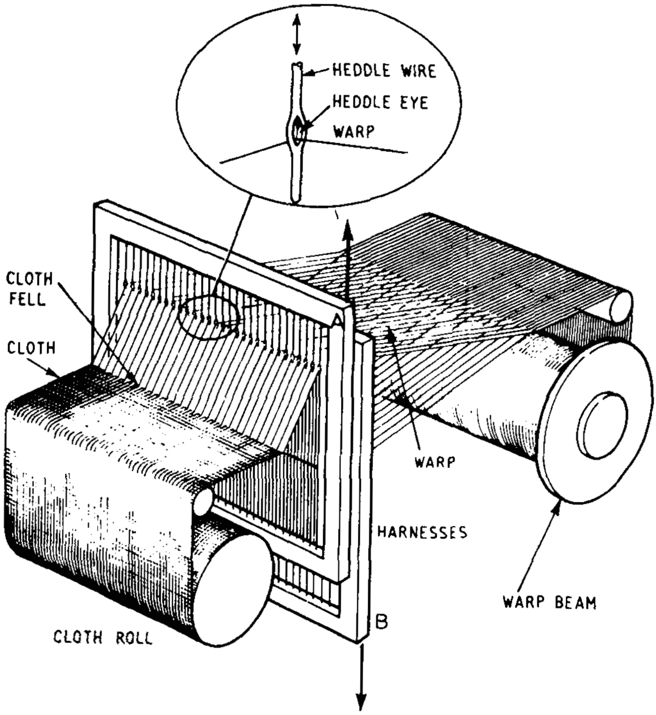


Fig. 2.8. Shedding

in essence, the *Jacquard* machine which used a series of punched cards. In 1745 de Vaucanson integrated these ideas and a short time later Jacquard improved the machine to give the first completely centralized control of the loom.

Other techniques were also used. For example (Fig. 2.8), a *heddle* (or *heald*) was used to open the *warp shed* and by grouping the heddles into several frames (called *harnesses* or *shafts*) and operating each frame by a separate *cam* (*tappet*), it was possible to generate small patterns having up to about 6 picks per repeat. Another technique was to use a *dobby* similar in principle to a Jacquard working with a diminished

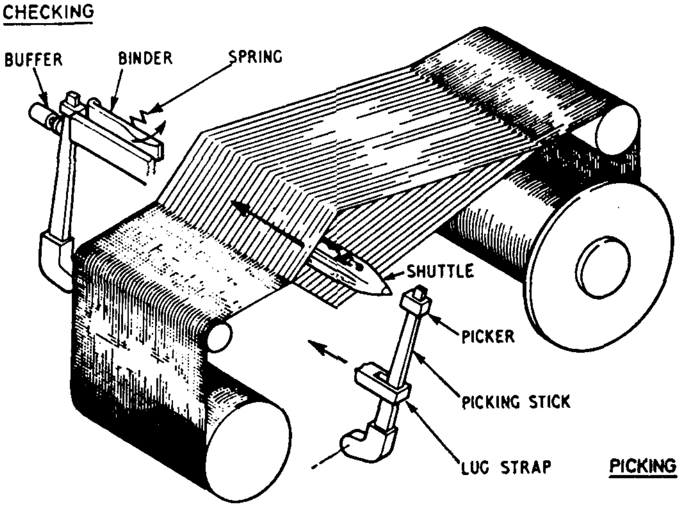


Fig. 2.9. Filling (weft) insertion.

number of groups; this is capable of producing small patterns.

The main mechanisms of the loom which evolved at the turn of the century were as shown in Figs. 2.8 to 2.11.

The warpwise control consists in the main of a cloth take-up system and *warp let-off* system which is restrained by a brake as shown in Fig. 2.11 so as to give the required tension in the warp. The cloth take-up speed is controlled to give the desired number of filling insertions in a given length of fabric. In addition, there are control devices designed to stop the loom in case of a yarn breakage or other event which might cause damage to the loom.

In the most common form of loom, shedding is controlled by the motion of the harnesses (heald shafts) each of which is capable of oscillating vertically as shown in Fig. 2.8. These frame-like structures contain a multiplicity of wires or flat strips known as heddles or healds and each of these contains an aperture through which one or more warp ends may be threaded. The apertures are called heddle eyes. By using two

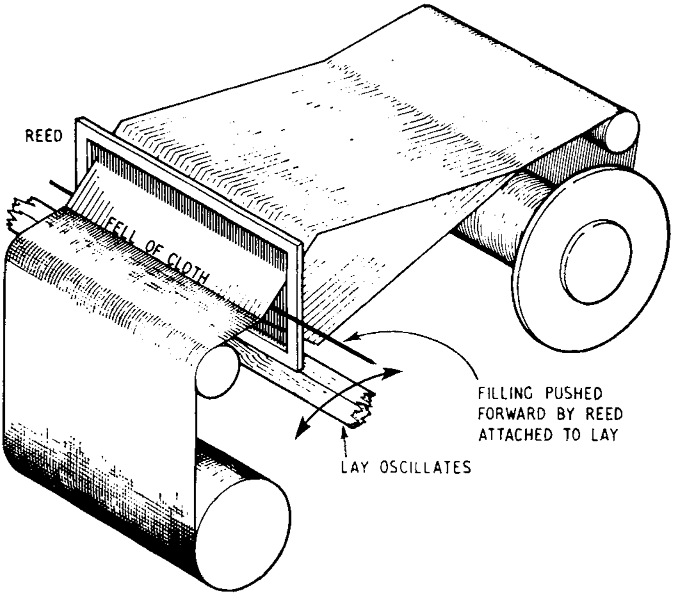


Fig. 2.10. Beat-up

or more harnesses, each of which controls its own group of warp yarns, it is possible to generate the desired fabric structure. For example, in a plain weave, group A will comprise all the odd numbered warp ends and will be in the up position, group B will comprise all the even numbered warp ends and be in the down position. After the filling has been inserted, group A is moved downward and group B upward to give a new warp shed and another length of filling is inserted. Groups A and B are then interchanged again and the process continues. To obtain patterns, more harnesses are used and the movement of the harnesses is more complicated, but the principle remains essentially the same.

In conventional looms, picking (insertion of the filling) is achieved by using a shuttle which contains a quill or pirn on which yarn is stored. The shuttle is passed through the warp

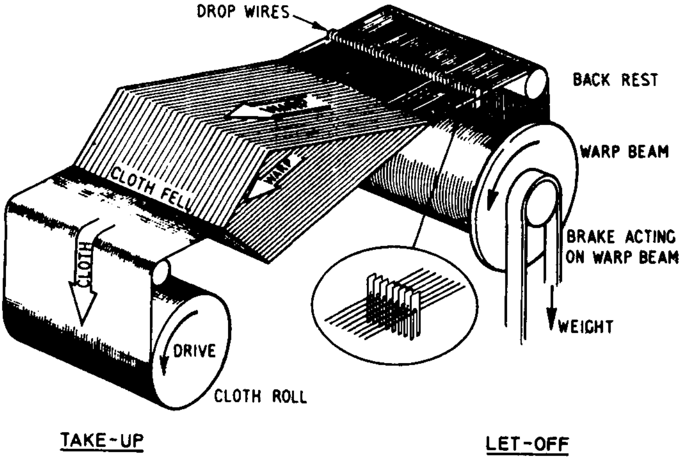


Fig. 2.11. Flow of material through the loom

shed and filling yarn is unwound from the quill by the movement of the shuttle; thus a rapid traverse of the shuttle leaves behind a length of filling lying along the path taken by the shuttle and the subsequent shedding locks the yarn into position. The shuttle is usually propelled by the movement of a wooden lever as shown in Fig. 2.9. It is interesting to note that this is not an archaic survival but derives from the fact that certain woods such as hickory have the special property of being able to absorb considerable amounts of energy time after time without fatigue damage. The shuttle has to be accelerated to about 50 km/h (30 mph) in a distance of only about 0.2 m (8 in) and at the other end it has to be similarly decelerated. The projecting of the shuttle is called *picking* and its deceleration is called *checking*. The wooden lever is a *picking stick* and the cam which drives it is a *picking cam* or picking bowl.

When the filling has been laid in the warp shed, it lies at a distance from its proper position and it has to be pushed there by a comb-like device called a *reed*. The positioning is done in a fairly violent manner and this helps to explain the term used to describe this function, viz. *beating up*. The warp is threaded through the reed which contains a number of spaces called *dents*. Depending on the fabric to be woven, one or more ends may be threaded through each dent and it is normal to refer to x ends per dent, where x stands for the relevant number.

The shuttle is partially guided by a so-called race board and by the reed which is attached thereto. The whole assembly of race board, reed, etc., is called a *lay* or *sley* which is carried by two levers called *lay swords* which pivot about *rocking shafts* at the base of the loom as shown in Fig. 2.10. The whole assembly oscillates about these shafts at the appropriate times and it is driven by a crank and connecting arm. The *loom timing* is concerned with the proper sequence of all these events and in a sense this is an additional function which ties all the others together.

In general, there has been little development of the basic design of the shuttle loom during the twentieth century although there have been many peripheral developments such as automatic quill winding at the loom, etc. There has been a somewhat halting progress towards new forms of loom. The shuttle, weighing perhaps 1/2 kg (1lb) is used to insert a length of yarn weighing less than one ten-thousandth of the shuttle weight at each pick; consequently, it is not surprising that there have been many attempts to reduce the mass of the filling insertion system. With too small a fly-shuttle, the payload is small; the frequent quill changes can increase the number of cloth faults and reduce the overall efficiency of the process (each change costs money).

An alternative technique is to use a *rapier* which inserts the filling in the manner used by the ancient weavers. Another technique is to use a small gripper which is propelled across the loom carrying the leading end of a single length of filling yarn. Alternatively, it is possible to use a blast of air or a jet of water to carry across a single piece of filling. All these techniques have been developed commercially and other possibilities are also being explored.

In the circular loom, it is possible to use several "shuttles" at once, each following the other in the same direction in steady succession. The productivity of the loom (for a given speed) increases in proportion to the number of shuttles and the limit is set mainly by the geometry of the system. A similar system is under development for the normal flat bed loom. These devices demonstrate the efforts that are being made by weavers to meet the challenges that lie ahead.

3

AN INTRODUCTION TO WEAVING PREPARATION

Key Words: *beam warping, clearing operation, creeling, cross-wound package, coning, doffing, drawing-in, drop wire, over-end withdrawal, parallel wound package, piecing, precision winding, quilling (pirn winding), section warping, side withdrawal, sloughing off, snarl, traverse (chase) tying-in, warping (beaming), warp winding, weavers' beam, yarn ballooning, yarn guide.*

Introduction

The selection of suitable yarns and the preparation of yarn for weaving have a considerable influence upon the efficiency with which the weaving operation itself can be performed. For maximum efficiency, yarn breakage at the loom must be reduced to a minimum and this is only possible if: (a) care is taken to select yarn of uniform quality; (b) the yarn is wound on to a suitable package in the best possible way; and (c) the yarn has adequate treatment before use. These requirements apply to varying extents to both warp and filling. The preparation of the warp differs from the preparation of the filling and it is necessary to deal with each of them separately. However, winding is common to both and may be considered in general terms.

Warp Preparation

The essential features of a good warp are as follows:

1. The yarn must be uniform, clean, and as free from knots as possible.
2. The yarn must be sufficiently strong to withstand the stress and friction of weaving without excessive end breakage.

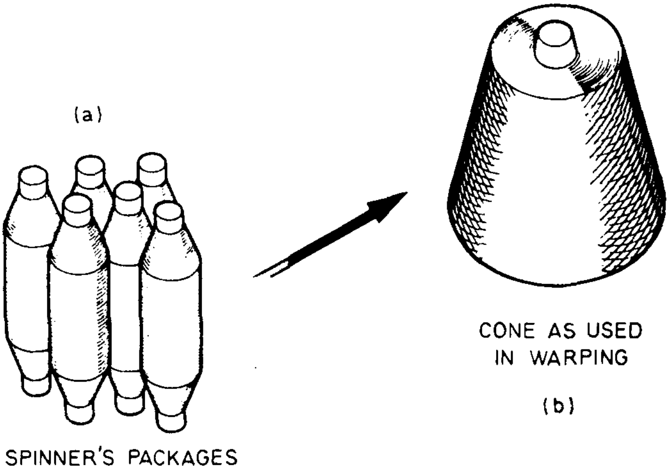


Fig. 3.1.

3. Knots should be of standard type and size, enabling them to pass easily through the heddles and reeds of the loom.
4. The warp must be uniformly sized and the amount of size added must be sufficient to protect the yarn from abrasion at the heddles and reed so as to prevent the formation of a hairy surface on the warp threads.
5. The ends of the warp must be parallel and each must be wound on to the loom beam at an even and equal tension; also, each warp end must be of the correct length and there should be no broken end therein.

The object of warp preparation is to transfer yarn from the spinner's package to a weaver's beam which can be placed behind a loom ready for weaving. A *weaver's beam* usually contains several thousand ends and, for a variety of reasons, it can seldom be made in one operation. It is usual to divide the warp preparation processes into the five sections described in the following pages.

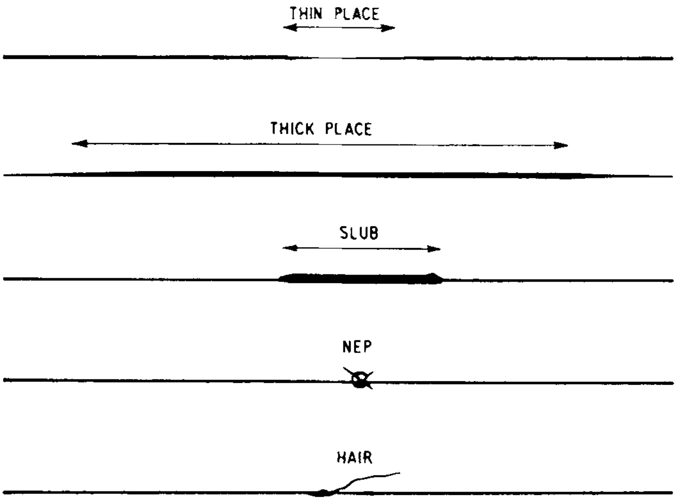


Fig. 3.2. Some typical yarn faults

Warp Winding (Coning)

One of the main purposes of warp winding is to transfer yarn from the spinner's or doubler's package (Fig. 3.1(a)) to another suitable for use in the creel of a warping machine (Fig. 3.1(b)) or for dyeing. Warping requires as much yarn as possible on each package and also a package which has been wound at comparatively high tension, but dyeing requires a soft wound package so that dye can penetrate; a compromise is sometimes needed, therefore, in the matter of winding tension.

A second main purpose of warp winding is to make it possible to inspect the yarn and to remove any thick or thin places, slubs, neps or loose fibers (Fig. 3.2). This *clearing-operation* applies mainly to staple fiber yarns where such faults are more prevalent.

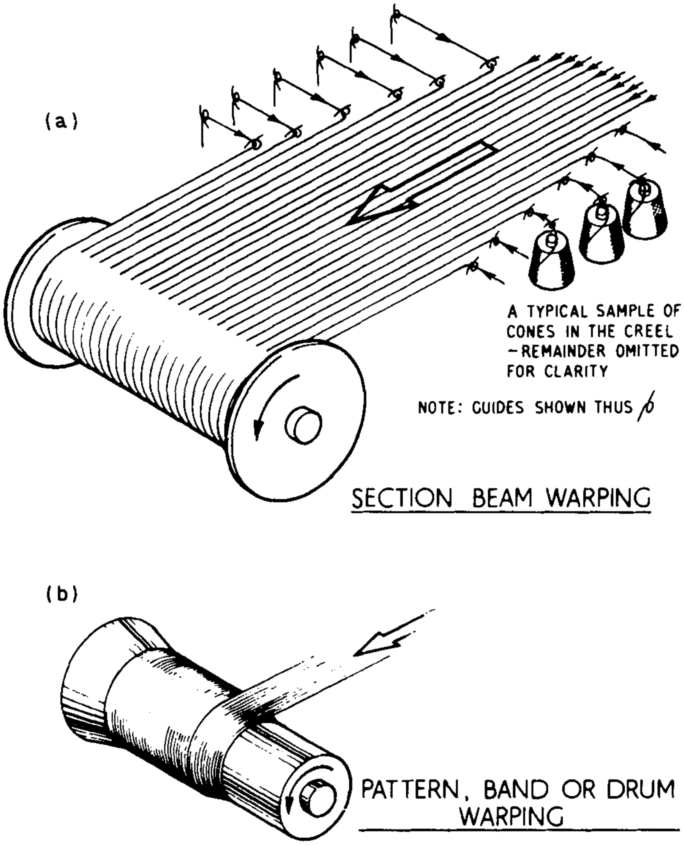


Fig. 3.3.

Warping (*Beaming*)

The purpose of warping is to arrange a convenient number of warp yarns so that they can be collected on a single warper's beam. There are two main types of warping: (a) beam warping and (b) section warping.

(a) *Beam warping* is used for long runs of grey fabrics and simple patterns where the amount of colored yarn involved is less than about 15 per cent of the total. The broad principle is depicted in Fig. 3.3(a). This is sometimes referred to as direct warping.
(b) *Pattern warping* is used for short runs, especially of fancy patterned fabrics where the amount of colored yarn is greater than about 15 per cent of the total. The broad principle of this type of warping is shown in Fig. 3.3(b). This is sometimes referred to as indirect warping or pattern warping.

Sizing (Slashing)

It is necessary to size the warp yarn for several reasons, namely:

(a) to strengthen the yarn by causing the fibers to adhere together;
(b) to make the outer surface of the yarn smoother so that hairs protruding from one yarn in the warp should not become entangled with hairs protruding from a neighboring yarn;
(c) to lubricate the yarns so that there is less friction when they rub together in the weaving process. Lubrication also reduces the friction between the yarns and the loom parts. The reduction of friction reduces the forces acting on the yarns during weaving.

Thus, the problem of reducing the warp end breaks during weaving is attacked from two different angles; that is, every attempt is made to reduce the loads imposed upon the yarns and also the yarn is strengthened. The warp breakage rate is important because, if a single warp end breaks, the whole loom has to stand idle until the warp break is repaired.

Drawing-in

At the sizing stage or afterwards, all the threads required for the warp are brought together on the weaver's beam. At this stage the beam is almost ready for use, but there remains one more operation—drawing-in—before the beam is mounted on the loom.

The loom is stopped whilst the new beam is being mounted, and in order to reduce this wasted time to a minimum each thread is provided with its own series of attachments. When running on the loom, the warp yarn is threaded through a heddle eye and the reed; it also supports a drop wire which will signal the loom to stop if that particular yarn end breaks. Bearing in mind that there might be several thousand such warp ends on a beam, it may take a considerable time for all these to be threaded; it is the practice, therefore, to carry out these operations away from the loom. Each warp end is threaded through an appropriate heddle eye and reed dent and is supplied with its own drop wire. Thus the beam brought to the loom has the required number of harnesses and reed as well as a multitude of drop wires. The beam in this state is useful only for the particular job at hand and can rarely be used to produce a different fabric structure without re-looming.

Tying-in

When fabric of a particular type is being mass produced, the new warp beams will be identical with the exhausted beams on the looms. Therefore, if every end on the new beam is tied to its corresponding end on the old beam, the drawing-in process can be omitted. Tying-in may be done by means of a small portable machine on the loom or as a separate operation away from the loom. In the latter case, there is then an opportunity for cleaning and lubricating the loom, but the "down time" (i.e. the time the loom is stopped) should be kept to a minimum. The former is normal practice.

It should be realized that one or more of the foregoing operations may be omitted or combined with other operations, but in general all operations are necessary. The particular system employed will depend upon whether the warp is grey (i.e. unfinished) or colored. If it is colored, the sequence will depend upon the stage at which it is dyed. The yarn may be dyed in one of the following ways:

(a) Pressure dyeing on the spinner's package before winding.
(b) Hank dyeing, which necessitates an additional reeling operation.
(c) Pressure dyeing on cones or cheeses after warp winding.
(d) Warp dyeing (where the warp is dyed before sizing). This can be achieved by ball warp dyeing or by pressure dyeing on the back beam itself.

The form of dyeing chosen is determined by the type of dyestuff to be applied and the fabric style.

Filling Yarn Preparation

On conventional looms the filling yarn is inserted by means of a shuttle carrying a bobbin. This bobbin should be tapered at the end so that the yarn may be pulled without interruption through the eye of the shuttle as the shuttle travels from one side of the loom to the other. This bobbin (filling bobbin) is termed a "quill" or "pirn". The machines used for winding these bobbins are known as "*quillers*" or *pirn winding machines.*

Spinning Filling Yarn on Quills

The quill is wound either on the spinning frame or on a twister frame. Because this method eliminates the winding process, it does not provide any opportunity for yarn inspection which is usually achieved at the winding stage; consequently, the technique is of diminishing importance.

The yarn on the quills has to be conditioned by wetting or steaming before it can be used, as the moisture content affects the character of the yarn and unconditioned yarn will not weave properly.

Staple yarns are commonly rewound after spinning to permit the removal of faults and to provide package sizes suited to the machines available. Filament yarn is not spun on a spinning frame as used for staple yarns. It may be received in the form of packages known as tubes, cops, cones, cakes, or cheeses which can vary greatly in size. Hence it is necessary to rewind the yarn onto quills of the required size.

Quill winding is usually carried out on automatic quillers or automatic pirn winders, the latter being the European term. These machines are automatic in the sense that when a quill is filled with yarn, an automatic device stops the rotation of the spindle, the full quill is ejected, a new empty quill is automatically placed on the spindle and winding recommences to continue until the quill is full, when the cycle is repeated. As the full quill is ejected from the quiller, it either drops into a quill box directly under the quiller or it is carried by mechanical means to be placed on a pin board.

In most newly designed looms, the shuttle is no longer used and alternative means of inserting the filling are employed. Generally, such systems do not require a small package capable of being transported through the warp shed. Rather, a length of yarn is removed from a large package and is then inserted into the fabric. Most of these new loom systems employ an intermediate yarn storage system so that the yarn package does not have to suffer the extremely rapid and intermittent yarn withdrawal that would otherwise be the case. Nevertheless, the average unwinding speed can still be high, and it is necessary to provide a package which can be unwound at a rapid rate and which can cope with sudden demands. The package should be as large as possible and yet still permit good unwinding; this often involves some compromise. It costs money to replace packages on the loom and from this point of view, the larger the package the better; on the other hand, poor unwinding will create loom stoppages which are equally undesirable. Cones

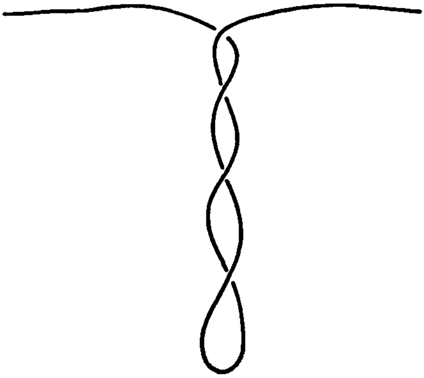


Fig. 3.4. Yarn Snarl

are preferred for looms of these types, but cheeses can be used; in general, any package suitable for high speed unwinding will be adequate for the filling supply.

Advantages of Filling Preparation

The advantages of a filling preparation are:

1. Removal of slubs and weak places during processing which otherwise would impair the running of the loom.
2. The production of tighter packages having more yards per quill. This reduces the number of quill changes in the loom which, in turn, reduces the possibilities of flaws and wastage.
3. Greater uniformity of quills used on the loom. This improves the uniformity of the fabric.
4. The easy handling of small lots.

Conditioning of Filling

This process is the same whether quills are made on spinning or twister frames, or wound on a quiller. It involves the wetting or steaming of the filling yarn to stabilize it so that it will weave satisfactorily. An unconditioned yarn is usually "lively"; if allowed to go slack, it will snarl as shown in Fig. 3.4.

Winding Machines

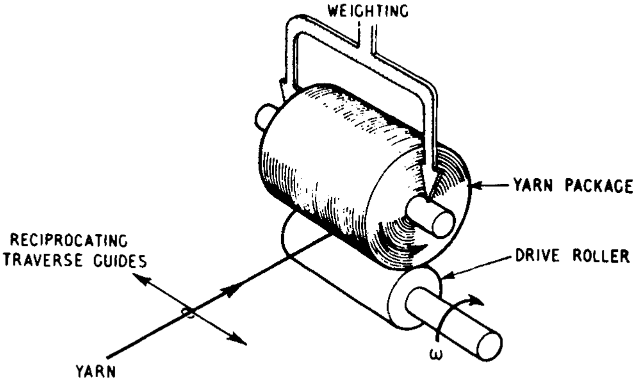
Driving the Package

The package may be rotated by one of three methods:

(a) Surface contact between the outer surface of the yarn on the package and a drum or roller. This gives a constant surface speed to the package and the yarn is taken up at an approximately constant speed. The system is illustrated in Fig. 3.5(a).

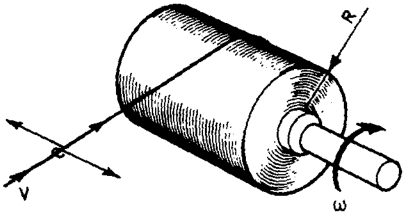
(b) Directly driving the package at a constant angular speed. This causes the yarn take-up speed to vary as the size of the package changes. The system is shown in Fig. 3.5(b).

(c) Directly driving the package at varying speed. To give constant yarn speed, it is necessary to cause the rotational speed to vary inversely with the package radius.



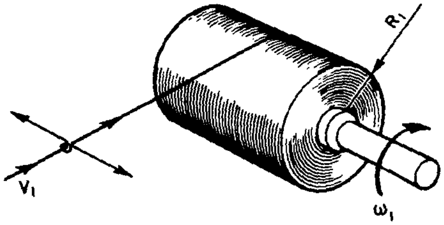
(a) CONSTANT SPEED DRIVE ROLLER

Fig. 3.5. (Above and following page) Package drives



ω IS CONSTANT
V INCREASES AS R INCREASES

(b) CONSTANT SPEED SPINDLE DRIVE



ω_1 IS VARIED AS R_1 INCREASES
SO AS TO KEEP V_1 CONSTANT

(c) VARIABLE SPEED SPINDLE DRIVE

Fig. 3.5. (cont.).

$$\text{package speed} = \frac{\text{constant}}{\text{package radius}}$$

(see Fig. 3.5(c)).

An expensive transmission system is used in method (c), and for this reason, it is seldom used except for delicate yarns. In general, method (a) is used for staple fiber yarns.

Yarn Traversing

There are three fundamentally different types of packages: (1) the parallel wound package; (2) the near-parallel wound package; and (3) the cross-wound package.

(1) *The Parallel Wound Package*

This comprises many threads laid parallel to one another, as in a warp. It is necessary to have a flanged package or beam, otherwise the package would not be stable and would collapse (Fig. 3.6(a)).

(2) *The Near-parallel Wound Package*

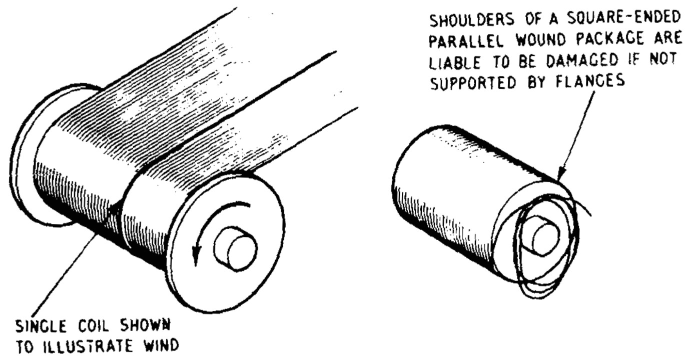
This comprises one or more threads which are laid very nearly parallel to the layers already existing on the package. It may be tapered as in Fig. 3.6(b) or have flanges as in Fig. 3.6(a).

(3) *The Cross-wound Package*

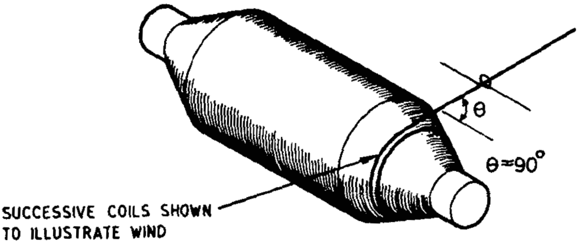
This type usually consists of a single thread which is laid on the package at an appreciable helix angle so that the layers cross one another to give stability, as shown in Fig. 3.6(c).

The second and third types of packages require a traversing mechanism on the winding machine to give the correct build.

The to-and-fro movement of yarn as it is laid on to a package, usually called *traverse* or *chase*, is controlled by a movable guide. When winding a type 2 package, the pitch between successive coils needs only to be small and the minimum distance traversed for each revolution of the



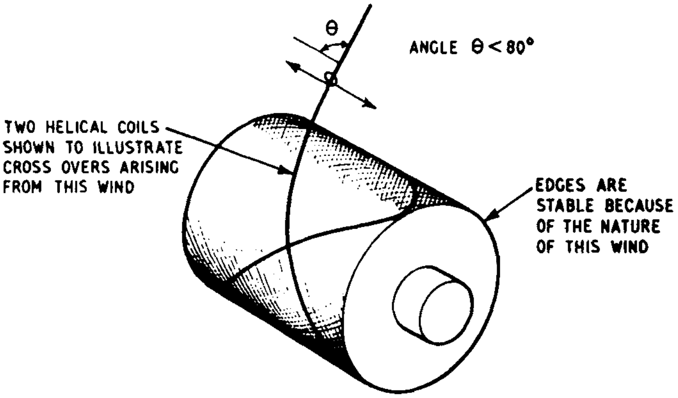
(a) PARALLEL WOUND PACKAGES
(TYPE 1)



(b) TAPER WOUND PACKAGE
(TYPE 2)

Fig. 3.6. (Above and opposite page).

package is determined by the yarn diameter (see Fig. 3.6). The yarn approaches the laying-on point almost perpendicularly.



(c) CROSS WOUND PACKAGE
(TYPE 3)

Fig. 3.6. (cont.)

When winding cones and cheeses (which have no flanges and are of type 3) the pitch between successive coils must be relatively large if the package is to be stable (see Chapter 4). For such packages the winding angle must, in general, not be greater than about 80°.

Traversing methods are as follows:

(1) *Reciprocating*

- (*a*) Single guide rod and traversing cam serving many winding spindles.
- (b) A guide and cam for each spindle (Fig. 3.7).

(2) *Rotating*

- (a) Grooved roller with single groove (split drum).
- (b) Grooved roller with multiple grooves (Fig. 3.8).

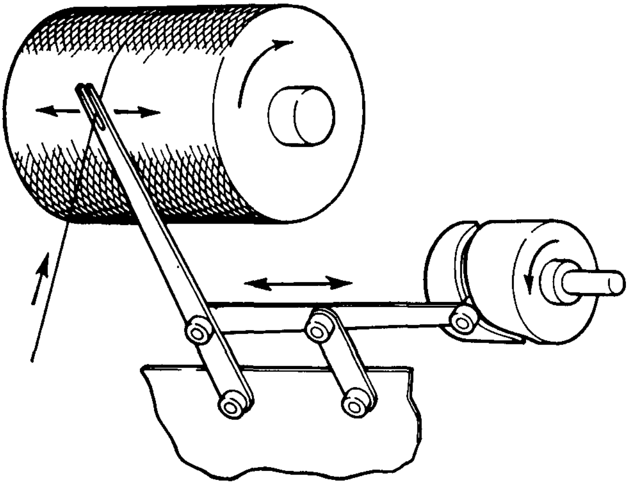


Fig. 3.7. Schematic diagram of a cam-driven reciprocating traverse mechanism

Precision and Non-precision Winding

When the successive coils of yarn on a package are laid close together and parallel, it is possible to produce a very dense package in which a maximum amount of yarn is stored in a given volume. With a cross-wound package in which the pitch between successive coils is large, a considerable number of voids are created because of the multiple cross-overs and consequently the package is much less dense. To get a dense package, it is necessary to control very precisely the position of the yarn as it is laid on the surface. Since this is best achieved by a reciprocating guide placed close to the laying-on point, it is usual to find that so-called "precision" packages are wound with a reciprocating traverse.

As the diameter of the package grows during winding, so the yarn helix angle and the distance between adjacent coils change. It is possible that, in successive layers, one yarn may be wound immediately on top of another. This causes a patterning which is visible on the surface and which interferes with subsequent unwinding. This patterning or

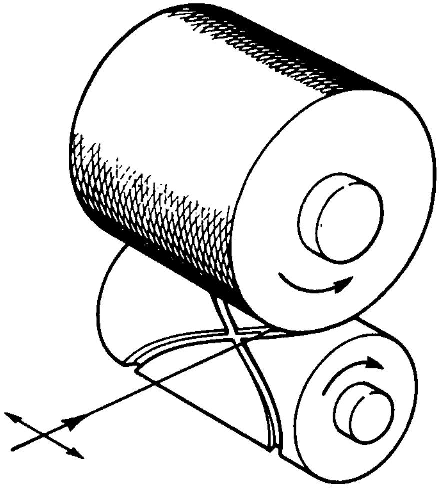


Fig. 3.8. Grooved roller traverse

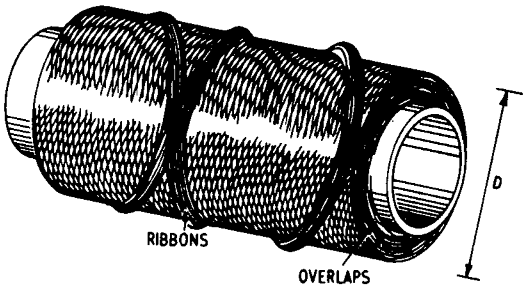
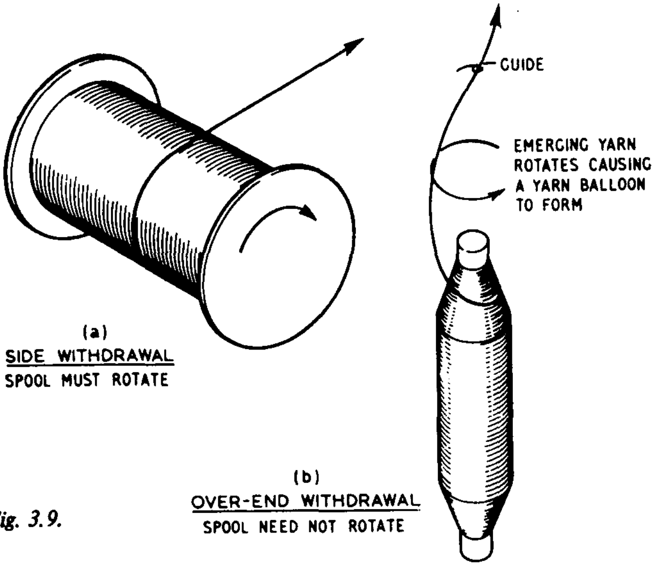


Fig. 3.8 (a). Ribboning or Patterning. This occurs, with its associated overlaps, when the yarn traverse guide oscillates in synchronism with the surface of the package and causes adjacent yarns in the wind to lay on top of one another. Patterning occurs only at specific values of D.

ribboning is shown in Fig. 3.8(a) and it will be observed that the closely packed yarns within the ribbon are unlikely to allow dye to penetrate as easily as elsewhere. Also, during unwinding, there will be marked yarn tension increases as yarn from the ribbon is removed; this is likely to cause an increase in *end breaks* during any rapid unwinding operation. In addition, the shoulders of the package will show *overlaps* where the ribbon reaches the edge of the package and this too can cause unwinding problems. It is usual to arrange the traverse speed to avoid this as far as possible; also, auxiliary mechanisms are sometimes introduced to break up the patterning. A precision winder works with pitches which are fairly close to patterning because this gives a dense package, but the patterning has to be avoided or it would persist throughout most of the wind. Non-precision winders work with relatively large pitches that often give intermittent patterning which is difficult to avoid and, as mentioned earlier, the package density is reduced and the package stability is improved.



(a)
SIDE WITHDRAWAL
SPOOL MUST ROTATE

(b)
OVER-END WITHDRAWAL
SPOOL NEED NOT ROTATE

Fig. 3.9.

Yarn Withdrawal

There are two ways in which a yarn package may be unwound, viz. (1) side withdrawal as shown in Fig. 3.9(a), and (2) over-end withdrawal as shown in Fig. 3.9(b). With over-end withdrawal, the package is stationary, but a special package build is required to permit clean withdrawal; furthermore, the yarn twist changes by one turn for each loop removed, but this can usually be neglected.

Broken Yarn Stop Motion

On winding machinery it is necessary to stop winding if a thread breaks or if the yarn supply is exhausted. Usually the yarn is made to support a light feeler; if the yarn breaks, the feeler moves and causes the package drive to be disconnected.

Auxiliary Functions

The functions previously described are common to most forms of winding machines, but there are other functions which pertain only to certain types.

These auxiliary functions may be performed manually or automatically. The latter class contains machines which are called automatic winders*. The auxiliary functions include:

(a) Creeling.
(b) Piecing.
(c) Doffing.

Creeling is the placement of full packages in position ready to be unwound as part of the transfer operation. An alternative meaning is the removal of the exhausted packages and their replacement with full ones.

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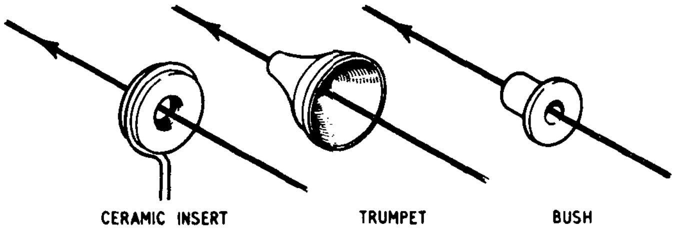
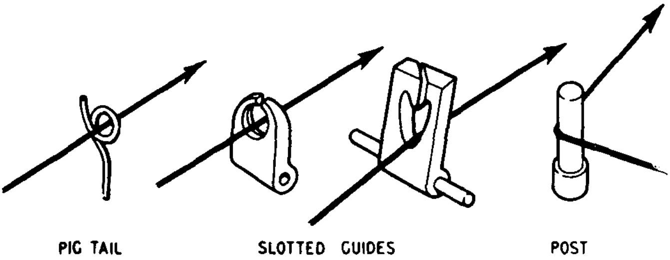
* At present, automatic winders of large packages seldom doff the packages automatically but it is likely that this will become the practice in the future. The technique of automatic doffing is now being applied to ring spinning, but it may be some time before it is economic to doff the larger packages found on winding machines. Nevertheless, it is logical to consider automatic doffers as part of automatic winding.



TYPE A A YARN END IS REQUIRED FOR THREADING



TYPE B A YARN END IS NOT REQUIRED FOR THREADING

Fig. 3.10. Types of guide

Piecing is the finding and connecting of the ends on the packages. The connection between the ends can be made by knotting, adhesion or welding but the former is by far the most common. Such connections are required whenever an end breaks or when a creeling operation has been completed.

Doffing is the removal of the newly wound packages and (usually) the replacement of these by empty packages which will receive yarn during the transfer process. It will be noted that creel packages are emptied as the packages to be doffed are filled.

Yarn Guides

In winding or unwinding, it is necessary to control the yarn path. If side withdrawal is being used, it is possible for the yarn to pass along a smooth unvarying yarn path, but if there is some vibratory force present the yarn may vibrate between the guides. These vibrations can be controlled by the strategic placing of guides along the yarn path. If over-end unwinding is used, the yarn does not move along a fixed path because a rotary motion is imparted as the yarn unwinds. Any given section of yarn moves not only along the length of the yarn, but also in a circular fashion; this is called *ballooning*. For a given yarn speed and package size, the position of the yarn guide will determine the balloon shape; this, in turn, determines the yarn tension. The guide position is thus important.

Guides are normally made of hard smooth steel or ceramic. Many man-made yarns are surprisingly abrasive and frequently it is essential to use ceramic guides. Guides of various shapes may be used, the choice depending on the yarn motion to be controlled (see Fig. 3.10).

Tension Devices

Yarn tension plays an important role in winding. Too high a tension can damage the yarn, whereas too low a tension can lead to unstable packages which will not unwind cleanly. A common fault associated with certain loosely wound packages is their tendency to "*slough off*" more than one turn to give a tangle. Variations in yarn tension in different parts of a wound package can cause undesirable effects. For instance, with many man-made fibers, high tension can cause molecular change which affects the dyeability, so that variations in tension ultimately show as apparently random variations in color shading.

In winding staple yarns, sufficient yarn tension is used to cause breaks in thin places whilst the yarn is being wound. This permits the thin places to be cut out, the yarn to be repaired and the winding to continue. Variations in running tension after the level at which the thin places are removed

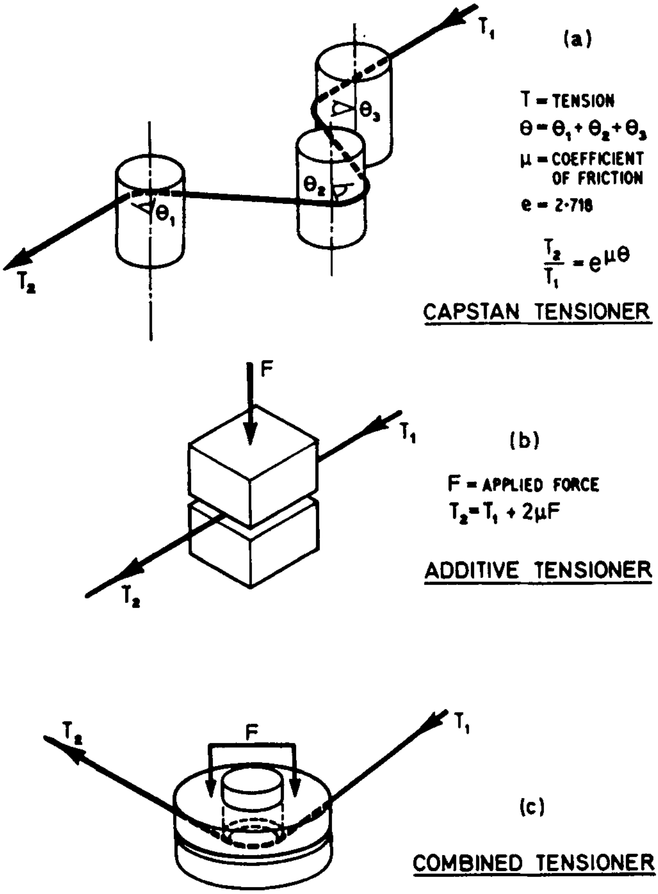


Fig. 3.11.

and so affect the yarn regularity in the final product.

There are many forms of yarn tensioner, the simplest of which works by merely deflecting the yarn around fixed posts. This induces a capstan effect which follows the classical law

$$\text{Output tension} = \text{input tension} \times e^{\mu\theta}$$

where μ = coefficient of friction between yarn and post
θ = angle of lap measured in radians
$e = 2{\cdot}718$

This is illustrated in Fig. 3.11(a).

It will be noted that a definite input tension is required before a tension increase can be obtained; in other words, it is a multiplicative device.

Another simple technique is to use a deadweight or spring to give a fixed increment of tension; this is called an additive system (see Fig. 3.11(b)).

The two systems can be combined as shown in Fig. 3.11(c).

These devices permit the tension level to be raised to any desired extent, but they do not permit a reduction in tension. The only way to decrease the tension is to use a positive drive which tends to overfeed. Such devices are seldom used.

More sophisticated systems of tensioning are also used, some of which incorporate automatic control. Of these, the

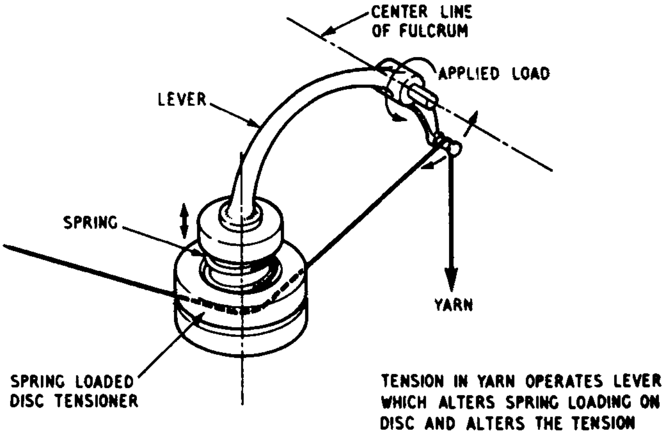


Fig. 3.12. Schematic diagram of one sort of lever-type tensioner

simplest and most common is the lever operated compensator tensioner, an example of which is shown in Fig. 3.12. The yarn tension operates on the pin at the free end of the lever and alters the amount of load applied in the disc region, which in turn changes the tension. The device is arranged so that when the measured yarn tension is too high, the pressure in the disc region is reduced to bring the tension back to its proper level. In control terminology, this is called "negative feed back".

There are several requirements which influence the choice of a tensioning device, including:

1. The device must be reliable.
2. It must be easily threaded.
3. It must neither introduce nor magnify tension variations.
4. It must not introduce differences in twist.
5. It must not be affected by wear.
6. It must be easily adjustable.
7. It must not be affected by the presence of oil or dirt.
8. It must not encourage the collection of dirt and lint.
9. It must be capable of easy cleaning.
10. The operating surfaces must be smooth.
11. It must be inexpensive.

Stability of the Package

The stability of a package is best defined in terms of its ability to withstand deformation. A package which disintegrates causes disorder in the yarn which makes it useless and results in excessive wastage. Most forms of package deformation create wastage in this way, and cause difficulty in subsequent operations. A package must be capable of retaining its shape and build even after considerable handling, permitting orderly and rapid removal of the yarn in the subsequent process.

As an extreme and hypothetical example of an unstable package, consider the winding of a perfectly smooth yarn on a flangeless bobbin in a truly parallel fashion as shown in Fig. 3.13. Since all coils making up the package are perfectly parallel, there can be no lateral forces to hold them together other than those arising from contact with the bobbin. If the package is loosely wound, the outer coils will be able to move

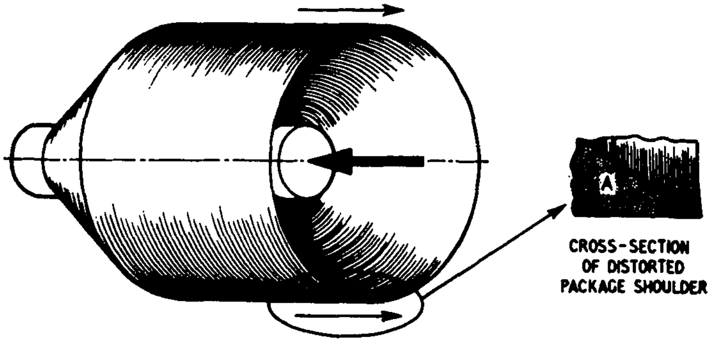


Fig. 3.13. Instability of package due to looseness of wind

relatively freely in a direction parallel to the bobbin axis, and the situation depicted in Fig. 3.13 could easily arise. The portions shown shaded at A are completely unsupported and would collapse into a hopeless tangle. In any case, the shoulders are very vulnerable to damage, with similar results. A solution to this is to use flanges to provide lateral support as shown in Fig. 3.14. The flanges, however, impede unwinding when the yarn is withdrawn parallel to the bobbin axis (i.e. over-end unwinding) and the use of bobbins with large flanges is commonly restricted to cases where the yarn is removed tangentially from the cylindrical yarn surface (i.e. side unwinding).

Most yarns are not completely smooth, so hairs and loops can intertangle to some extent and provide a degree of stability; the shoulders are still very vulnerable, however, and to use such a package without flanges it is necessary to taper the ends as shown in Fig. 3.14. Since the main purpose

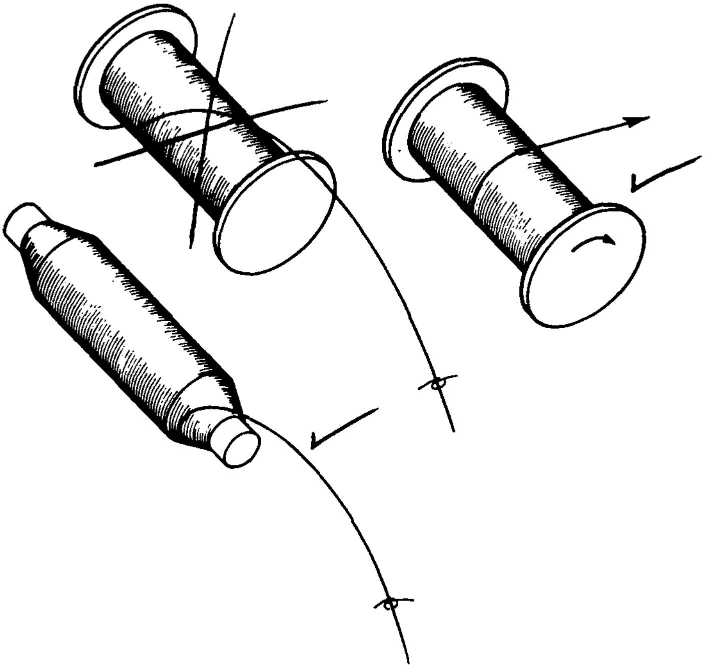


Fig. 3.14. Unwinding parallel-wound packages

of dispensing with flanges is to permit over-end unwinding, the consequences of this must be considered.

Consider the point where an element of yarn is just leaving the surface of the package. The ballooning will cause a yarn tension to exist at that point and this tension may be resolved into three mutually perpendicular components. One of these components may be parallel to the bobbin axis, another tangential to the cylindrical surface and the third one will be radial as shown in Fig. 3.15. The parallel one (*P*) must be opposed by frictional and cohesive forces between the subject yarn element and the neighboring material or the cylindrical surface. The tangential one (*T*) will be balanced by a com-

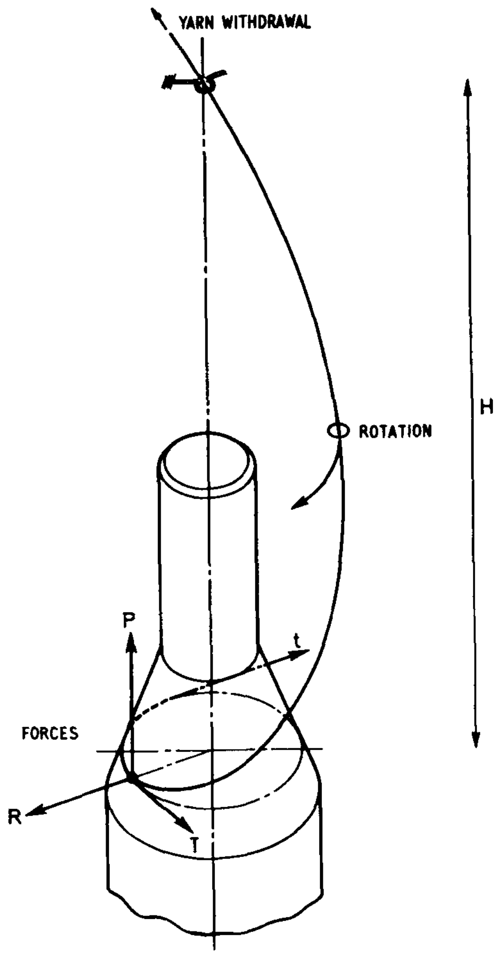


Fig. 3.15. Yarn ballooning

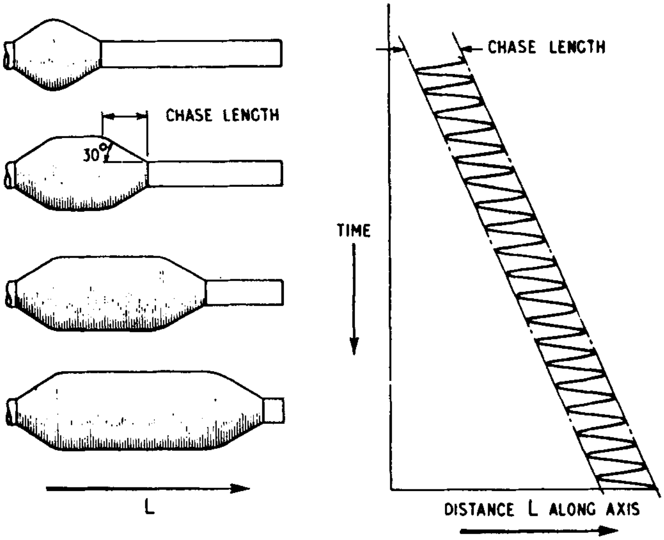
ponent of the tension in the yarn just about to be removed and the radial one (R) will be balanced by the tension t plus the frictional and cohesive forces which act in that direction. The angle of yarn departure will automatically adjust itself until these conditions are met. The radial cohesive forces will tend to lift the coil of yarn below the departing element and loosen it; the parallel cohesive force will try to move that underlying coil laterally from its proper position. If the tension in the underlying coil is sufficiently high, it will not lift and it will not be displaced laterally by the departing yarn. On the other hand, if the tension is low, a whole coil can be displaced and in bad cases it will slough off as shown in Fig. 3.6(a). This is especially true if the package is tapered in such a way that the displacement of the coil further loosens it.

So far, it has been assumed that the coils are parallel to one another. If the coils are helical and the helices cross one another as shown in Fig. 3.6(c), we have a cross-wound bobbin which is much more stable.

Firstly, the parallel force P is now opposed by a component of the yarn tension as it exists on the package. Secondly, the cohesive forces acting are no longer concentrated locally and extend over a much larger surface of the package so that many more coils are involved in contributing to the stability. This reduces the chance of local variations giving trouble. Thirdly, the cross-overs give an interlocking effect which can result in great stability.

Special Requirements

It would seem to be desirable always to use a cross-wound package in which the traverse extends over the full length of the package, since this appears to give the maximum stability. Unfortunately, there are circumstances in which such a package cannot be used and a degree of compromise is required. An example is the quill used in a shuttle. One requirement is that the quill should carry the maximum mass of yarn in the space available in the shuttle. To get the maximum density it is necessary to use a parallel wind, but this could cause stability problems and a progressive conical traverse is used therefore, as shown in Fig. 3.16. This provides a sufficient degree of stability. It might still be argued that a cross-wound package with a full traverse could be



STAGES IN BUILDING A QUILL

PROGRESSIVE RECIPROCATING TRAVERSE

Fig. 3.16

used, but this is to ignore the special unwinding conditions which exist within the confines of a shuttle. Since a full balloon cannot develop, the coils of yarn rub the surface of the quill between the yarn removal point and the quill tip. With a traverse from end to end, yarn coils would be dragged over others causing them to move and perhaps even to be damaged. With the wind shown, the yarn has little chance to touch the other yarn and in the main it slides along the polished wood of the quill.

A further reason for using this type of build is to limit the tension variations induced in the original winding of the package. Grishin's formula for the tension generated in a ballooning yarn states that the yarn tension is a function of the balloon height as well as other factors which need not be considered here. Thus if a large traverse is used, the balloon height (*H* in Fig. 3.15) during spinning will vary considerably and the tension acting on the yarn will be affected. This will be detrimental to the smooth progress of subsequent operations.

All these factors suggest that it is desirable to reduce the traverse length on the quill to a minimum. However, a limit is imposed by the incidence of sloughing-off, and there has to be a compromise between mass storage and tension variation on the one hand and package stability during unwinding on the other.

4

WINDING

Key Words: *automatic winder, balloon, bobbin, bunch, chase length, cheese, clearing, cone, cone angle, creel package, creeling, doff, doffing, down time, feeler, knotting, magazine creeling, magazining, negative let-off, package, package build, picks, piece, quill, quillers (pirn winders), ring tube, sloughing-off, spool, spindle, spindle efficiency, winding head.*

The Need for Winding

At first sight, winding machinery appears to fulfill no purpose other than a simple transfer of yarn from one package to another. This is, however, an oversimplification of the winding process.

Clearing

At one time it was a common practice to spin yarn directly onto the quill or pirn to be used in weaving. However, yarn from the spinning machine has imperfections in the form of faults and blemishes which can cause trouble in later processes.

Thin spots in the yarn are usually weak spots which may break during weaving, causing the loom to be idle until a repair is made. The breakage of such a weak spot in a single warp end will bring the entire loom to a stop, even though there may be a thousand or more perfectly good warp ends in the loom. Thus if there is a potential break in every 100 m (110 yd) and there are (say) 4000 warp ends, there will be (on average) a loom stop for every 100 ÷ 4000 = 0.025 m of fabric. Thus the incidence of thin spots and other blemishes is a very important matter and it is essential to remove them and replace them with standard knots. The operation of removing these undesirable elements of yarn, called *clearing*, is usually carried out during the winding process. The cost of the winding/clearing operation is usually less than that of allowing the flaws to remain. Left in the yarn, such flaws would increase the cost of weaving and reduce the value of the fabric.

Package Size

Other factors to be considered are the practicability and economics of transferring yarn from the spinner's package to the form in which it is ultimately required. Consider the problems in mass production where beam after beam has to be produced, each identical with the others. With staple yarn produced on a ring frame, each package (ring tube) might contain some 4000 m (4400 yd). The actual length, however, would vary from spindle to spindle and if the ring tubes were used as the *creel packages** in winding the beams, creel package replacement would eventually become random. If winding then proceeded at 800 m/min and there were 900 creel packages, the machine would only run for 4000 ÷ (800 x 900) = 1/180 minute (i.e., 0.33 second) before a new creel package would be required. Assuming it takes (say) 5 seconds to remove the empty package, replace it by a full one and *piece*†, then the machine would run less than 6.25 percent of the time. If, however, the package were 50 times larger, the machine would run 77 per cent of the time; hence package size is of great importance and it is usual to wind yarn from the ring tube to a large creel package in order to improve the efficiency of warping. Also, random replacement of creel packages is avoided since this too diminishes the efficiency.

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* A creel package is a supply package.

† "Piecing" is joining the ends of two yarns.

Textiles are subject to the vagaries of fashion and long runs are not always possible; in consequence, only one warp of a given kind may be required. This means that each creel package will need to have about the same length of yarn as that required in the warp. Variations in this length on the creel package will lead to waste in one form or another. Too short a length in a single package can stop the whole operation whilst a new one is pieced in (also introducing an unwanted knot). Too great a length will leave excess yarn which must be discarded or rewound and pieced onto another end for subsequent use (yielding a different sort of waste as well as a knot). When it is realized that this might be multiplied a thousandfold in a single warp, the virtues of winding the creel packages to a specification can be appreciated. Add to this the fact that winding provides an opportunity of clearing and rewinding the package to a build most suitable for high-speed warping, and it is apparent why expensive winding machinery is found to be an economic necessity.

With some of the newer methods of spinning (for example, open-end spinning) the spinners' package is much larger and may prove suitable for direct use, but there still remains the problem of clearing. It is possible that this might be carried out on the spinning frame, eliminating one of the stages in conventional preparation. However, such things take time to develop and it will probably be necessary to retain the rewinding stage for certain purposes even if a new system does evolve.

Synthetic yarns are usually supplied on packages containing large quantities of yarn. The many users of such yarns employ a wide variety of fabric-making machinery which demands many different package sizes, shapes, and builds. There is thus a problem of matching the requirements of supplier and user. If the supplier has to provide many types of package for each of a wide variety of yarns, he has an expensive inventory problem. A partial solution is for the yarn supplier to use standard packages and for the user to rewind the yarn according to his particular needs. The cost can be minimized in this way. Similar considerations apply to large staple spinners' packages.

Package Build

Sometimes the yarn has to be dyed or otherwise treated between spinning and weaving. In such cases it is usually necessary to wind the yarn on a special package to permit this treatment. In the case of dyeing, the package must allow even penetration of dye so that all parts of the yarn are similarly treated. The tube or cone on which the yarn is wound is usually perforated, the yarn is wound rather less tightly than normal and the build is such as to create many interstices through which the dye may pass. The cost of rewinding has to be weighed against the extra cost of using a less dense package which might be of an unsuitable shape and build for subsequent use in the following process.

When there is a disparity in size and shape of package between the output of one process and the input of the next, there is an obvious need to rewind. For example, the ring frame produces small almost parallel-wound packages, whereas the warping operation requires large cross-wound cones if it is to work efficiently at high speeds. As another example, texturized yarn may come on large capacity cheeses whereas the shuttle can only accept small long packages which have a special type of wind.

Even when the sizes match reasonably well, there can still be good reasons for rewinding. For instance, it would not be possible to use a cross-wound package of type 3 (Fig. 3.6) in a shuttle; such a package would not unwind properly. In a shuttleless loom, it is possible to use large packages but it is very doubtful if smaller packages could be used. These examples illustrate the importance of obtaining the correct build as well as the correct size of package.

During the winding process, tensions are created which can damage the yarn in subtle ways. A continuous filament when stretched can change in several of its characteristics, so if the yarn tension is high and varies in some periodic manner along the length of the yarn, the woven fabric will exhibit an undesirable patterning. With some structures of staple yarns, overstraining weakens them; an example of this category is the open-end spun yarn referred to earlier. On the other hand, a sufficient tension is required to give the package stability and density.

Winding Requirements

The requirements for winding may be summarized as follows:

(i) The fault level in the yarn must be reduced to an acceptable level.

(ii) The yarn must not be damaged in any way in the winding process.

(iii) The yarn must be wound in such a way as to permit unwinding in the following processes with a minimum of difficulty at the required speeds.

(iv) The package size, shape, and build must be the most technologically suitable for the particular end use.

(v) The package size should be controlled to meet the particular economic requirements.

(vi) The winding operation must be geared to give the best possible economic performance of the whole process of fabric manufacture.

The Winding Operation

The normal winding operation consists of unwinding one package and rewinding onto another. The user may not have a free choice in the sort of package he unwinds but he does have a choice when it comes to the package he builds. Consequently, it is necessary to consider in some detail the structures which can be built to withstand reasonable handling and use.

In this section, winding is considered under three main headings, i.e. unwinding, package stability, and winding. The first deals with the creel package and the unwinding thereof, the second with the limitations which apply in the matter of the structure of the package, and the third with the winding of the package which is about to be doffed. The latter includes the tension control which is vital to the proper performance of the package produced.

Bearing in mind that the package *doffed* from one machine becomes the creel package for the next, it will be realized that the principles discussed are bound to go beyond the narrow topic of winding.

Unwinding

(i) *Side Withdrawal*

If paper is pulled from a roll, the roll has to rotate; similarly, when yarn is withdrawn tangentially from a package, the package must rotate (Fig. 3.14). If the package is driven, its rotational speed must be capable of variation if the yarn is to be delivered at an even rate. Such a system is usually too expensive for practical use and, where side withdrawal is used, the package is usually dragged round by the departing yarn. This is called *negative let-off.*

At high speeds, the inertia of the package has to be considered because any change in operating speed will cause the yarn (or yarns) to go slack or to suffer appreciable changes in tension depending on the magnitude and direction of the speed change. At very high speeds the package tries to grow larger due to the centrifugal forces; for this reason, the layers of yarn may become loose and slip over one another, thus impairing the stability of the package. Side unwinding, therefore, is usually restricted to low yarn withdrawal rates and to negative let-off systems. Typical uses of side unwinding are to be found in the various operations on a warp; in view of the multiplicity of ends in a warp it is virtually impossible to use anything but side withdrawal.

Since tension is so important in winding and subsequent operations, it is relevant to consider the various means of control available for use with side withdrawal. Yarn tensioners can be used to increase the tension to the required level, but with negative let-off systems this leaves the relatively massive *spool* uncontrolled. It is quite normal to use a brake acting on the spool to achieve at least part of the required tension in the yarn, because this also gives some control of the package rotation and tends to prevent over-runs when the demand for yarn is reduced. If an unvarying braking force is applied to an unvarying diameter of a portion of the spool, then as the diameter of the yarn wound on the spool varies, so will the tension in the yarn being withdrawn. If the torque applied by the brake is constant at T g. cm, the radius at which yarn is withdrawn is r cm and the corresponding yarn tension is t gram, then if all other forces are ignored

$$T = t \times r \quad \text{g.\,cm} \tag{4.1}$$

Since the radius diminishes as unwinding proceeds, the tension increases and there is an inverse relationship between tension and radius. If the spool speeds up during unwinding, then it is possible for the torque to increase because of changes in the braking force and this will alter the relationship somewhat.

If the tension is to be kept constant, it is necessary to use some control device. Leaving aside the possibilities of controlling by additional tensioners, let us assume that the spool brake is the sole means of generating the tension. Basically, the control systems may be divided into two classes, viz. (a) those which measure the radius of the yarn package on the spool and adjust the torque accordingly and (b) those which measure the yarn tension and adjust the torque until the tension reaches the desired value. Method (a) works on dead reckoning but is relatively simple whilst method (b) is a control system of greater complexity which tends to be too expensive for wide use. Also, where many ends are involved—as with a warp—it is not easy to measure a tension which is always truly typical of all the ends and it is impracticable to measure the tension of all the ends, of which there may be several thousands. Consequently, the dead reckoning system based on measurement of the package radius is frequently used. It must be appreciated, however, that a periodic calibration of the control can be of value; because of changes in the coefficient of friction at the brake, there is not a unique relationship between the force applied to the brake and the torque produced. Consequently, the figures used in the dead reckoning may not in fact be constant and the tension would then be in error. For example, a spot of oil on the brake drum could affect the yarn tension; therefore, care is needed to ensure the proper functioning of the device.

(ii) *Over-end Withdrawal*

The second method of yarn withdrawal is to take the yarn away along a line which roughly coincides with the axis of the package as shown in Fig. 3.9. Using the technique it is not necessary to rotate the package; this avoids some of the difficulties associated with side withdrawal and permits very high rates of yarn removal. Consequently, it is used in circumstances where high unwinding speeds are required, such as in high-speed beaming and the removal of yarn from weft packages.

With over-end withdrawal from a stationary package, there is a change of one turn of twist in the yarn for each coil removed from the package. A simple experiment in which two yarns of different colors are wound side by side on a package and then withdrawn over-end will demonstrate the phenomenon; the yarns withdrawn will show a ply twist. Suppose the length of yarn in one coil is L cm, and it originally contained S turns/cm, then before unwinding, the length will contain SL turns. After unwinding it will contain $SL \pm 1$ turns (the ± sign has to be included to account for the directions of wind and twist being in opposition or not). The twist rate after unwinding is $S \pm (1/L)$ turns/cm, and since L is at least 5 cm and S is frequently greater than 10 turns/cm, the change in twist is rarely greater than about 2 per cent.

The rotation applied to the departing yarn during unwinding sets up centrifugal forces which cause the yarn to move in circular fashion rather like a skipping rope. The

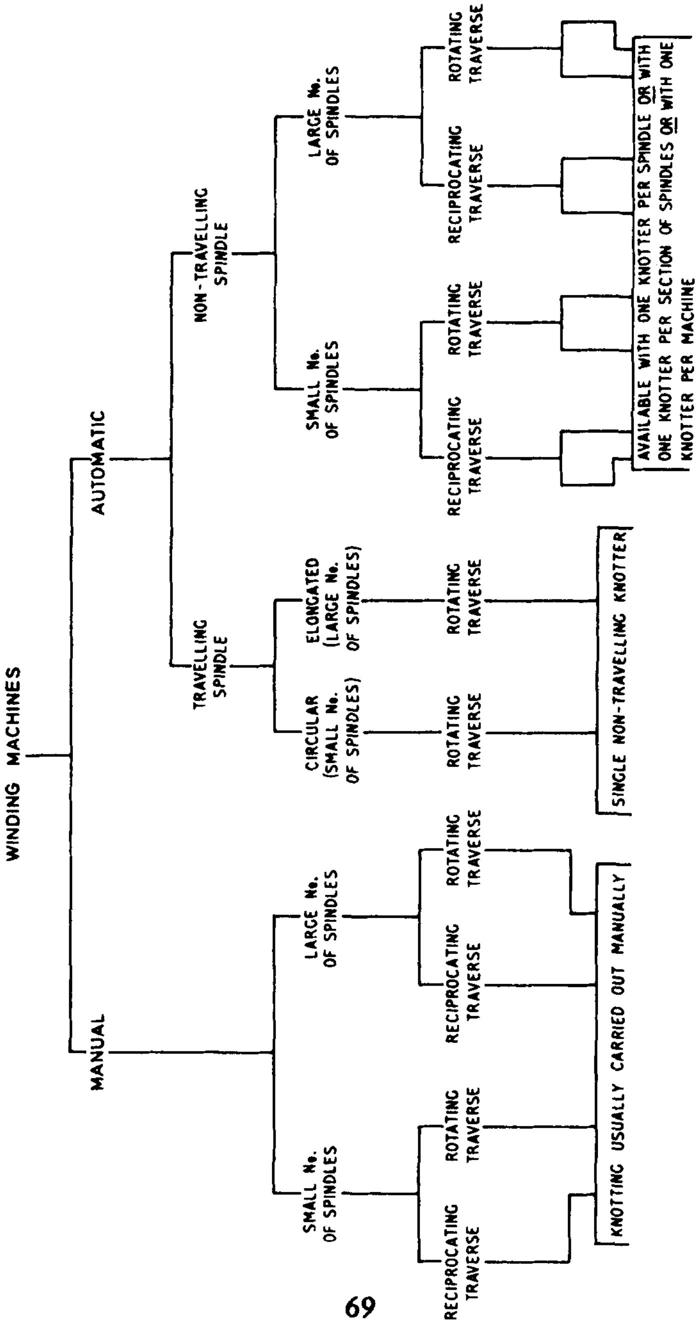
WINDING MACHINES
MANUAL
AUTOMATIC
SMALL No. OF SPINDLES
LARGE No. OF SPINDLES
RECIPROCATING TRAVERSE
ROTATING TRAVERSE
RECIPROCATING TRAVERSE
ROTATING TRAVERSE
KNOTTING USUALLY CARRIED OUT MANUALLY
TRAVELLING SPINDLE
NON-TRAVELLING SPINDLE
CIRCULAR (SMALL No. OF SPINDLES)
ELONGATED (LARGE No. OF SPINDLES)
ROTATING TRAVERSE
ROTATING TRAVERSE
SINGLE NON-TRAVELLING KNOTTER
SMALL No. OF SPINDLES
LARGE No. OF SPINDLES
RECIPROCATING TRAVERSE
ROTATING TRAVERSE
RECIPROCATING TRAVERSE
ROTATING TRAVERSE
AVAILABLE WITH ONE KNOTTER PER SPINDLE OR WITH ONE KNOTTER PER SECTION OF SPINDLES OR WITH ONE KNOTTER PER MACHINE

Fig. 4.1.

rotating yarn assumes a form known as a *balloon*, the name arising because persistence of vision causes the yarn to appear as a three-dimensional object resembling a balloon.

Winding Machines

Types

Winding machines in common use may be classified as shown in Fig. 4.1. All the classifications can be further subdivided into *cone* and *cheese* (spool) winders; generally, these are not mixed on any one machine but it is possible for sections of some machines to produce cones while others produce cheeses.

An *automatic winder* is commonly defined as a machine in which *creeling* (including tying) and *knotting* of broken ends (which arise due to clearing flaws or to natural breakages) are automatic but *doffing* is not necessarily so. From this it is evident that knotting is crucial to the operation of an automatic winder and the knotting device provides a means of identifying the class of machine as illustrated in Fig. 4.1.

Manual Machines

Usually, a major characteristic of a manual or non-automatic winding machine is its high winding speed, and the reason for this lies in the economics of winding. With an automatic winder of other than one knotter per spindle, there is little point in winding the package in less time than it takes for the knotter to get to the package (or vice versa). Thus, with automatic winders there are several alternatives, viz. (1) the winding speed must be limited, (2) the supply package size has to be increased, or (3) the number of knotters must be increased. The third alternative is expensive, the second alternative is controlled by the spinning process and, therefore, the first alternative is the most common solution to the problem. Non-automatic winders are not so limited, and they can be operated at any desired speed within their operating limits. In the case of a one-knotter-per-spindle machine, this is not so, but such a machine has a high capital cost which affects the winding cost. In fact, the one-knotter-per-spindle machine might almost be regarded as an automated version of the manual one.

Where traveling packages or knotters are used, then the yarn count, length and characteristics should be the same for each section patrolled by the given knotter; otherwise, there would be undue interference because of differential knotting operations arising from varying fault rates, package run-outs, etc. Manual winding machines are not limited in this way and it is possible, but not always desirable, to wind a different sort of yarn on each spindle. Hence, great flexibility is one of the chief characteristics of the manual machine.

Inevitably, labor costs are relatively high in the case of manual machines. The elements of capital, labor and power costs have to be balanced to yield the most efficient operating conditions. The choice of machine is determined by these factors and generally, the higher the labor wages, the more complex and expensive are the machines likely to be.

For a given size of package, the time to unwind is proportional to the yarn number (count); hence, a package of very fine yarn needs infrequent service from the knotter whereas a package of coarse yarn needs frequent service. In the case of very coarse yarn, the machine will be stopped for knotting operations (i.e. the *down time*) for a large proportion of the available time. If the machine is very expensive, this means that the winding cost per pound will be increased and, in consequence, the manual machine can enjoy an advantage for coarse counts.

Automatic Winders with Non-Traveling Spindles

Let us consider first a specific example of a machine which has a large number of spindles per knotter. Assume that the winder works at 1000 m/min and the knotter takes 0·2 min to creel a new supply package and to find and piece the ends. Ignoring all end breaks during winding, let four different yarn numbers (yarn count) be considered and let

TABLE 4.1

N_e	n	L	L	t	τ	T	M	η_{max}
Yarn Count (Cotton)	*Yarn Linear Density*	*Yarn Length* $L=157.5N_e$	$L = \frac{85000}{n}$	*Winding Time* $t = \frac{L}{1000}$	*Service Time*	*Total Time* $T = t+\tau$	*Max No. of Spindles Per Knotter* $M = t/\tau$	*Max Machine Efficiency* $\eta = \frac{t \times 100\%}{T}$
hank/lb	*Tex*	*Yards*	*Meters*	*Min*	*Min*	*Min*	*#*	*%*
10		1575		1.575	0.2	1.775	7.8	89
	60		1416	1.416	0.2	1.616	7.1	88
20		3150		3.150	0.2	3.350	15.7	94
	30		2833	2.833	0.2	3.033	14.2	93
30		4725		4.725	0.2	4.925	23.6	96
	20		4250	4.250	0.2	4.450	21.3	96
40		6300		6.300	0.2	6.500	31.5	97
	15		5666	5.666	0.2	5.866	28.3	97

NOTE: In case of English Measure – Package Wt. = 3 oz. and Winding Speed = 1000 yd/min
In case of Metric Measure – Package Wt. = 85 gram and Winding Speed = 1000 m/min

the supply package be constant at 85 gram in weight (3 oz). Also for simplicity, let the doffing time be neglected.

Table 4.1 shows clearly that the maximum machine efficiency and the maximum number of spindles increase as the yarn gets finer. Conversely, a coarse yarn restricts the number of spindles per knotter to a very low figure and this shows why many coarse yarns are wound on manual machines or those having a knotter for every winding spindle. However, the most important fact that emerges from the calculation is that the maximum number of spindles per knotter, theoretically, should be varied according to the yarn number, but in practice, an existing machine cannot be varied. Thus, automatic winding machines of this type are all limited to a narrow range of yarn numbers.

It will be appreciated that many of the assumptions made in the previous calculation were rather sweeping and it is necessary to qualify them in practice.

Winding speeds vary from machine to machine and the range normally encountered varies from 600 m/min (660 yd/min) to 1200 m/min. While the knotter might take 0·2 min to creel a new package, it also has the duty to patrol and find any broken ends and repair them; consequently the machine efficiency will be reduced from that quoted in Table 4.1. It also follows that the quality of the yarn supplied and the degree of clearing demanded will affect the efficiency.

When the newly wound packages are built up to the desired size, winding stops automatically and there will be a loss in efficiency if there is any delay in doffing. The doffing time itself will decrease the efficiency because it requires a finite time to complete the operation; furthermore, it is unlikely that the waiting time will be negligible. Obviously, the larger the package being produced, the lower will be the loss in machine efficiency due to this cause; however, the size is limited by the requirements of the next process.

If there is a person or mechanical device attending to a particular spindle, then the waiting time could be zero. However, that person or device would work perhaps 10 sec in a doffing cycle which might be as much as an hour and the efficiency of the doffer would only be a fraction of a per cent. Such a situation would be intolerable and it is necessary to balance the work load of the doffer against that of the winding machine to give the best advantage.

In practice, a winding operator may look after some fifty spindles and would have duties other than doffing. These would include *magazine creeling** and watching for malfunctions of the machine. The machine efficiency seldom exceeds 75 per cent.

Let efficiency be defined as

$$\text{Spindle efficiency} = \frac{t}{T} \times \frac{n}{N} \times 100 \text{ per cent}$$

where t = productive winding time of one spindle per patrol of a single knotter (min).

T = total time spent by that knotter in patrolling its section (min).

n = number of productive patrols needed to wind the given mass of yarn.

N = total number of patrols needed to wind the same mass of yarn.

Consider a practical example based on a 30 tex (20s cotton count) yarn being wound from a 85 gram (3 oz) *ring tube* at 1000 m/min (1100 yd/min) on to a package of 1·1 kg (2½ lb). Let the creeling time remain at 0·2 min, and assume that the breakage rate is 4 per kg, the knotting time is negligible, an average of one patrol is lost for each doffing occasion and one half a patrol is lost for every yarn break. The value of t/T will remain the same as quoted in Table 4.1. However, in winding one package, there will be one doff

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*See p. 80

and 1·1 x 4 end breaks; thus the total patrols lost will be $1 + \frac{1}{2}(1 \cdot 1 \times 4) = 3 \cdot 2$. In winding 1·1 kg, there will be $(1 \cdot 1 \times 1000) \div 85 = 12.94$ productive patrols, hence

$$N = 12.94 + 3 \cdot 2 = 16 \cdot 14 \text{ patrols}$$

and

$$\frac{n}{N} = \frac{12.94}{16.14} = 0.802$$

whence the average spindle efficiency

$$= \frac{n}{N} \times \frac{t}{T} \times 100 \text{ per cent}$$

$$= 0 \cdot 802 \times 0 \cdot 94 \times 100 \text{ per cent}$$

$$= 75 \text{ per cent}$$

The actual efficiency of any one spindle will depend upon the incidence of end breaks. For example, if an end break occurs as the knotter is just approaching, no patrol will be lost. On the other hand, if the knotter is just leaving, then a complete patrol will be lost. The efficiencies corresponding to the two extreme cases will be 87 per cent and 66 per cent (the average of these two is *not* 75 per cent). This example illustrates why the overall machine efficiency is not the same as the average spindle efficiency, but the difference is sufficiently small to be ignored in practice.

In machines where there is only one knotter per machine, the knotter may proceed continuously in a loop. Where there is more than one knotter, then it is usual for the knotter to patrol in a reciprocating manner. Where there is one knotter per spindle, no patrols are required but the efficiency is still less than t/T because of doffing.

Automatic Winders with Traveling Spindles

The principle of this type of machine is as follows: the machine winds from *bobbin* to cone or cheese, according to

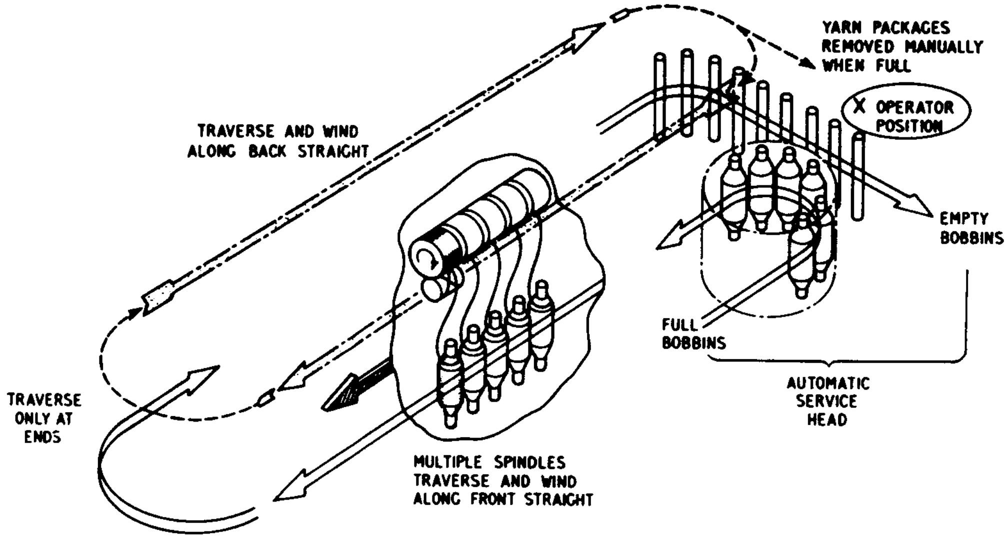

Fig. 4.2. Automatic winder with travelling spindles.

machine supplied. It consists of a number of winding heads that can be attached to and move on an endless chain at a predetermined speed around the machine during the course of which the following operations take place (see Fig. 4.2):

1. The winding head comes up to the magazine and winding stops.
2. The empty bobbin is ejected.
3. The full bobbin is fed in.
4. The threads from the bobbin and the cone are then knotted together and the loose ends cut off.
5. The winding head continues to move forward and commences winding again.
6. During the traverse on the endless chain, the winding head continues to wind and, when it comes to the magazine, the used bobbin is replaced by a full one regardless of whether the original one was completely empty or not.
7. Winding is stopped as the winding heads pass round the ends of the machine because of the difficulties in driving them.

Should a thread break during the journey, the winding ceases until it approaches the magazine, when a new bobbin is fed to the *winding head* and winding is resumed as previously described. If the break occurs at the start of the journey, the rejected creel bobbin will be almost full.

The length of the frame is determined by the amount of yarn to be transferred from the bobbin to the cone. The work is brought to the operator, who is seated at a fixed position.

Since patrol times are fixed, winding speeds have to be varied considerably to deal with the variety of counts, condition and classes of yarn to be wound. The winding speed varies from 450 m/min (490 yd/min) for worsted yarn winding to cone, to 1200 m/min for cotton yarns.

The production of the machine depends upon the rate of spindle movement along the winder. A normal recommendation is that 20 heads/min should pass a single operator.

The production depends on the winding speed, the weight of the supply bobbin and the yarn breakage rate.

The automatic head does the following:

(1) Rejects all ring tubes whether empty or not.
(2) Finds the yarn end on the cone by suction.
(3) Takes the yarn end from ring tube. After dropping into winding position, the two ends are tied together while winding is still discontinued.
(4) Measures the cone size, indicates full cones and permits the continued winding of partially filled cones.

Example

If the machine winds 37 tex (16s cotton count) yarn from 0·1 kg (0·22 lb) ring tubes at 600 m/min (660 yd/min) on to 2 kg (4·4 lb) cones, how many spindles will the machine have, if maximum efficiency is obtained at the maximum knotting rate of 20 per minute? Each spindle is stopped 0·7 min/cycle for serving and passing the frame ends. Also calculate the spindle efficiency for 2·5 end breaks per kilogram. Assume one patrol lost each doffing and each piecing occasion.

Solution

$$\text{Let } L = \text{yarn length} = \frac{1\text{ km}}{37\text{g}} \times 0.1\text{ kg} \times \frac{1000\text{g}}{\text{kg}}$$

$$= 2.7\text{km}$$

i.e., $L = 2700$ meter

R = rate of spindle movement = 20 units/min.

W = winding speed = 600 m/min.

K = constant for units stopped (18 for a typical machine).

Then

$$
\begin{aligned}
U &= \text{number of winding units}\\
&= \frac{(\mathrm{L} \times \mathrm{R})}{\mathrm{W}} + \mathrm{K}\\
&= \frac{(2700 \times 20)}{600} + 18\\
&= 108 \text{ spindles}
\end{aligned}
$$

Running time per ring tube in creel $= \frac{L}{W} = 4.5$ min.

Patrol time = 4·5 + 0·7 = 5·2 min.
For example, consider 5 kg of yarn:

Creeling patrols 5 ÷ 0·1 = 50·0
Piecing patrols 5 × 2·5 = 12·5
Doffing patrols 5 ÷ 2·0 = 2·5
Total = 65·0 patrols

$$\text{Spindle efficiency} = \frac{4.5 \times 50 \times 100}{5.2 \times 65} = 66.6\%$$

Quillers (*Pirn Winders*)

In most of the winding operations previously discussed, the creel packages consist of uncleared small or medium sized packages and the material doffed is wound on large packages from which most faults have been removed. In quill (or pirn) winding, the conditions are rather different. The creel package is nearly always a cone of considerable size which contains cleared yarn; consequently, no clearing system is needed in practice. On the other hand, the package to be doffed has to be small so as to fit in a shuttle. Hence there is a greater need for automation in the doffing operation than the creeling operation; consequently, most quill winding machines do not have automatic creeling systems but do have automatic doffing. There is no clearing system and creeling is fairly infrequent, therefore these machines are not fitted with automatic knotters; in fact, even manual knotting is rare because it is easier to start a new quill. Quillers might be regarded as a collection of single spindle machines on a common frame. The work load of the operator consists of manual creeling and *magazining**.

A further difference between quill winders and other winders is to be found in the package build. The yarn on the quill has to be wound on a long thin package so that it will fit in the shuttle, and the build has to be such as to permit intermittent high-speed over-end unwinding within the confines of the shuttle. This imposes special limitations; for example, it would not be possible to use a fully cross-wound package nor would it be possible to use a completely parallel package. In the one case, the tension variations would be impossibly high and in the other case the package would disintegrate. Hence it is necessary to use a compromise in which there are overlapping short conically cross-wound sections as shown in Fig. 3.16. The length of this section is called the "*chase length*" and the *cone angle* is usually maintained at about 30° because this gives reasonable stability and allows clean unwinding without undue danger of turns *sloughing off*. However, these factors are affected by yarn tension and it is necessary to control the tension during winding within quite close limits, hence it is necessary for these machines to be equipped with suitable tension control devices.

A further very important factor is the unwinding tension created when the quill (pirn) is in use in the loom. If the quill itself is merely cylindrical then there will be a large variation in tension depending on whether yarn is being removed from the tip or the base of the quill and to a lesser extent upon the position along the chase as shown in Fig. 4.3. Because the

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* Magazining means maintaining an adequate number of empty quills in the supply magazine and removing the full ones from the output by the boxload.

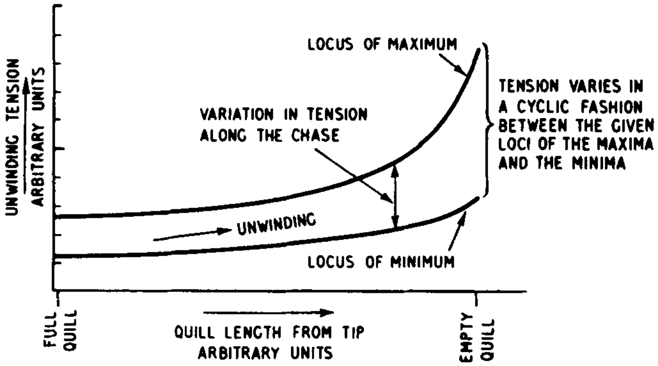


Fig. 4.3. Unwinding tensions from a straight quill.

unwinding takes place in a confined space, the balloon is collapsed and yarn exists as a helix in contact with the bare quill. If this portion of the quill is cylindrical, considerable tension will be generated by frictional contact, whereas if the quill is made conical as shown in Fig. 4.4, then the tension will be reduced. In this case the removal of yarn along the axis reduces the contact forces between the yarn and quill surface; this reduces the frictional drag which in turn reduces the tension. If the conical angle is made sufficiently large, the yarn can be induced to come free of the surface and a

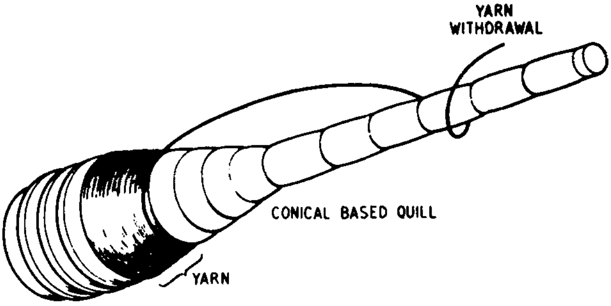


Fig. 4.4. Yarn ballooning from taper reduces tension.

form of balloon is created. Since the frictional drag is dependent on the amount of yarn wrap along the quill and this varies as the quill empties, it is advantageous to just make the yarn balloon out from the surface, thus reducing the variation in tension to a mimimum as shown in Fig. 4.5.

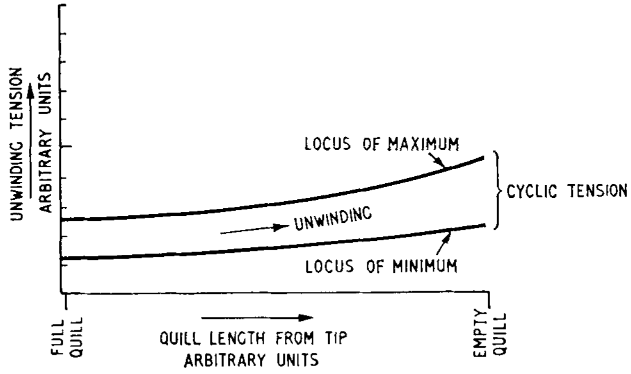


Fig. 4.5. Unwinding tensions from a conically-based quill.

While a tapered quill gives relatively even unwinding tensions, the space occupied by the enlarged base is not used to carry yarn. The economics of weaving are affected by this and it is necessary to compromise between quality as determined by tension and cost as determined by the frequency of quill supply.

In weaving it is desirable to use as much of the filling on the quill as possible and yet it is undesirable completely to exhaust the supply, in order to avoid partial *picks*. For this reason it is usual to wind a so-called "*bunch*" at the base which gives a small reserve of two or three pick lengths. The loom has a *feeler* which detects when the quill is empty. However, the feeler is not capable of detecting when the quill is nearly empty, and with the normal package construction there would be an insufficient reserve when the feeler signals for

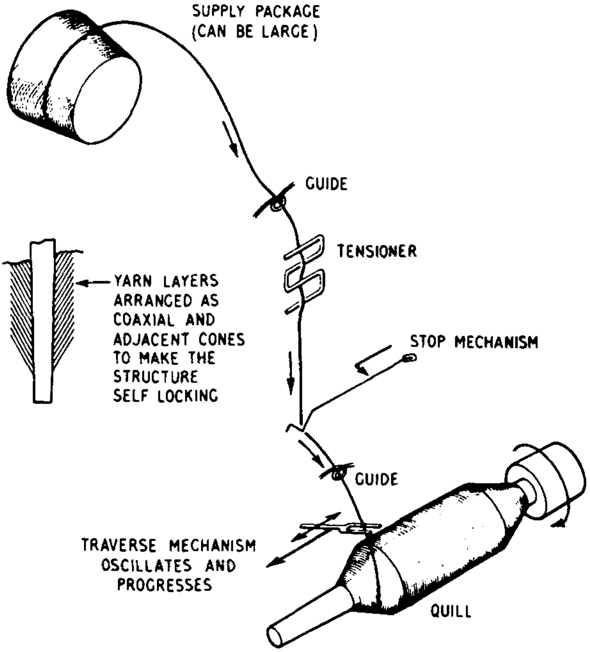


Fig. 4.6. Quill winder.

a change. Consequently, the bunch is wound in a parallel fashion over a short length away from where the feeler operates, so that when the remainder of the quill is exhausted the reserve remains.

In some cases, it is necessary to wind another bunch at the tip to permit a transfer operation in weaving.

Having set out the main requirements of quill winding, it is relevant to consider the machine itself. Fig. 4.6 shows a typical yarn path through a machine and it will be observed that many of the features are common to all winders. There are yarn guides, tension controllers, stop motions, traverse motions, and package drives which are similar to others, but there are some differences due to the particular needs. The main differences are:

(a) The supply package is large and output package is small.
(b) The output is automated and packages are delivered by the boxload.
(c) There is no clearing or knotting.
(d) The traverse has the character of a creeping oscillation in which the package diameter is controlled continuously.
(e) It is necessary to build one or more bunches which have a structure different from that of the remainder of the package.

5

WARPING

Key Words: *ball warping, band warping, contracting-vee reed, creel, duplicated creels, drum warping, headstock, lease bands, leasing rods, magazine creels, multiple-package creels, nose, pattern warping, section warping, single-end creels, stop motion, tension devices, travelling package creel, truck creel, warper's beam, weaver's beam.*

The stages involved in warp preparation are:

(a) Winding from spinner's package to cones.
(b) Winding from cones to warp (i.e. warping).
(c) Application of size and lubricant to warp (i.e. slashing).
(d) Drawing-in or tying-in.

Stage (a) has already been discussed in Chapter 4; stage (b) is considered in the present chapter; stages (c) and (d) are dealt with in subsequent chapters.

Types of Warping

As mentioned earlier, there are two main types of warping,

(a) *Section, or beam warping.*
(b) *Pattern, band or drum warping.*

N.B. The term "section warping" is used in some districts to describe (a) and in others it is used to describe (b).

There is also a third type which must be considered:

(c) *Ball warping.*

General Discussion

A weaver's beam may have up to 10,000 ends and if this were to be produced directly it would be necessary to have up to 10,000 creel packages. Such an arrangement would be very difficult to accommodate and manage; consequently, it is normal practice to produce intermediate or *warper's beams* which may contain up to about 1000 ends and these are combined at the slashing stage. Because of the difficulties involved in combining the ends, patterned warper's beams are seldom produced on the direct system and any pattern that is produced is achieved by combining beams of various colors at the later stage of slashing. As mentioned previously, this imposes limitations which can only be overcome by changing to pattern warping. In the latter case, sections are made sequentially and, because of this, the process is rather slow; it is the practice, therefore, to produce no more than is required to fill a single weaver's beam. The result is that section warping is used mainly for short runs or for complex color patterns.

Because many warper's beams are combined in the direct system, this is usually regarded as a high speed process particularly suitable for single color work. Providing the warper's beams are of a single color, it is possible to combine them to produce simple patterns distributed over the warp width.

Ball warping is an intermediate process for storing yarn for transport, dyeing or reserve; it does not produce a beam. The usual form is a cross-wound cheese in which multiple ends are wound at the same time in a ribbon which contains perhaps fifty or a hundred ends.

In all cases the warping machine consists of a *creel*, a *headstock* and control devices. The details of these vary according to the type of warper and they will be compared on this basis.

Creels

There are three main types of creels (which can be further sub-divided), i.e.

(1) *single end creels,*
(2) *magazine creels,*
(3) *traveling package* or *multiple package creels.*

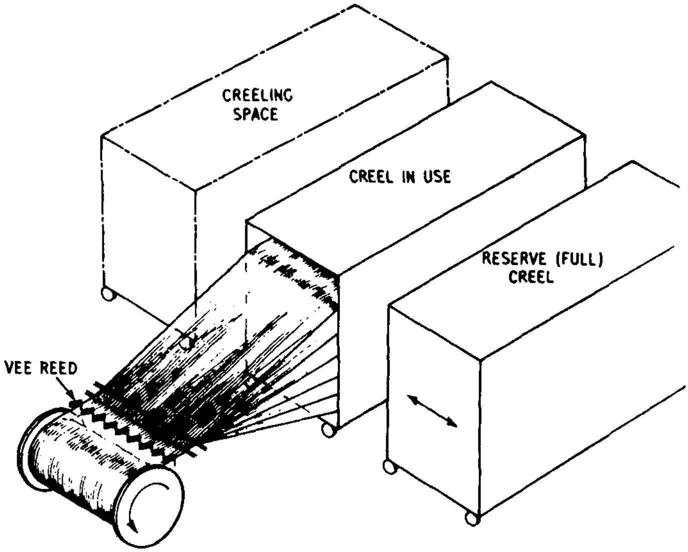
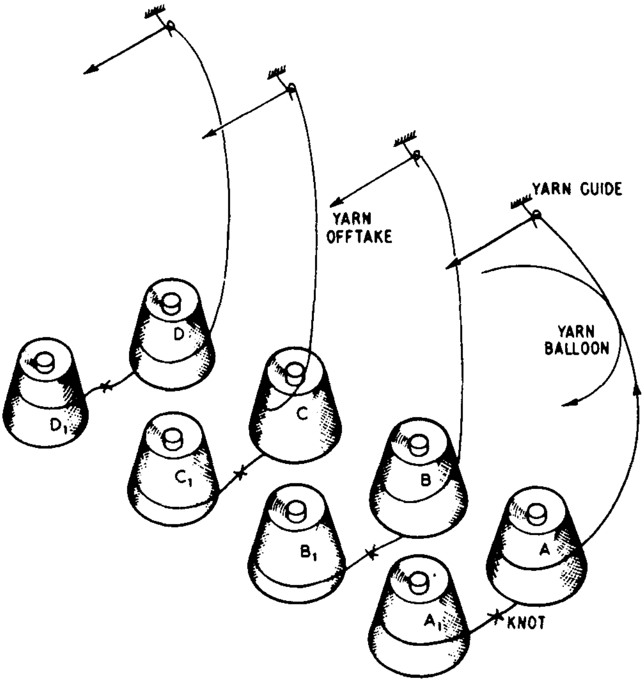


Fig. 5.1. Truck Creels

The so-called single end creel is one in which a single package is associated with each end being wound; this does not necessarily mean that only a single end is wound at any one time. It is usual to make the creel package of such a size as to produce an integral number of beams, and remnants are usually sent for rewinding. Since creeling takes a considerable time, it is essential to make it possible to transfer from one creel to another and this may be done by moving the headstock with respect to some fixed creels or by moving the creels with respect to fixed headstocks. Because of space limitations it is usual, in the case of a movable headstock, to restrict the system to two creels which are known as *duplicated creels.* In the case of the fixed headstock only two creels are used, but an extra space is required into which the exhausted creel can be moved before the full one can be brought into action. This is known as a *truck creel* (see Fig. 5.1).



THE LEADING END OF A₁ IS TIED TO THE TAIL OF A
SIMILARLY FOR B₁ AND B, C₁ AND C ETC.

Fig. 5.2. Magazine creel.

The magazine and traveling package creels are multiple package creels. They are systems in which two or more packages per end are warped. In the case of the magazine creel, two packages per end are used, the tail of the one in use being tied to the leading end of the other one as shown in Fig. 5.2. This permits creeling to proceed while the warping operation continues uninterrupted. The obvious economic advantages of this are offset by the following factors: (1) about 1 per cent of the ends break at the time of transfer from one package to the other, and (2) there cannot be as many ends per creel because of the space taken by the reserve packages. Also, it is desirable to avoid concentrations of knots. In normal practice, the knot is used merely to thread the new packages and efforts are made to prevent knots in the body of the warp.

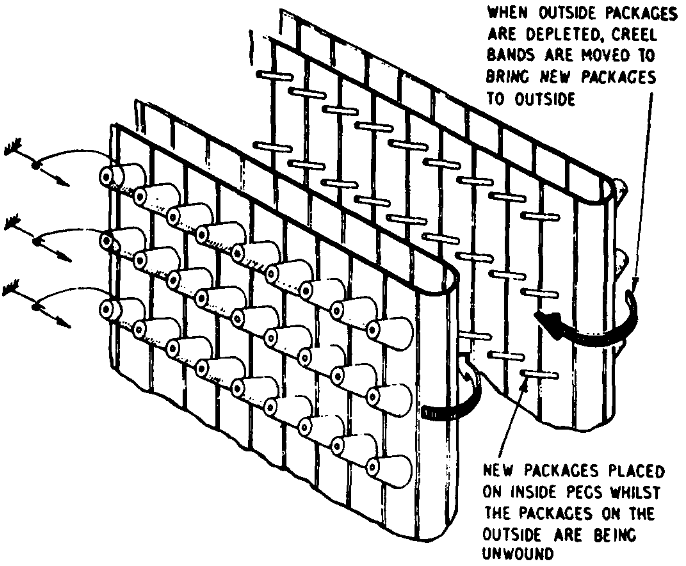


Fig. 5.3. Travelling package creel.

With the traveling package system, the package carriers move in loops so that, while the yarn is being withdrawn from the outside of the loops, the inside carriers may be creeled as shown in Fig. 5.3. At change time, the full packages are moved as a body to the outside of the loop and the newly exhausted packages are moved to the inside ready for replacement. Unfortunately, some threading time is needed at each change over and this reduces the efficiency appreciably.

An assessment of typical comparative performances may be made by considering the efficiency of warping. Assume that in each case the beam has 540 ends of 30 Tex (20s cotton) yarn and a capacity of 250 kg (550 lb). Also assume that the warping speed is 800 m/min (880 yd/min). The creel packages contain 2 kg (4½ lb) of yarn. The end-breakage rate is 0.15 breaks per 100 ends per 1000 meters, and it takes 0.9 min to mend an end break. The calculations are set out on p.91 and summarized in Table 5.1, where it can be seen quite clearly why the magazine and duplicated creel systems are more attractive than the single end system. The difference between the duplicated and magazine creels is not so significant because the relative merits depend on how long it takes to change the headstock in one case and the rate of transfer failures in the other case. Clearly, the assumptions made here are fairly critical and any decision should be made on the facts relevant to the particular cases. Generally, the magazine creel can only deal with a limited number of creel packages and may not be suitable where a large number of ends is required.

Headstock

It is a requirement that the yarn speed should remain reasonably constant throughout the warping operation and there are several ways of achieving this. In the case of section warping, the thickness of yarn built up on the drum is never great, the drum diameter is usually large and therefore there is little error in using a constant speed direct drive to the drum. In the case of direct warping, the error would be unacceptable and the solutions used in winding are adopted. Of these, the surface friction drive is the simplest, but it is also possible to use a variable speed drive to the beam spindle. The latter is usually used with continuous filaments because, at the higher speeds involved, the surface friction can be troublesome and the extra machine cost is not a large proportion of the total.

$$\text{Length of one end} = \frac{300\text{ kg}}{540\text{ end}} \times \frac{1\text{ km}}{30\text{ g}} \times \frac{1000\text{ g}}{\text{kg}} \times \frac{1000\text{m}}{\text{km}}$$

$$= 18{,}500\text{ meters/end}$$

this is the same as the warp length, *i.e.* 18,500 m

TABLE 5.1

Comparison of Warping Efficiencies

Item	*Calculations*	*Type of Creel*		
		Single End	*Duplicated*	*Magazine*
		all figures in minutes unless otherwise stated		
U = running time	18,500 ÷ 500	37·0	37·0	37·0
Repair time	$\frac{18{,}500}{1{,}000} \times \frac{540}{100} \dot{\times} 0{\cdot}3 \times 0{\cdot}9$	27·3	27·3	27·3
Beam doffing	say 5 min	5·0	5·0	5·0
Comb threading	say 15 min/creel (two creels)	7·5	NA	NA
Creeling packages	say 0·1 min/end/beam Creeling time = 540 × 0·1 =	54·0	NA	NA
Headstock change	say 1·5 min/beam	NA	1·5	NA
Transfer failure	say 1% of ends one transfer/2 beams. Time lost = $1 \times \frac{1}{2} \times \frac{540}{100} \times 0{\cdot}9$ = 2·4	NA	NA	2·4
T = total times		130·8	70·8	71·7
η_w = warping efficiency = $\frac{U}{T}$		28.3%	52.3%	51.6%
For 400 end/beam with 25 km warp length on the same basis,				
η_w		39%	60%	60%

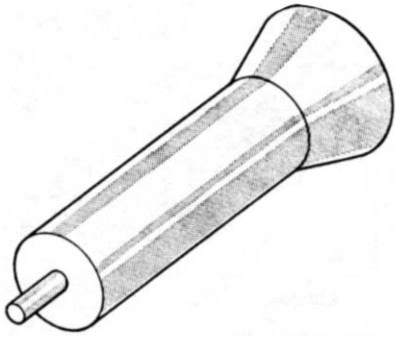


Fig. 5.4. Section warping drum.

The two types of machine require different designs of winding surface. In direct warping, all the yarn can be wound at once and it follows that, in this case, a simple flanged beam will suffice; however, in the case of indirect (or section) warping, the surface onto which the yarn has to be wound must be more complex. The reason lies in package stability. When a direct warp is wound, the edges are supported by the flanges, but when a tape-like section is wound there is no such support; consequently, it is necessary to taper the unsupported edge. In fact it is necessary to build a structure somewhat similar to a cop or quill except that multiple ends are wound rather than single ones. One important difference is that each layer of warp must contain the same number of ends and for this reason it is necessary to make one end of the winding drum tapered as shown in Fig. 5.4. The angle of taper of the conical portion (often referred to as a wedge or conical flange) is a variable, and limiting angles are bounded on the high side by package stability and on the low side by the amount of yarn which can be warped for a given traverse.

It will be noted that modern machines are long traverse low angle machines which give good stability and yet permit sufficient yarn to be warped. Consider the volume of yarn stored, and refer to Fig. 5.5. The radial depth or thickness of warp on the cylinder $= (D - d) \div 2 = x \tan \alpha$.

Let $S > x$ so as to maintain stability

L = axial length of warp on the drum = ΣS

and V = volume stored on drum

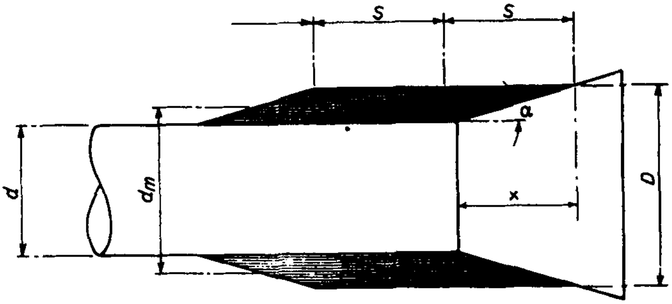
$$V = \frac{\pi}{4}(D^2 - d^2)L$$

$$= \pi\left(\frac{D+d}{2}\right)\left(\frac{D-d}{2}\right)L$$

but $$\frac{D-d}{2} = x \tan\alpha$$

$$\frac{D+d}{2} = d_m = \text{mean diameter}$$

then $$V < (\pi d_m L)(S \tan \alpha)$$



SEE FIG. 5.6 FOR PICTORIAL REPRESENTATION

Fig. 5.5. Section warping

The group $\pi d_m L$ is approximately constant for a given warp, therefore the volume which can be stored may be considered to be proportional to $S \tan \alpha$. In other words, if S is small it is necessary to increase α to get sufficient volume. With large traverse machines, the need to alter α from one operating condition to another tends to vanish;

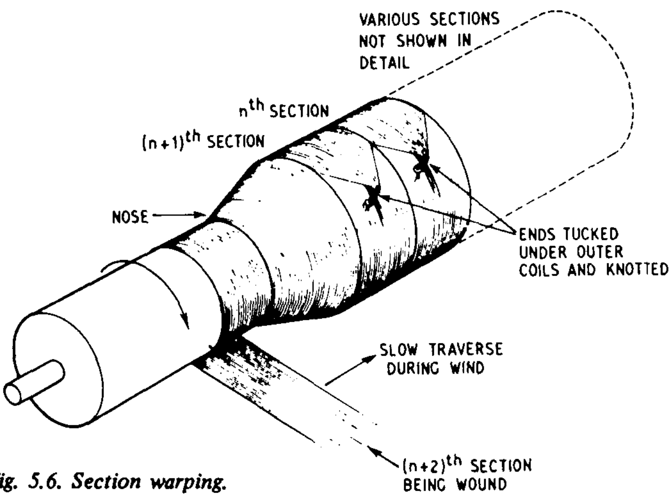


Fig. 5.6. Section warping.

modern design adopts this solution because of the simplification and it is common for such machines to be capable of storing 1000 kg (2200 lb) of yarn on a 1 meter (40 in) diameter drum.

In making the warp, each end of the tape-like section is threaded through *tension devices*, *stop-motion*, *leasing rods* (or reed), *contracting vee reed* and then is led over a measuring roller to the drum. The leading end of the section (which is normally knotted) is then attached to the drum so that the edge of the section lies at the *nose* formed either by the conical portion of the drum or by the previous section, as shown in Fig. 5.6. After an initial few turns, *lease bands* are inserted in a direction parallel to the drum axis in the fashion shown in Fig. 5.7. These lease bands make it possible to identify the correct layers of yarn to be used in unwinding so as to give a continuous sheet of warp across the width of the beam. It is usual to insert about six of these bands, after which the traverse is set in motion so that the build required is obtained. At the end of the build of that section, the tape-like section of yarns is cut, the ends are knotted and the end attached to the drum is fixed by tucking it under a previous layer. The next section is then wound and so on. The measuring roller ensures that the same length of yarn is wound for each section and, since this is important, the machine is normally stopped automatically after the predetermined length is wound.

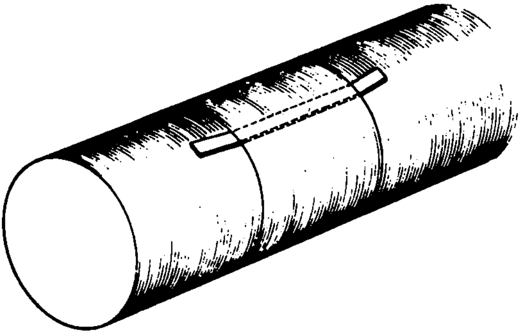


Fig. 5.7. Lease band.

After completion of the warp, it is later wound onto a beam and the lease bands which were originally on the inside now come to the surface; these are very helpful during the subsequent processes. It is possible, however, to have transportable drums for use in subsequent slashing and, in this case, it is necessary to carry out the leasing operation at the end of each section wound instead of at the beginning. The choice between the two systems is determined by the relative costs of an extra wind as against the extra capital tied up in a transportable drum.

Control Systems in Warping

As is usual with most textile operations, it is necessary to control tension such that all ends are as nearly alike as possible. The tensions are not high and it is usually sufficient to apply just enough to prevent the yarn snarling and entangling. Each end has to be controlled, therefore one tension device per end is needed; it is normal for the device to be sited in the creel very near to the package. Also, since many are required and the tension is low, a simple disc type tensioner is usually preferred.

A simple tensioning device is only able to increase the tension and it is necessary to ensure, therefore, that the input level is considerably lower than that ultimately required. In the case of warping, this means that the ballooning of the yarn coming from the creel package must be controlled. It is important that the yarn guides be placed in the correct position with respect to the package and that there is sufficient space between packages. It is helpful to arrange all packages to unwind in the same direction so that the balloons do not interfere and cause entanglements. In high speed warping, the unwinding tensions become somewhat more important and variations caused by the progressive exhaustion of the creel packages should balance as far as possible to maintain similarity between all ends. This is particularly relevant to section warping, where the tension in the last section may be quite different from that in the first.

It is necessary to have a stop motion since a good warp should not contain many broken ends. A drum of perhaps 1 meter (40 in) in diameter or even a simple flanged beam together with its drive will have considerable inertia, especially at high speed, and the stopping time is considerable. Consequently any stop motion must be sited in such a way as to allow sufficient time for any stop to occur before the broken end reaches the headstock. Once an end is allowed to reach that point, there is little or no possibility of repairing it, especially since warping is irreversible. Any attempt to unwind the warp at this stage is likely to lead to entanglement. For these reasons, the stop motions are usually sited as a group near the creel exit, the stop devices are usually electric to give quick response and the machine is always fitted with powerful brakes.

Some designs of warper incorporate a warp storage system which allows a limited amount of warp in transit to the beam to be stored at the time of a break. When a break occurs the fault zone can be retrieved from storage and this enables higher warping speeds to be used.

Normally, the yarn on the creel packages has passed through a clearing operation and no further clearing is required during warping. With some of the new methods of yarn production it is possible to obtain uncleared packages of the correct size and build which, if warped, might give subsequent trouble. Even here, the best solution would appear to be to clear the yarn elsewhere rather than stop the entire warping operation for a single break.

It is most desirable, especially in pattern warping, to control the length of warp wound and a measuring roller is used in combination with a suitable counting device to stop the machine at the appropriate delivered length.

As mentioned earlier, it is desirable to control the surface speed of the warp particularly when a large change in warp diameter is involved. The frictionally operated surface drive needs no further comment but it may be helpful to consider the variable speed spindle drive in a little more detail. In any control-system, it is necessary to measure the parameter to be controlled, hence in this case one would have to measure the yarn velocity or compute it from a measurement of the warp diameter. The latter method is popular, but it will be realized that if the sensing element depresses the surface of the warp to any appreciable extent, then an error will arise. Much electrical equipment has become progressively cheaper over the last few decades and speed measuring control devices might be expected to gain in popularity.

The density of the warp on the beam has to be controlled, depending on whether it is prepared for slashing or dyeing. The density may be controlled by tension, pressure or a combination of both. In the case of frictional drive, an element of pressure control is unavoidable and it is not easy to produce a very soft warp beam because of the pressure needed to drive it. In the case of spindle drive, it is possible to use tension alone, but it is a common practice to use a pressure roller, the pressure of which is often hydraulically controlled.

In warping yarns made from man-made fibers, a considerable degree of static electrification may be produced and some form of elimination is required to avoid yarn entanglements. There are several means of control, viz: (a) chemical fiber finishes, (b) ionization of the air and (c) humidification of the air. The chemical finish introduced by the fiber producer has to be compatible with all the operations and may be insufficient to meet the need at this stage. Consequently, it is usual to apply one of the other methods or a combination of them. Excessive humidification can produce unpleasant working conditions which may affect the labor force and it can cause machine damage by deposition of dew during non-working periods. The hazards of ionization have to be considered, and the expense must be weighed against the savings.

With staple fiber yarns, lint and fly can cause trouble, particularly at the tension control and break detector points. Also, they bring about a deterioration in working conditions. Blowers are frequently used to remove the fly and lint from the creel, but this would be useless unless the air-conditioning system is capable of removing the material from the environment. Preferably, the air-conditioning system should remove the contaminated air from points as near to the source as possible.

6

SLASHING (WARP SIZING)

Key Words:
beam creel, breaker bars, byrometer, clearing, comb crimp, cylinder drying, desizing, direct sizing (slashing), drawing-in, drying section, dusting off, end breakage, exfoliate, fibering-off, clearing, fly, gelatinization, hot-air drying, immersion roller, indirect sizing, lease bands, lease rods, leasing, loom state, mixing beck, penetration (of size), slashing, shed opening, size box, size liquor, size shedding, size take-up, softeners (in size), squeeze roller, tying-in, viscosity, warp sheet, warp sizing, wet finished.

Introduction

The primary purpose of *warp sizing* is to produce a warp which will suffer the least damage in weaving. In some cases it is also used to modify the character of the yarn so as to have an effect on the fabric weight, stiffness or hand, but if this secondary use should interfere with the primary one, then the process has been misapplied. Warp sizing achieves its primary purpose by causing fibers mutually to adhere in such a way as to make the warp yarns stronger, smoother and better lubricated (see p. 36). However it is also important that the sizing materials should not interfere with the processes following weaving. Wherever possible the sizing should aid in these processes and not hinder them. Hence it is necessary to consider not only the way in which size is applied and its effects in weaving, but also the effects on subsequent processes (such as dyeing) and on the resulting fabric.

Although the ultimate aim should be to eliminate all sizing (and other preparatory processes) to achieve minimum cost, this is not at present practicable. Indeed, not only does adequate preparation reduce overall costs by making the weaving operation more efficient, but it is almost impossible to weave most warps found in industry without sizing. Size is often applied to yarns to give them added strength, but even with continuous filaments where the strength is adequate, lack of size may allow slack or broken filaments to protrude from the body of the yarn, especially in the cases of low twist and textured yarns. These protruding yarns can entangle or form fuzz balls and cause end breaks. In general, the higher the twist level, the less the amount of size required. If the twist is exceptionally high, it is possible to weave a warp without size, but the resulting fabric is harsh and unacceptable for most purposes. Acceptable fabrics may be obtained by weaving unsized ply yarns but the cost of plying has to be set against the cost of slashing. Usually slashing is used in preference to plying unless the fabric demands the use of plied yarn. Towels frequently fall into this latter category.

Looking to the future, new yarn structures may modify sizing requirements. Twistless yarns (in which fibers are held together by an adhesive) obviously need little or no further sizing and it is quite possible that any attempt to slash them would cause yarn damage especially if the original adhesive were water soluble. Composite yarns (in which the fibers may be held in position by frictional or chemical forces and in which there are both staple and filament components and perhaps other polymeric material) may need special treatment which could differ quite radically from present experience. Open-end spun yarns (which have a more open structure in the outer sheath of the yarns) require a diluted size liquor. Furthermore, the weaving apparatus is undergoing change; shuttle-looms are giving way to shuttleless looms and the conditions imposed on the warp are altering. The water-jet loom, for example, is a special case in which the filling is inserted by a jet of water, and this obviously introduces sizing problems when a water-soluble size is used.

Water pollution has become a matter of increasing concern in our modern world, and there is mounting pressure to prevent industrial wastes (of which size is one) from contaminating rivers and other waterways. Consideration must be given to the question of recycling the material removed during de-sizing. One possibility is the use of reverse osmosis through membranes to separate the clean water and another is to use non-aqueous solvents in the size, but such solvents are either toxic or flammable and need great care to prevent hazards to the workers. Meanwhile most industrial plants continue to use water-based solvents and the rest of the chapter will be written assuming that water soluble sizes are used.

Warp Breaks During Weaving

A warp end will break when the tension applied is greater than its breaking strength. Failure may be caused either by an increase in tension or by a decrease in strength.

Tension may increase for several reasons; these fall into two categories, viz. :–

(a) Controlled by machine design parameters *or* (to a limited extent) by the setting of the loom.
    Too large a warp shed opening.
    Insufficient tension compensation.
    Heavy beat-up.
    Improper warp let-off.
    Loom settings.
(b) Controlled by operational parameters.
    Passage of knots.
    Entanglement between warp yarns (often caused by slack ends).
    High friction between warp and machine.

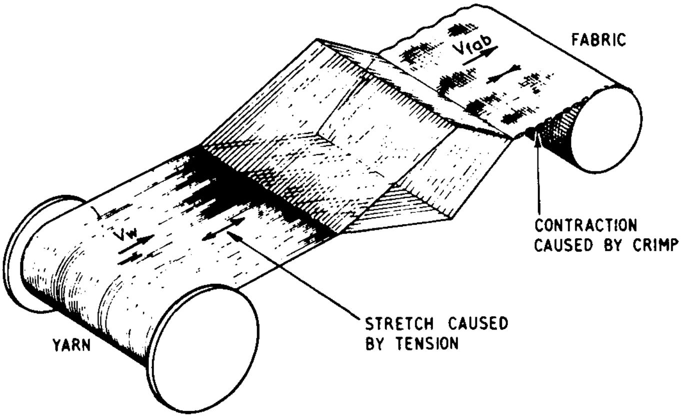


Fig. 6.1. Warpwise length changes during weaving

Nicks, cuts and roughnesses in machine part surfaces in contact with the warp (particularly important with textured yarns).

Decreases in strength of the warp yarn may be caused by the following:

Yarn damage caused by the machine.
Weak places in the yarn supplied.
Uneven distribution of load over all the warp ends.
Inadequate knotting or joining.

Causes of High Tension

Tension levels in a warp may be sub-divided into three components, viz:

(a) Constant mean tension.
(b) Cyclic variations about the mean.
(c) Transient variations which occur randomly.

Constant Mean Tension

The mean tension is determined by: (1) the relative rates of take-up of the cloth and let-off of the warp; (2) the contraction of the warp due to *crimp* created by weaving; and (3) the stretch of the warp due to the tension (Fig. 6.1). With proper setting, high mean tensions are rarely the cause of high *end breakage rates* and the topic need not be further discussed at this point.

Cyclic Variations About the Mean

The principal cyclic variations in tension are caused by the shedding and beat-up. The *shed opening* has to be sufficient to allow the shuttle to pass; also, the shed must be changed periodically to give the desired weave, which means that the path of the warp end through the shedding zone changes in length. Without compensation, this would lead to large variations in tension. Tension compensation devices are commonly used to reduce tension variation but, because of dynamic effects, it is not possible to eliminate the variations entirely. The cyclic variations due to beat-up tend to consist of sudden pulses and the magnitude of the pulses is a function of the cloth structure. A dense fabric gives a much higher amplitude of pulse at beat-up than a more open fabric. The point of highest tension in the cycle (which might be at shedding or beat-up) is the point in time where a weak yarn is most likely to break and where yarn damage is most likely.

Transient Variations Which Occur Randomly.

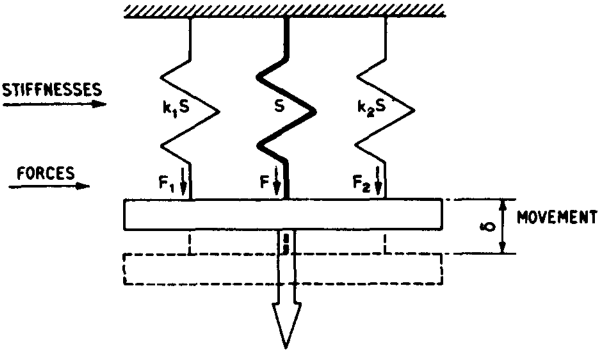
The randomly occurring transient tension peaks are the most important of all, being frequently the cause of breaks. For example, a large badly-shaped knot may be unable to pass through the reed (or heddle eye) producing a very high tension peak in that particular yarn, which may break even though it has no weak spot. Of course, the conjunction of such a knot with a weak spot almost certainly leads to an end break. Similarly, entanglements of (a) fibers or broken filaments protruding from yarns, (b) the yarns themselves, or (c) knot tails may give similar results except that in some of these cases several adjacent ends are likely to be involved.

Relative movement and pressure between the warp yarns and the various parts of the loom lead to tension build-ups along the warp yarn. The relative movement is not unidirectional and in places there is a sort of chafing action superimposed on the general movement from the beam to the cloth roll. The tension build-up at the rubbing point depends upon the direction of movement, the coefficient of friction, the mean tension in the yarn as well as the geometry of the contact between the yarn and machine part. This is somewhat complex but it is important to understand the phenomenon at least qualitatively. If these tensions are allowed to become large, as they can be, then the end-breakage rate would become totally unacceptable. In marginal cases, the difficulty is ameliorated by the application of lubricant whereas a more complete understanding might have eliminated the problem.

Causes of Low Yarn Strength

The chafing mentioned earlier may damage the yarn; fibers may be torn from the yarn, disrupting its internal structure and weakening the yarn more than might have been expected from the removal of a single fiber. Other fibers may be cut or damaged, especially on the yarn surface, and this further weakens the yarn and adds to the problem of generation of *fly* which can accumulate and create a fire hazard or can collect in clumps on the yarn and create faults. High peaks in tension tend to cause permanent elongation which usually reduces yarn strength and increases local stiffness. Since a yarn of greater than average stiffness takes more than its fair share of the load, it has an increased tendency to break. Clearly, such overstraining of the warp is to be avoided.

Obviously a yarn with many weak places will give many end-breaks and it is desirable for the yarn strength and



ΣF = TOTAL APPLIED LOAD

$$F_1 = (k_1S)\,\delta$$
$$F_2 = (k_2S)\,\delta$$
$$F = S\,\delta$$
$$\text{TOTAL LOAD} = \Sigma F = F_1 + F_2 + F = (k_1 + k_2 + 1)\,S\delta$$
$$\frac{F}{\Sigma F} = \frac{1}{(k_1 + k_2 + 1)}$$

If k_1 and k_2 are small, central member takes a large share of the load
If k_1 and k_2 are large, central member takes only a small share of the load
i.e. load acting on a given member depends upon the associated system

Fig. 6.2. Redundant structures

linear density to be as uniform as possible; indeed, this is one of the main reasons for *clearing* warp yarn to remove thick and thin (or weak) spots from the yarn.

Yarn stiffness is an important factor. Consider three springs as shown in Fig. 6.2. The two outer springs have a lower stiffness than the center spring, which is seen to take a large share of the load. The model may be regarded as a simplified version of a warp, in which the warp yarns are represented by the springs. Consequently, the relative stiffnesses of the warp ends are important. For example, with a striped warp in which the tensile stiffness of the yarns forming one stripe is higher than the rest, the yarns in that one stripe will suffer higher tensions than the rest and this could lead to excessive end breaks in that stripe. Similarly with single warp ends. Uneven sizing can affect the yarn stiffness and this in turn can affect the end breakage rate and distribution.

In normal operation the extension is fixed by the machine and the stiffness of the yarns will affect the tensions generated. With very stiff yarns, such as glass or improperly sized yarns, small variations in the extension can increase end-breakage rates. Deflections in the loom itself may cause bad distribution of load among the ends, sufficient to present problems in the case of very stiff yarns. Such variations might be of little significance, however, in the case of more extensible yarns in which the variations are offset by the stretching of the yarns during weaving. After weaving has been in operation for some time, tension differences due to local effects (including local stiffnesses, repaired ends, slackness, etc.,) tend to disappear or "weave out".

TABLE 6.1.

Ingredients For Water Based Sizes

Adhesives	*Lubricants*	*Additives*
Potato starch	Mineral waxes	Salicylic acid
Starch from cereals (corn, wheat, rice, etc.)	Vegetable waxes	Zinc chloride
	Animal fats	Phenol
Carboxy methyl cellulose (CMC)	Mineral oils	Emulsifiers
Polyvinyl alcohol (PVA)	Vegetable oils	
Polyvinyl chloride (PVC)		

TYPICAL SIZE RECIPES

STARCH	KG LB			45	100								
STARCH GUM	KG LB									45	100		
PVA	KG LB	23	50							9	20		
CMC	KG LB					20	45	9	20				
ACRYLIC BINDER	KG LB					2	5			4.5	10	136	300
FAT	KG LB			3	6								
WAX	KG LB	1	2.5	0.5	1	1	2.5			1	2.5		
VOLUME AT FINISH	LITER GALLON	378	100	378	100	378	100	378	100	378	100	378	100
TAKE-UP	%	8	8	12 to 14	12 to 14	8	8	3	3	12 to 14	12 to 14		
NOTE: To use table, select any one column according to fiber and system of units	UNITS	POLYESTER COTTON		COTTON		SYNTHETIC COTTON		SPUN RAYON		NYLON COTTON		FILAMENT	

Table 6.2

Size Ingredients

A warp yarn should be strong, elastic, extensible and smooth. The ingredients used in sizing are usually starches, gums or synthetic adhesives and fatty or oily substances (to act as lubricants and plasticisers or softeners). The two types of ingredient tend to have opposing effects on the yarn and a compromise has to be made to yield the lowest end-breakage rate for the given yarn under the given conditions. With some synthetic sizes, particularly those used for textured yarns, it is not necessary to add an additional lubricant and in those cases it might even be harmful to do so. In many instances, antiseptics, anti-mildew agents etc., might be added to the recipe. Typical ingredients for water based liquors are shown in Table 6.1.

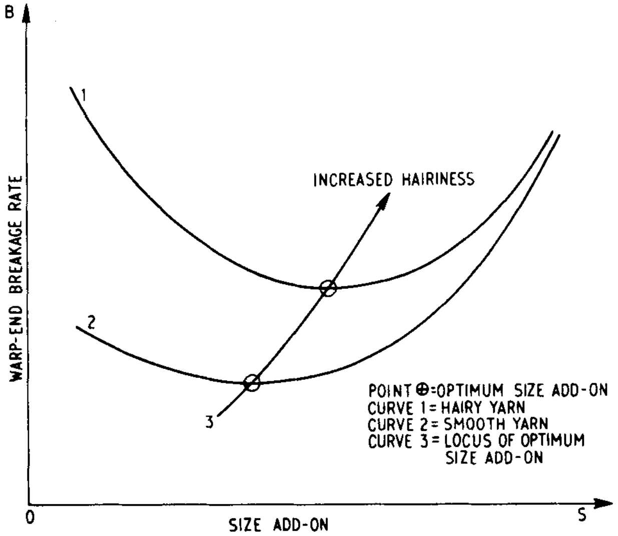
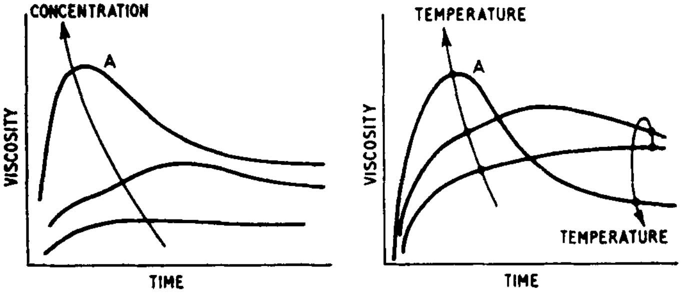


Fig. 6.3 (a). Typical B-S curves.



NOTE: THE ADDITION OF SOFTENERS TENDS TO REDUCE THE CHARACTERISTIC VISCOSITY PEAK SHOWN AT A IN EACH CURVE

Fig. 6.3 (b). Typical size cooking curves

It is possible that non-aqueous liquors will be used in the future, but as yet there is little experience in this area. Consequently, only aqueous solutions are considered and typical recipes are given in Table 6.2.

The adhesive, usually in granular form, is mixed with water and heated to form a paste which ultimately becomes a viscous fluid. Starch is a complex carbohydrate which combines with water; this causes the material to swell and change character. The *viscosity* of the boiled starch is controlled to a great extent by the amount to which the surface of the granule is dissolved. This in turn is affected by the recipe, the degree of mechanical mixing, the temperature and time of boiling. Typical viscosity curves are shown in Fig. 6.3. It will be seen that under certain conditions prolonged boiling will cause a decline in the viscosity. Similar effects can be obtained by over-vigorous mechanical working. In both cases, this is caused by breakage of the fairly weak hydrogen bonds formed during the gelatinizing phase. The viscosity is one of the important factors influencing the amount of size picked up by the yarn.

Other sizes behave in a somewhat similar manner and the temperature of the size liquor and the time factor both affect the viscosity with similar effects on the ultimate size add-on.

Lubricants, soaps, and waxes are commonly used as *softeners*. Without such softeners in certain sizes, the yarns would not be sufficiently extensible; the size would crack and particles would drop away from the yarn (i.e., *exfoliate* or *dust off*) and this in turn would create local stress concentrations which would encourage end-breakage.

The most important factors in choosing size ingredients are:

(a) The recipe should be that which gives fewest end breaks.
(b) It should be that which gives the least exfoliation.
(c) It should be that which permits easy *de-sizing*.
(d) It should give good fabric characteristics.

(e) It should be compatible with the machinery (*e.g.*, it should not cause size build-ups during weaving or blockages during slashing).
(f) It should not cause any health hazard.
(g) It should not cause any degradation of the textile material.
(h) The cost of sizing plus the cost of weaving and finishing should be a minimum.

Lubricants or Softeners

Tallow

This lubricant is the fat of beef or mutton, or a mixture of the two. The weight of tallow used in a size based on sago flour as the adhesive is up to 10% of the oven dry weight of the starch (sago). In many cases tallow substitutes are used to reduce the cost of sizing.

Soap

This lubricant is used with many sizes as a softener but it is not used alone. It is often mixed with tallow before introducing to the size in the *mixing beck*.

Japan Wax

This softener is popular in the U.S.A. It melts at 50°C (122°F). If adulterated with paraffin wax, it is difficult to remove in finishing.

Factors which Affect the Properties of Sized Yarn

The most important factors affecting the properties of the warp yarn after sizing are:

(1) Lubricant added to fiber or filament prior to slashing (i.e., *fiber finish* or *coning oil*).
(2) Lubricant added to the adhesive as part of the size recipe.

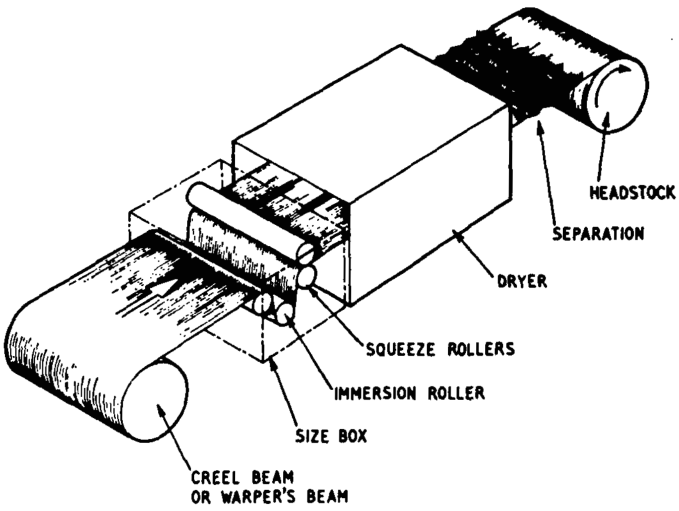


Fig. 6.4. Warp Sizing (Simplified)

(3) Adhesive type.
(4) Recipe (i.e., percentage adhesive, percentage lubricant, etc.).
(5) Size add-on (the amount of size put on the yarn).
(6) Technique of sizing.
(7) Operational conditions such as yarn speed, temperature of drying, yarn tension etc.,
(8) Weave room relative humidity.

Man-made fibers usually have some sort of fiber finish to act as a lubricant during fiber and yarn manipulation and to reduce static electrification of the fiber. Common natural fibers, (unless scoured), have a fatty or waxy coating. In some cases, extra lubricant is added to the fiber or yarn during yarn manufacture (such as coning oil). Such oils and additives may plasticize the polymer used as size and, if

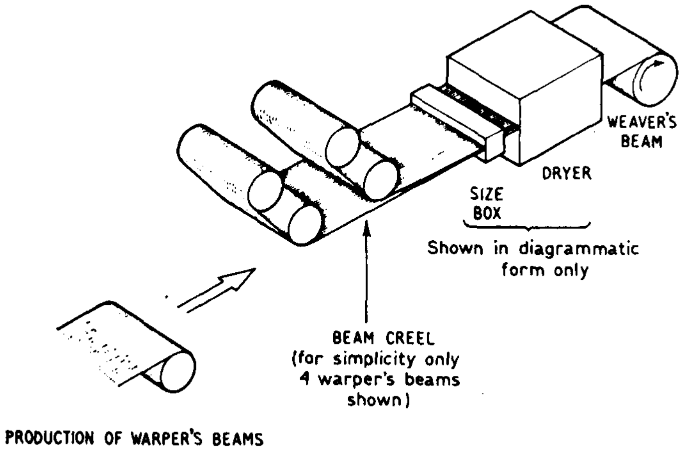


Fig. 6.5. Use of Section Beams

such plasticization is excessive, the material will become tacky to the point of being unusable. Furthermore the oils or additives may adversely affect adhesion between the size and the fiber and thus the additives must be compatible with the size recipe. Also, the percentage lubricant on the yarn prior to slashing must be minimised, just sufficient lubricant being needed for the prior processes. A typical maximum percentage at this stage is 1%. The total lubricant percentage will determine adhesion and toughness of the size, and the size recipe may have to be varied to take into account the lubricant already on the yarn. For example, if one were to attempt to use a knitting yarn for a warp, it might be found that the yarn oil level is high for weaving purposes. It might be necessary to reduce the lubricant in the size or it might even be impossible to slash the yarn satisfactorily because of too high an oil level.

For spun yarns there is a wide choice between the various sizes, such as starch, PVA, CMC, etc., and the choice is commonly determined by cost. For filament yarns the

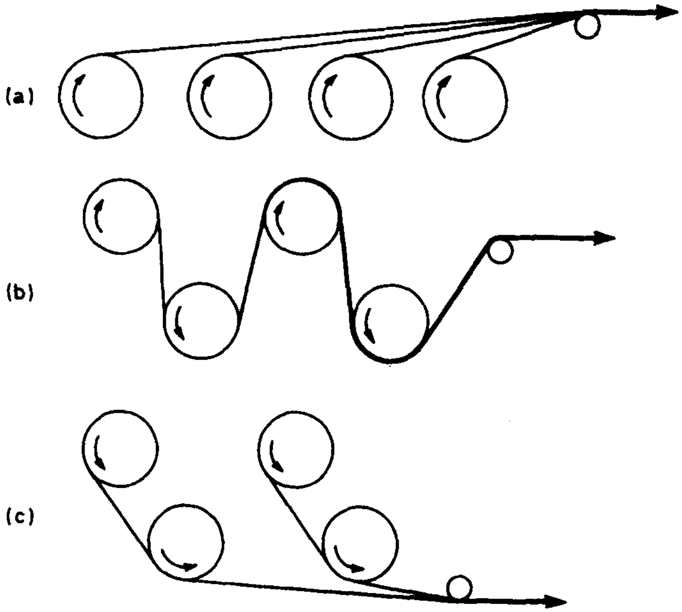


Fig. 6.5(a) Beam creel arrangements
Note: For simplicity, only four warper's beams are shown in each arrangement. Normally there are more.

choice is not so wide because compatibility between fiber and size becomes more important. For example, with nylon, polyacrylic acid is frequently preferred because of the adhesion properties, whereas with polyester, acrylate sizes are usual. In this latter case, care must be taken in respect of plasticization from either the lubricants or the moisture in the air. In other words, the weave-room relative humidity is important and it may be necessary to vary the size formulation according to the weave room conditions expected.

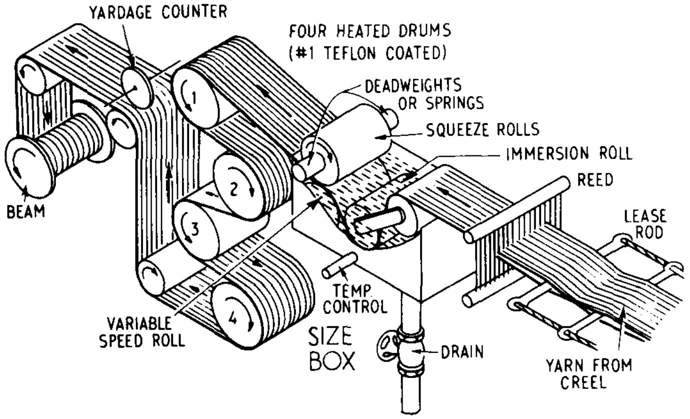


Fig. 6.6. 'Single-end' slashing (creel not shown).

The amount of size add-on depends on yarn structure and size recipe, thus there are significant differences between the requirements for flat filaments, textured and spun yarns. Also, the roles of bulk, hairiness and twist levels vary according to the type of yarn. One major function of slashing is to control the surface of the yarn; in general, the more size add-on, the smoother the yarn, and a smooth yarn will weave better than a hairy or non-smooth one; thus one might expect a curve such as (1) in Fig. 6.3(a) to indicate performance. As the size add-on is increased the yarn becomes stiffer, less extensible and more difficult to weave. At low add-on, the yarn is more likely to break because of lack of strength and increased hairiness. The net result is that there is an optimum add-on level at which there is a minimum end-breakage rate and the best add-on level varies according to the smoothness of the yarn.

Warp sizing techniques and the operational requirements are discussed in the following sections.

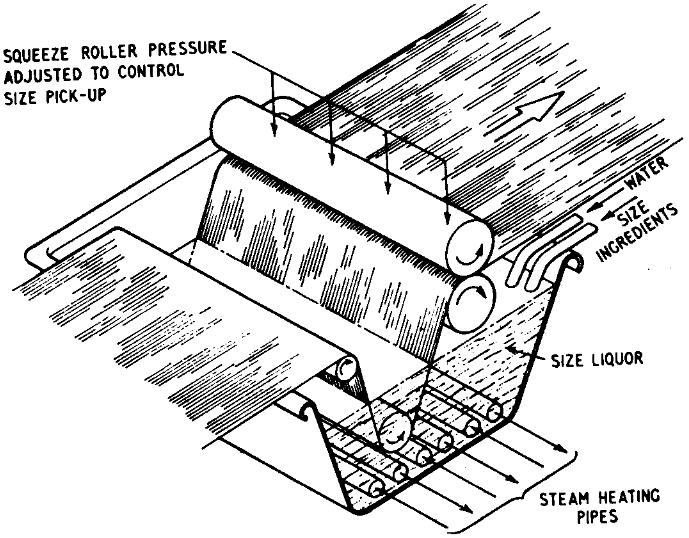


Fig. 6.7. Section of a size box

Warp Sizing Techniques and Operational Conditions

Sizing or slashing machines can be classified according to the method of drying as follows:-

(1) *Cylinder drying.*
  (a) *Two cylinder types.*
  (b) *Multi-cylinder types.*
(2) *Hot air drying.*
(3) *Infra-red drying.*
(4) *Combined systems.*

Machines may be further classified according to the method of yarn supply, *i.e.*, direct (Fig. 6.4), indirect (Fig. 6.5) or "single-end" (Fig. 6.6) slashing. Unfortunately the term 'single end' is also used to describe a machine in which only one yarn end is sized rather than a sheet of yarns from a beam or creel as discussed above. In the single-end slashing referred to in the present context, yarns are taken from a creel rather than from a beam; this is a particularly valuable technique for slashing textured yarns, since individual yarns can be controlled separately especially in the matter of tension. The direct and indirect methods are used frequently for spun yarns, although it is possible to slash textured yarns also if proper care is taken. In both the direct and indirect systems, beams are used to supply a sheet of yarn to the size box and in the indirect case a *beam creel* (not to be confused with the creel in single-end slashing) is used and there are several possible beam arrangements (Fig. 6.5(a)). Negative let-off is normally used because of its simplicity, but occasionally the beams are directly driven and controlled to give constant warp tension.

The *size box* is used to apply the *size liquor* to the yarn (Fig. 6.7). The warp sheet is guided through the solution by means of the *immersion roller*, and then passed through the *squeeze rollers* where the yarns are pressed to maintain the desired percentage of size material on the yarns. The size-box temperature is usually maintained by means of steam pipes and the steam flow is regulated to control the temperature. It is also necessary to control the level of the solution in the size box as well as the concentration of size. The latter is controlled by a byrometer which measures the density of the solution and controls the relative supply rates of the various ingredients. The density and concentration are related and the byrometer is thus an effective control device, but it must be realised that the squeeze rollers also play an important part. The bottom squeeze rollers are usually made of stainless steel and the top ones are usually covered with felt or rubber. The hardness of the top roller is an important variable; furthermore, it is a variable which can change with time as the covering hardens with use. The roller hardness is usually measured in terms of the Shore hardness and should be checked from time to time. Variations in roller hardness and weighting alter the pressure acting on the yarns in the squeeze zone and will cause variations in size add-on. In some cases more than one pair of rollers are used and this is said to improve control.

The *drying section* determines the maximum throughput rate. It is required to dry the wet sized yarn rapidly, thoroughly and uniformly. A simple two-cylinder machine is too slow as it is difficult to get a sufficiently high heat transfer rate. By introducing more cylinders, more drying surface is made available and the contact time for a given yarn speed is increased.

On a multi-cylinder machine, it is possible to control accurately the drying temperature cycle to which a given element of yarn is subjected. In practice, it is found desirable to increase the temperature during the first phases of drying and to decrease it during the last phases, but too high a temperature causes too deep a size penetration. A typical range of temperatures used is from 80 – 105°C (180 – 220°F). In the case of filament yarns, and textured yarns in particular, it is desirable to have the last cylinder unheated to enable the yarn to cool sufficiently to make the size less plastic before splitting. In the case of staple yarns using starch, CMC or PVA etc., there is less need to so reduce the temperature and the last cylinder is commonly heated to raise the overall evaporation rate and increase speed.

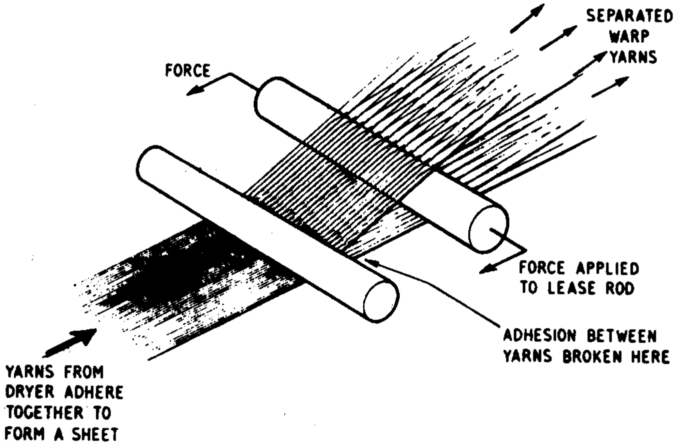
In cylinder machines it is possible to assess the evaporation rate in terms of the mass of water evaporated per unit time per unit area of contact between warp and drying cylinder. A typical figure for a modern machine is about 12 kg/hr/m^2 (2¼ lb/hr/ft^2).

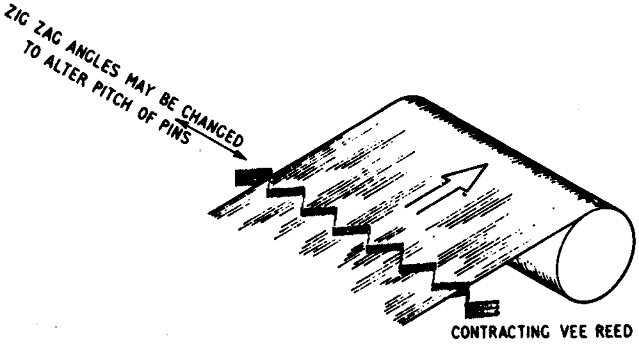
A disadvantage with the multi-cylinder machine is that the yarn leaves the first rollers in a wet condition. The consequent adhesion between yarn and roller can be overcome by using a Teflon coating but this increases the cost of the machine. Most modern machines use this technique and are capable of working at some 120 m/min (400 ft/min). If the yarn leaving the last cylinder is completely dry, it is probable that it will be flattened by contact with the cylinder. Also, overcrowding of yarns on the cylinder surface can cause changes in the yarn cross-sectional shape and in either case the shape changes are likely to cause a streakiness in the final fabrics. This is especially so for textured yarns. Furthermore, if complete drying is achieved, higher tensions will have to be used for separation and this can cause considerable stretch; this especially critical with textured yarns, and undue stretch will produce so-called ‘shiners’ in the fabric caused by the different reflective capabilities of an overstretched textured yarn. To overcome these problems, pre-dryers are often used between the size-box and the first cylinder. The yarn is separated in the wet state and is partially dried by hot-air or infra-red heating. This tends to make it more nearly possible to retain the uniform and round yarn cross-section desired.

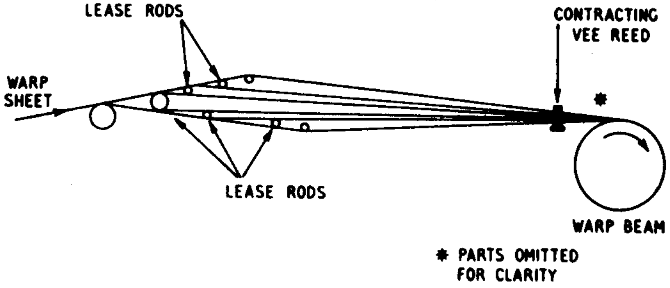
When hot-air drying is used it is difficult to obtain adequate heat transfer without unduly extending the distances between the cylinders. If the distance is too great, entanglement and involuntary stretching may be increased and there are difficulties in threading and piecing. For this reason, a combined system is often used in which the rollers are heated. In either case, it is necessary to use an air temperature of the order of 150°C (300°F) and it is essential, therefore, that the temperature should be reduced automatically if the machine should stop. This ensures that there can be access to the drying section (to piece broken ends) and prevents local over-drying which could lead to local brittleness and to the probability of end breakages during weaving. Air drying is usually more expensive than cylinder drying, but in the form of a combined system it can lead to an increased throughput.

In order to prevent adhesion between the yarns, it is necessary to separate each sized end from the others before

Fig. 6.8. (Opposite). Typical leasing system (not to scale)


SEPARATED WARP YARNS
FORCE
FORCE APPLIED TO LEASE ROD
ADHESION BETWEEN YARNS BROKEN HERE
YARNS FROM DRYER ADHERE TOGETHER TO FORM A SHEET


ZIG ZAG ANGLES MAY BE CHANGED TO ALTER PITCH OF PINS
CONTRACTING VEE REED


LEASE RODS
CONTRACTING VEE REED
WARP SHEET
*
LEASE RODS
WARP BEAM
* PARTS OMITTED FOR CLARITY

the warp can be used for weaving. To separate the ends, the outgoing sheet is divided into two sections. These are then further divided, usually in such a way as to give a pattern similar to that used in combining the sheets on the ingoing side of the machine. This maintains strict order which facilitates rapid *drawing-in* and the finding of broken ends. It also permits the *leasing* of the completed warp (the placing of *lease bands* or tapes across the width of the last layers of warp). Leasing facilitates the subsequent drawing-in or *tying-in* operations. *Lease rods* or *breaker bars* (Fig. 6.8) are used to divide the main sheet as described. A single *comb* is used to maintain the division of the sheets into separate ends and to position them for winding on to the beam. The comb is usually an expanding one which enables the number of ends per unit width to be controlled.

Energy has to be expended in dividing the yarns and the yarns become heated in the process. Separation of the splitting zones allows heat generated by the division process to disperse. It is common practice to cool the yarns in this zone by means of an air stream. If such measures were not taken, the temperature of the yarn might increase to the point at which the yarn could suffer damage.

Mechanism of Size Take-up

The size liquor is viscous and does not penetrate the yarn structure very quickly. In a production machine the time is limited and there would be difficulty in causing even a low viscosity size to penetrate to the core of the yarn without squeeze rollers. In any case, it would be undesirable for the size to penetrate completely because the yarn would be very stiff and unmanageable. On the other hand, it would be equally undesirable for the size merely to coat the yarn because the size would tend to crack, chip or peel off, especially when the yarn was bent or twisted. Thus whilst the coating initially would serve the purpose of producing a smooth yarn, it might not yield a smooth surface after the yarn had been worked. Also, for the yarn to have added strength, some size penetration is needed.

Lubrication is another factor, because lubricant can exist at the surface or exist inside the structure and later work itself to the surface as the yarn rubs over a friction surface. It is also possible to *overwax* (put a coating of wax over the already slashed yarn) but care must be taken to avoid over plasticisation of the size and the generation of wax build-ups during weaving.

The degree of size penetration determines the stiffness for a given yarn bearing a given size. If some fibers are free to move relative to one another the stiffness will be reduced and so will the tendency for the size to crack. Consequently, the sizing machine has an adjustable squeeze roller to control the size penetration, (Fig. 6.7) but, as was mentioned earlier, the roller hardness and size viscosity and type all affect the issue. The size penetration also depends on the yarn structure, as does the stiffness generated by a given percentage size add-on. There is a considerable art in optimising all the various factors to give a satisfactory warp which will weave well under the prevailing circumstances.

With novel yarn structures, such as those likely to be encountered as new spinning methods develop, it will be necessary to alter the size viscosity, squeeze roller pressure and machine speed to meet particular requirements. For instance, with open-end spun yarns, it is desirable to reduce the size concentration in the liquor to about 85 per cent of that normally used and to avoid excessive tension during the process. The reason for this is that the fibers in the outer layers of the yarn are less densely packed than in the core, and excessive strain tends to break fibers in vital areas where the load is concentrated within the yarn. It is impossible to foresee the requirements for types of yarn, but an understanding of the sizing process and the principles of sizing will enable these requirements to be worked out.

The chart in Fig. 6.9 shows the chief factors which, in ordinary sizing practice, can affect the percentage size put on the yarn. This percentage depends initially on the

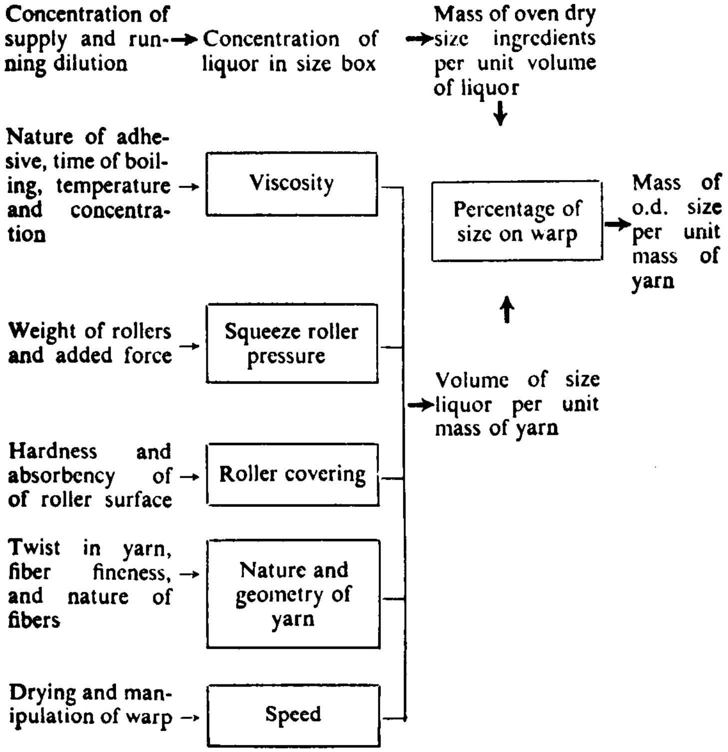


Fig. 6.9.

concentration of sizing liquor and the amount taken up. These quantities depend, in turn, upon other factors.

As viscosity increases with concentration, an increase in concentration causes more than a proportionate increase in the percentage of size applied to the warp for the usual type of take-up. A change in concentration from 6 to 8 per cent could bring about an increase in the percentage of size applied from about 8 to 16 per cent.

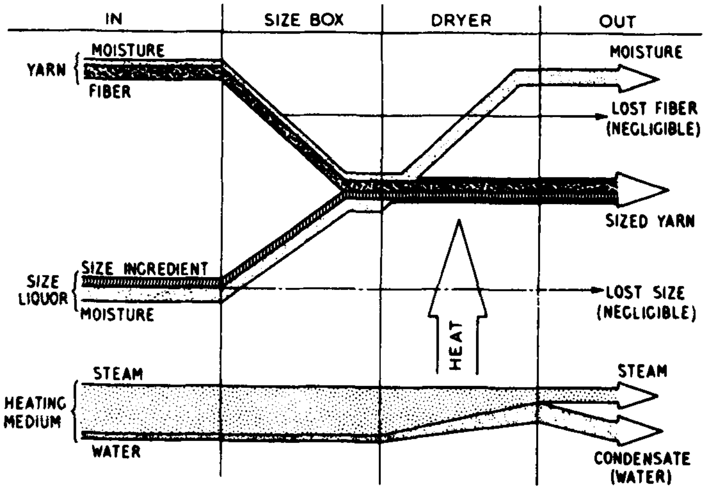


Fig. 6.10. Heat and mass transfer in sizing. N.B. The flow of air has been ignored to simplify the diagram

Automatic Control of Size Application

The basic principle of the technique of automatic size regulation is that, at equilibrium, the substances entering the size box must leave at the same rate, so that there is no gradual accumulation or depletion in the system (i.e., mass flow is conserved).

For full control it is necessary to maintain equilibrium and this implies that:

(1) Mass flow must be conserved for all ingredients severally and totally.
(2) Levels must remain constant at equilibrium values.
(3) Temperatures must remain constant in respect of time and position across the width of the machine.

There is little difficulty in maintaining levels and temperature, but control of the mass flow of ingredients can present problems. There is no reliable method of measuring continuously and immediately the percentage of size on the warp as it leaves a sizing machine. The control of size application by instrumentation has so far been based on the measurement of viscosity and size concentration; these two quantities must be measured simultaneously. Although such measurements have been carried out successfully under research conditions, it has been difficult to apply them in commercial practice. The system of measurement is essentially an open loop which relies upon a calculated relationship and this is usually satisfactory once the proper coefficient has been determined and proved. It is somewhat difficult to predict this coefficient, especially in the case of unusual yarn structures.

The flow diagram in Fig. 6.10 shows that there is both heat and mass transfer in the process. In particular, adequate heat transfer is essential in the drying section and the heat transfer surfaces must be kept clean.

Man Made Fibers

Most synthetic fibers have poor moisture absorption characteristics, as shown in Table 6.3. Sizing materials must have high adhesive power and, in general, the requirements of man-made fibers are different from those of natural fibers. Nevertheless, some sizing materials are suitable for both types of fiber. For example, CMC is suitable for many synthetic fibers and can also be used for cotton, wool and cellulosic fibers. For a given fabric construction, the amount of size on the warp has to be increased if synthetic fibers are used, and a lubricant is essential.

Some man-made fibers (such as rayon) are relatively weak in the wet state. Also, most man-made fibers are highly extensible, especially at high temperatures. Therefore tension and temperature controls are very important in slashing such yarns. Static electricity is also a major

TYPICAL FIBER CHARACTERISTICS

FIBER	GLASS	POLYESTER	COTTON	NYLON	MODACRYLIC	ACRYLIC	VISCOSE
TENACITY mN/tex	840	300-800	300	500-800	200-380	180-370	550
(gf/tex)	(85)	(30-81)	(30)	(51-81)	(20-39)	(18-38)	(56)
(gpd.)	(9.5)	(3.4-9.1)	(3.4)	(5.7-9.1)	(2.3-4.3)	(2.0-4.2)	(6.2)
ELONGATION AT BREAK %	4	15-40	8	18-45	30-40	20-55	11
MOISTURE REGAIN %	neglig	0.4	7	4.5	0.4-4.0	1-2.5	11.0

TABLE 6.3

problem. In most cases static eliminators must be used after the yarn has been dried; the eliminator is usually situated at the headstock just before the beam.

7

DRAWING-IN AND TYING-IN

Key Words: *dent, denting plan, drawer-in, drawing-in, drawing-in draft, drop wires, heddles, pattern chain, pointed draft, reacher-in, reed plan, skip draft, straight draft, tying-in, warp stop motion.*

During slashing the exact number of warp yarns required in the fabric is wound onto the loom (or weaver's) beam. The warp ends are then passed through the *drop wires* of the *warp stop motion*, the *heddles* of the harness frames and the *dents* of the reed. This can be achieved either by drawing-in or tying-in, the choice depending upon whether or not the new warp is different from the warp already on the loom.

Drawing-in

This is the process of drawing every warp end through its drop wire, heddle eye and reed dent as shown in Fig. 7.1. Drawing-in can be performed manually or by means of automatic machines.

Manual Drawing-in

The warp beam is taken from the slashing room to the drawing-in area, where there are frames on which the drop wires, harness frames and reed are supported in the order in which they are found on the loom.

A length of warp yarn, just enough to reach to the other side of the frame, is unwound. Leasing of the warp at this stage simplifies separation of the yarns. In normal practice, two operators sit facing each other across the frame and the

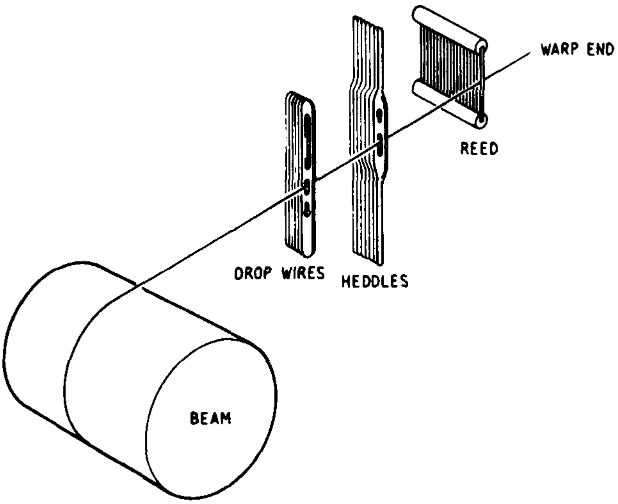


Fig. 7.1. Schematic diagram for drawing-in

operator facing the reed (the *drawer-in*) passes a hooked needle through the heddle eyes and drop wires. The needle hook is then exposed to the second operator (the *reacher-in*) on the other side of the frame; the reacher-in selects the correct yarn in its proper order and puts it on the hook so that when the needle is pulled out the yarn is threaded through the two loom parts. This is done according to a plan known as the *drawing-in draft* (D.I.D.). The yarns are then threaded through the reed dents as required by the *denting plan* or *reed plan* (R.P.).

To prevent the ends from being pulled back through the system, groups of ends are tied together by knots. The operators then tie together all three elements (drop wires, harness frames and reed) to prevent any end breakage during movement of the beam, which is then ready to be placed on the loom.

Machine Drawing-in

Hand drawing-in is a time consuming operation, and it has been made fully automatic. There are two systems available, namely:

(1) Three machines each performing a single operation; a wire-pinning machine, a drawing-in machine and a reed-denting machine.

(2) One machine for drawing the warp through all the elements.

The machines used in these processes employ a *pattern chain* to control a selector finger which selects the warp threads separately and delivers them to a hook which draws them through the required element. The machines are very expensive and require a special type and shape of heddle. Accessories are needed to facilitate the preparation of the machine for drawing-in. Examples include a pattern punching machine and a heddle counter to determine the number of heddles required on every harness frame. A certain level of efficiency and continuous use of the equipment are necessary if the use of such machines is to be economically justifiable. A modern warp drawing machine may be able to handle some 6000 ends per hour, but the speed achieved is dependent on the specific conditions (see Table 7.1). Machines are available to deal with one or two warps, flat or leased, and with different widths.

The Drawing-in Draft

This indicates the pattern in which the warp ends are arranged in their distribution over the harness frames. Wherever possible, the ends which are to be woven similarly should be drawn through the same harness frame. This rule is applied when the density of warp yarns does not exceed 8 end/cm (20 end/inch) on a single row harness or 16 end/cm (40 end/inch) on a double row harness (see Fig. 7.2). For example, a plain weave fabric with 32 end/cm (80.end/inch) will require either 2 double-row harnesses or 4 single-row harnesses. For dobby weaves it is recommended that the

TABLE 7.1

Tying-in Rates for Typical Cases

Case Number	1	2	3	4
Yarn type	Cotton	Spun rayon	Filament acetate	Worsted
Yarn count	36/2	25/2	154/41	2/50
Yarn linear density	33 tex	48 tex	17 tex	18 tex
Type of warp	Flat sheet	Flat sheet	1 × 1 lease	1 × 1 lease
End/cm	35	24	35	31
End/inch	90	60	90	80
No. harness frames	8	16	6	12
Type of draft	Skip	Skip	Straight	Skip
Banks of drop wires	4	4	4	6
Ends/dent in the reed	2	4	2	4
Av. speed in ends/hr	4800	3800	5000	4000

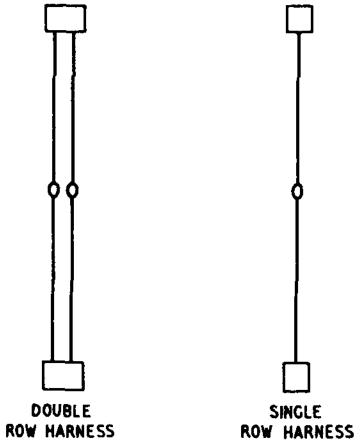


Fig. 7.2.

number of ends per harness should be as nearly equal as possible.

There are three different methods for the yarn arrangement in the drawing-in draft, these are:

(1) *Straight draft* (Fig. 7.3(a)).
(2) *Pointed draft* (Fig. 7.3(b)).
(3) *Skip draft* (Fig. 7.3(c)).

These represent both the harnesses and the warp ends; each vertical row in the draft represents one end and each horizontal row represents one harness. The bottom horizontal row is normally the first or the front harness. The harness capacity of the loom to be used must be known before the drawing-in draft can be decided. The drawing-in draft must be known not only to the drawer-in but also to the weaver, who will be able to draw broken ends during weaving. Any misdrawn end will produce a fault in the fabric.

The drawing-in draft varies with different fabric designs as discussed in Chapter 9.

The Reed Plan

The reed plan indicates the arrangement of the warp ends in the reed dents. It is general practice to draw more than one warp end in a reed dent. This allows the use of reasonable wire dimensions and number. Normally 2 ends/dent for the body of the fabric and 4 ends/dent for the selvage is a reasonable combination. However, in many cases, 3 or 4 ends/dent are used. The reed plan can be either regular or irregular depending on whether or not the same number of ends per dent is used regularly across the width of the body of the warp. Some designs require the use of different numbers of ends per dent in the body of the fabric to produce certain effects in the fabric.

Tying-in

Tying-in is used when a fabric is being mass produced. The tail end of the warp from the exhausted warp beam is tied to

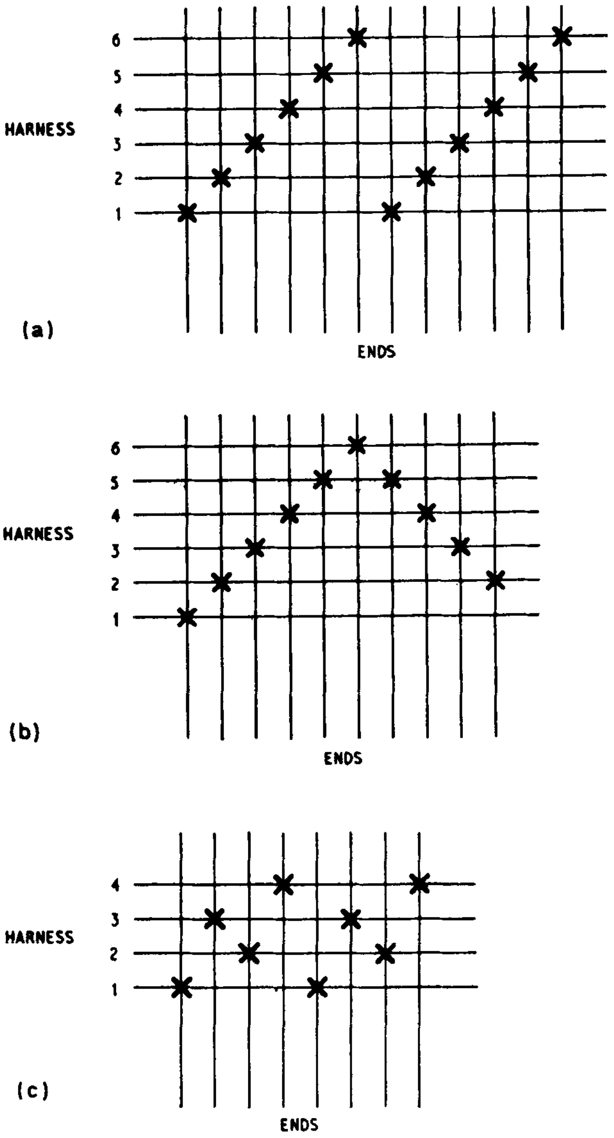


Fig. 7.3. (a) Straight draft. (b) Pointed draft. (c) Skip draft

the beginning of the new warp. Two types of machine are used:

(1) *Stationary machines.* The tying-in takes place in a separate room away from the loom.
(2) *Portable machines.* These are used at the loom.

Stationary machines have the disadvantage that they necessitate moving the exhausted beam and all its parts from the loom and taking it to and from the tying-in department. However, they have the advantage of permitting maintenance of the loom to be carried out.

The time taken to tie-in a complete warp depends mostly upon the total number of ends in that warp, but it is also affected by secondary factors which tend to retard productivity. For example, a color stripe must be tied in proper register and the operator will have to stop tying if there has been a broken end in order to adjust the machine to give proper register. The count and type of yarn (together with the reed and heddle details) determine the type of knot to be used and this affects the rate of knotting. Also the nature of the yarn can affect the breakage rate during knotting, and thus influence the total time needed for tying-in.

The capacity of warp-tying machines has remained unchanged for years. A capacity of about 600 knots/min appears to be the maximum. The machine can deal with flat warp or leased warp and with a warp width of about 5m (5 yd). The sequence of operations is normally as follows:

(1) The machine selects the warp ends from the new beam.
(2) It selects the corresponding end from the old beam.
(3) It ties the two ends together and moves to the next.

Following the tying-in process, all knots are pulled through to the cloth roller, the drop wires, heddles and reed; the loom is now ready for operation.

A similar process can be used where similar (but not identical) fabrics are to be produced. Obviously, identical drawing-in draft and reed plans are required.

8

THE FUNDAMENTALS OF FABRIC STRUCTURE

Key Words: *aspect ratio, basis weight, biaxial load, cover factor, contraction, covering power, crimp, crimp exchange (crimp interchange), crimp factor, fabric construction, fabric extension, hand, jamming, plain weave, slit film, square construction, uniaxial load.*

The Structure of a Weave

The warp and filling may be interlaced in a variety of patterns to produce fabrics which are surprisingly flexible and yet are strong and durable. These characteristics arise from the structure of the fabric itself and also from the structure of the yarns which are used to make it. Obviously, if stiff wire were used to make a fabric, the fabric would also be stiff, and this would be the case no matter what type of weave was used. On the other hand, it is possible to weave very flexible strands into fabrics with a very wide range of stiffnesses depending on the fabric structures used.

The way in which the component yarns are assembled enables a very wide range of patterns to be made, merely by varying the weave. These patterns, which can be either large or small, are obviously important in textiles which are used for their decorative effect.

Varying the weave varies the facility with which the component yarns can move relative to one another, with the result that the shear characteristics of the material are affected and, in turn, the drape.

Theoretically, it is possible to design a fabric structure to produce the characteristics demanded, but in practice this is not quite so easy as it may sound. For example, often it is

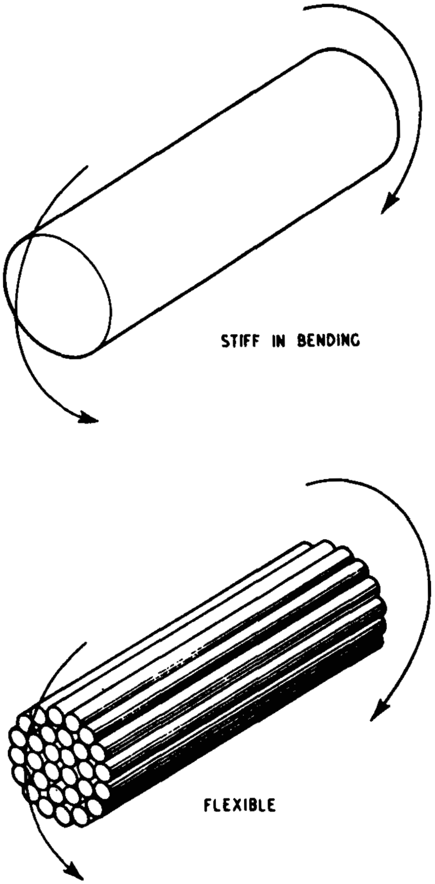
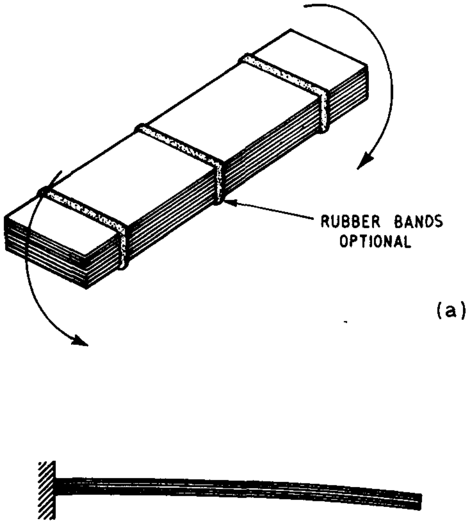
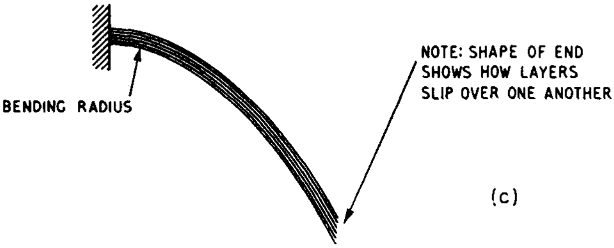


Fig. 8.1

difficult to obtain a complete specification of the fabric needed for a given end use, particularly when it is fashion rather than utility which dictates the sort of material to be used. Complete case histories of the many types of fabrics are available in well documented forms, and the motivation to reduce the matter to fundamental principles is reduced.



GLUED ASSEMBLY IS STIFF (b)



UNGLUED ASSEMBLY IS FLEXIBLE

Fig. 8.2

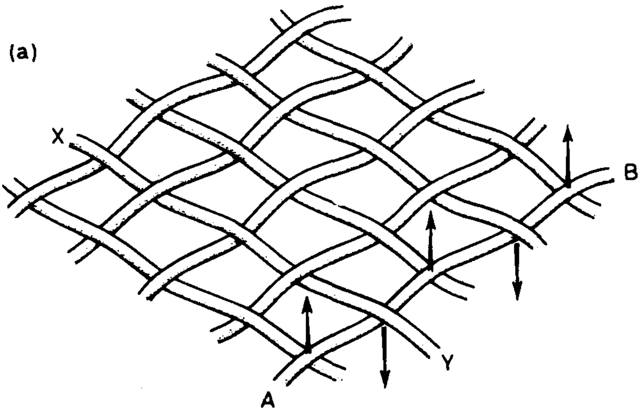
Also, it is far from easy to analyze a fabric in scientific terms, let alone synthesize the characteristics; in general, therefore, the art of fabric analysis and synthesis has been based on craft knowledge rather than science. However, the scientific approach can provide a deeper understanding of the factors involved and, for this reason, a simplified scientific analysis of some fabric structures will be made.

The Stiffness of Various Assemblies of Fibers

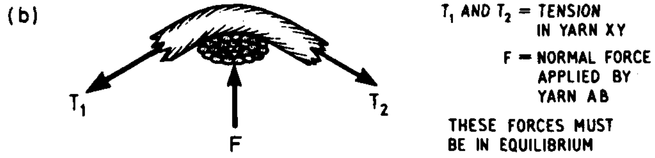
If a rod is divided into portions in the fashion indicated in Fig. 8.1, then the stiffness of the assembly will be reduced. If the rod is divided into many component fibres, the stiffness will be further reduced. It is the smallness of diameter of the individual fiber that makes possible the high degree of flexibility which is normally associated with a textile material. To take the fullest advantage of the inherent flexibility, it is necessary to give the individual fiber the greatest freedom of movement possible and, in particular, the amount of shear energy which can be transmitted from one fiber to its neighbors should be at a minimum (in other words, the fibers should be able to slip over one another).

Two paper models may be used to demonstrate this relationship between flexibility and structure. In both models, similar strips of paper are arranged in the form of a rectangular prism as shown in Fig. 8.2. In the one case, the strips are fixed together only at one end. In the other case, the strips are glued together using a minimum of glue. The first model will be found to be extremely flexible and the minimum bending radius when held as a cantilever will be very small (see Fig. 8.2(c)). The glued model will be very stiff because the elements cannot slip over one another and cannot act independently.

A textile material lies usually between these two extremes. Sometimes fibers are bonded together, which tends to make the structure stiff. Frequently, the fibers are held together by frictional forces arising from the disposition of the components in the structure. The effect of frictional forces can be simulated by placing rubber bands around the first (unglued) model. When the rubber bands exert a fairly small lateral force, the assembly is stiff for the first small increment of distortion because the frictional forces are not overcome and the assembly behaves as a stiff solid body. A large



FORCES ACTING ON YARN AB ASSEMBLED INTO A FABRIC

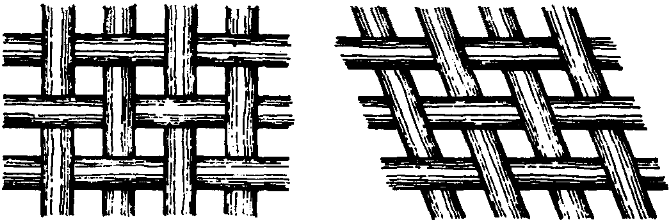


FORCES ACTING AT A TYPICAL CROSS-OVER

Fig. 8.3

distortion can produce a lower apparent stiffness and yet a further small distortion will again make it appear to be stiff. If the rubber bands exert a large compacting force, the assembly will have to be grossly distorted to produce other than the solid body stiffness. Thus it is not surprising to find that a sized yarn is stiffer than an unsized one or that a high twist yarn (which has large compacting forces) is stiffer than a low twist yarn.

In the case of fabrics, a material made from sized yarns is much stiffer than that made from unsized yarns or a fabric from which the size has been removed. "Hard" twisted yarns (i.e. highly twisted yarns) will make a fabric stiffer than a fabric made of low twist yarns; also, there will be a difference in the tactile character of the fabric, the fabric from hard twisted yarn feels harsh to the touch whereas the fabric from low twist yarns feels soft.



FABRIC IN NORMAL STATE　　SHEAR DEFORMATION IN FABRIC

Fig. 8.4

When assembled into fabric, the yarns exert forces upon one another at the crossovers (Fig. 8.3) and these forces act like the rubber bands in the model. In a very tight structure where considerable yarn tensions are involved, the fabric is likely to be stiff. Conversely, a loose structure is likely to be flexible and soft. A loose structure allows yarns to move more easily over one another at the crossovers, which makes shear deformations easier (see Fig. 8.4). This in turn makes it easier for the fabric to mould to a surface and drape well.

In finishing, the aqueous treatment will often release some of the compacting forces and allow fibers more freedom, with the consequence that yarns and fabrics tend to become softer. Laundering and use generally have a similar effect.

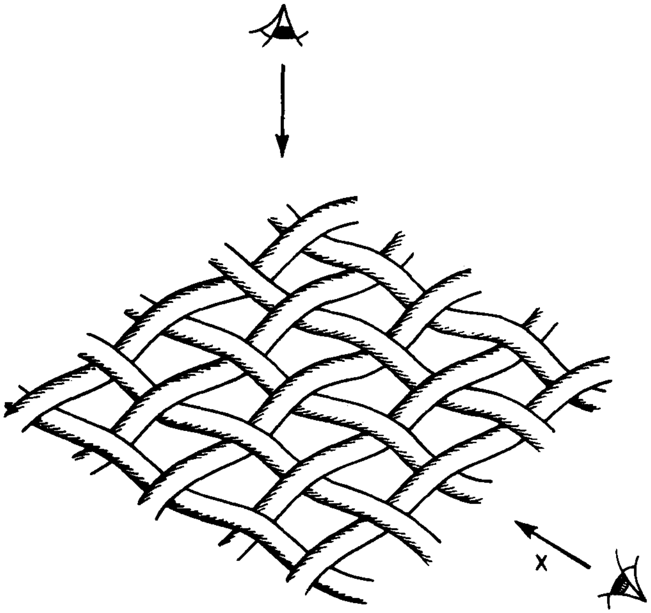


Fig. 8.5

Fabric Geometry

Yarns are interlaced into an interlocking structure to produce a sheet-like material which has a three-dimensional macro structure (Fig. 8.5). The weave shown in Fig. 8.5 is a *plain weave* and although there are many other patterns of weaving, this particular one has been chosen for illustration purposes because it is the simplest.

Frequently, a woven fabric is used to obscure whatever lies beneath it and in such cases the *covering power* of the material is important. There are two aspects of covering power, viz. the optical and the geometrical. The optical aspect is a function of the readiness with which the surface of the material reflects and scatters the incident light. The geometrical aspect is a function of the extent to which the superficial area is covered by the component yarns.

The optical effects are controlled by the nature of the fibers and the surfaces presented to the incident light. Certain fibers are more opaque than others; for example, nylon can be supplied in dull or bright forms, the dull form reflecting more light than the bright form, which transmits more of the light to give a translucent effect. For a given fiber, optical characteristics are also affected by the structure into which the fibers are fitted. Thus both the yarn and fabric structures will influence greatly the overall optical behavior. Dyeing and finishing will also play a part. Continuous filament yarns tend to be less opaque than staple yarns, high twists tend to produce less covering power than low twist yarns for a given geometry.

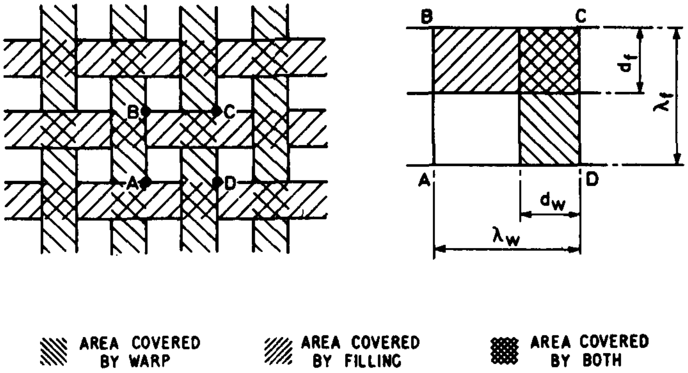


Fig. 8.6. Cover factor

The geometrical aspect may be defined by the *cover factor*. (This differs from covering power, which takes into account the optical effects; cover factor is concerned only with the geometry.) Let the cover factor be defined in terms of projected areas. Seen from above, the material illustrated in Fig. 8.5 would appear as shown in Fig. 8.6, and the projected areas are those seen in this way. The diagrams in Fig. 8.6 show in a qualitative manner what is meant by cover factor. It should be noted that 100 per cent cover factor does not mean that the fabric is impermeable. Air can pass quite readily through interstices of the weave and the permeability of the fabric as normally measured is not a direct function of the cover factor. It is, of course, related to it.

Unfortunately, many of the terms used have a variety of meanings in commercial use and it is important that the definitions used should be clearly understood. For example, cover factor is frequently taken to include all the various factors mentioned whereas in other instances it is taken as quoted here. Thus care is needed when using these terms.

Cover Factor

Let d_W = the width of the warp yarn as it lays in the fabric
d_f = the width of the filling yarn as it lays in the fabric
λ_W = the pitch of the warp yarns,
λ_f = the pitch of filling yarns.

The warpwise cover may be defined as

$$\frac{d_w}{\lambda_w} = C_w$$

and the fillingwise cover be defined as

$$\frac{d_f}{\lambda_f} = C_f$$

The percentage fabric cover factor

$$C_{fab} = \frac{\text{total area obscured}}{\text{area enclosed}} \times 100 \text{ per cent}$$

$$= \frac{(\lambda_w - d_w)\, d_f + d_w \lambda_f}{\lambda_w \lambda_f}$$

$$C_{fab} = \frac{\lambda_w d_f + d_w \lambda_f - d_w d_f}{\lambda_w \lambda_f} \times 100 \text{ per cent}$$

$$= \frac{d_f}{\lambda_f} + \frac{d_w}{\lambda_w} - \frac{d_w}{\lambda_w}\frac{d_f}{\lambda_f} \times 100 \text{ per cent}$$

$$= (C_f + C_w - C_f C_w) \times 100 \text{ per cent} \qquad (8.1)$$

Thus if $C_f = 1{\cdot}0$ then $C_{fab} = 100$ per cent irrespective of the value of C_w but as C_w changes so will the permeability; this is an illustration of the lack of direct relationship mentioned earlier. The same argument applies if C_f and C_w are interchanged. A further point is that $C_{fab} \neq 100$ per cent unless either C_f or $C_w = 1{\cdot}0$. With a plain fabric using conventional yarns it is almost impossible to make either C_f or $C_w = 1{\cdot}0$. However, with *slit film*—which has very little thickness as compared to its width—it is possible to approach these values. Also by using other weaves, where the yarns can "pile up" as shown in Fig. 8.7, it becomes possible to approach 100 per cent cover.

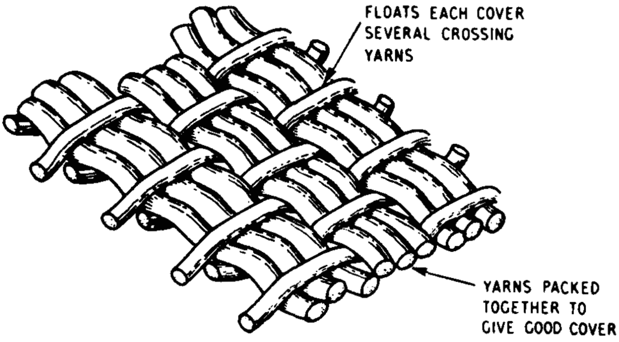


Fig. 8.7

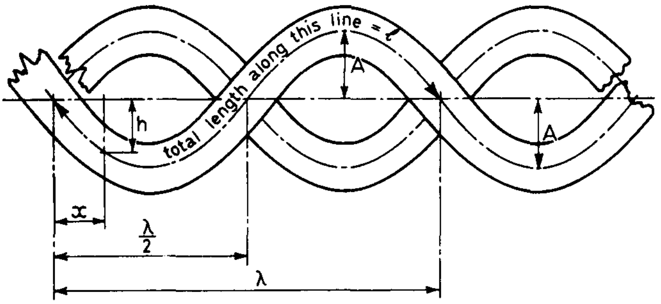


Fig. 8.7(a)

Crimp

The yarn at the edge of a piece of fabric (direction X in Fig. 8.5.), appears to be wavy, as illustrated in Fig. 8.7(a). In general terms, this waviness is called *crimp*. It has important effects on the dimensions and performance of the fabric; for example, the existence of crimp means that the lengths of filling or warp yarn required are greater than the width or length of the cloth. Since the *basis weight* of the fabric (which is usually measured in oz/sq yd) depends not only upon the linear density of the yarns used but also on the total length of the yarns assembled in the fabric, it is apparent that the crimp has to be taken into account. Other parameters are also affected, which will be discussed later.

There are two alternative ways of defining crimp:

$$\text{(a) } \textit{crimp factor } (S) = \frac{(\ell - x)\,.\,100 \text{ per cent}}{x} \tag{8.2}$$

or

$$\text{(b) } \textit{contraction} = \frac{(\ell - x)\,.\,100 \text{ per cent}}{\ell} \tag{8.3}$$

where ℓ = length of yarn before crimping,
x = length or width of the fabric.

ℓ and x are measured in the same direction.

Equation 8.2 is often expressed in the form

$$\ell = x(1 + S) \tag{8.2a}$$

A theoretical value for the crimp factor may be obtained by assuming that the yarn is forced into sinusoidal shape as depicted in Fig. 8.7. In other words the shape of the crimped yarn may be expressed mathematically by the following:

$$h = A \sin \frac{(2\pi x)}{\lambda} \tag{8.4}$$

The symbols are described in Fig. 8.7(a).

As shown in Appendix III, the true length of the yarn is given approximately by the following expression:

$$\ell \simeq \lambda \left[1 + \left(\frac{\pi A}{\lambda}\right)^2\right] \tag{8.5}$$

From this latter expression it is simple to derive the crimp factor, namely

$$\text{crimp factor} \simeq \left(\frac{\pi A}{\lambda}\right)^2 \times 100 \text{ per cent} \tag{8.6}$$

This approximation is good for a plain weave but it is necessary to modify it for other weaves.

If the warp were made out of stiff bars of metal and both warp and filling were perfectly circular, then the situation shown in Fig. 8.8(a) would exist, and

$$A_f = \frac{(d_f + d_w)}{2} \quad \text{and} \quad A_w = 0$$

This is not a practical situation because such a malbalance is rarely met and there are forces acting which cause the warp to become crimped at least to some extent (see Fig. 8.8(b)). When this crimping takes place, not only is the element of warp moved bodily away from its original position but it is squashed into an eye shape. Hence it is not very meaningful

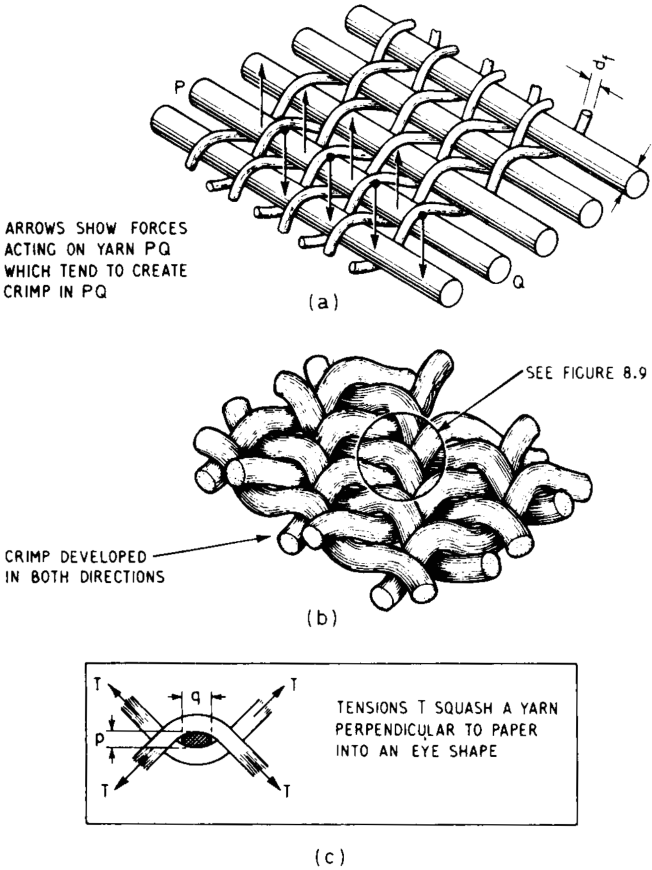


Fig. 8.8

to talk about the yarn diameter (d); rather it is necessary to talk about the yarn depth and width which are shown as p and q in the diagram. The value q, the width, affects the cover factor very strongly and p, the depth, affects the crimp. As a very rough approximation, pq may be taken as proportional to the linear density of the yarn (or inversely proportional to the yarn count) for a given level of twist.

The values of p and q are greatly affected by the yarn twist because a softly twisted yarn will squash much more readily than a hard twisted yarn. Let the ratio p/q be termed the *aspect ratio*. A flat tape, such as is now commonly used for making carpet backing, might have an aspect ratio as low as 0·01 (which means that it will have excellent cover and a low crimp factor), whereas a highly twisted yarn will have an aspect ratio approaching 1·0 (which gives poor cover and high crimp). A normal yarn assembled in a typical fabric might have an aspect ratio varying between 0·6 and 0·9.

As a comparative example of the interrelationship consider two fabrics of the same construction, where $\lambda = 6d$ and where the same yarns are used and the value of p/q is the same for both warp and filling. In the first fabric $p/q = 0{\cdot}5$ and in the second, $p/q = 1{\cdot}0$. If the yarn in the first case is squashed into an elliptical shape, then $pq = d^2$, whence $q = 1{\cdot}41d$ and $p = 0{\cdot}71d$. This is an approximation purely for the purpose of explanation.

$$\text{In this case } C_f = C_w = \frac{2q}{\lambda} = \frac{1{\cdot}41d}{3d} = 0{\cdot}47$$

The cover factor

$$C_{fab} = (C_f + C_w - C_fC_w)\ 100 \text{ per cent} = 72 \text{ per cent}$$

whereas if the yarn had not squashed, the cover factor would have been only 55 per cent. Assuming the crimp amplitude to be the same in both directions; for the squashed yarn

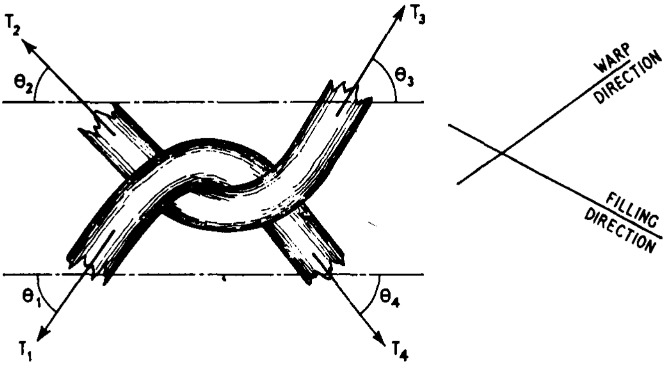
$$A = p/2 = 0{\cdot}352d$$

and the crimp factor

$$= \frac{(\pi A)^2}{(\lambda)^2} \times 100 \text{ per cent}$$

$$= \frac{(0{\cdot}352\ \pi d)^2}{(6d)^2} \times 100 \text{ per cent}$$

$$= 3{\cdot}4 \text{ per cent}$$



ALL ANGLES θ REPRESENT TRUE ANGLES RELATIVE TO THE PLANE OF THE FABRIC

Fig. 8.9(a). An enlargement of inset in Fig. 8.8(b).

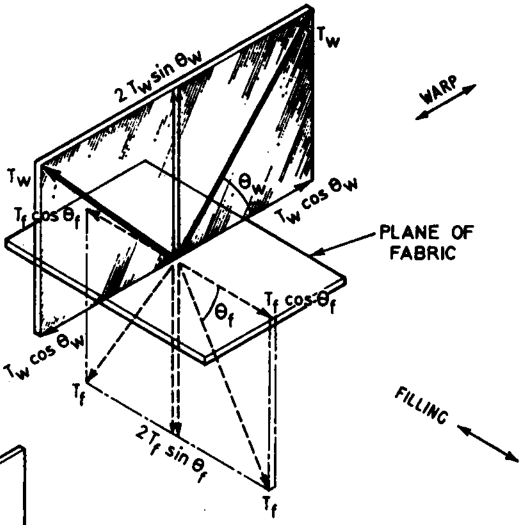
whereas with the unsquashed yarn the crimp factor would have been about 7 per cent. The yarn which squashed would give a basis weight of $(1{\cdot}034/1{\cdot}07)^2 \times 100$ per cent $= 92{\cdot}3$ per cent of a similar fabric made from unsquashed yarns.

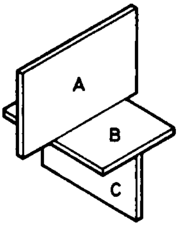
The fabric thickness will be about $2p$ and $2d$ respectively; in other words, the yarn which squashes will give a fabric which is about 71 per cent of the thickness of one in which the yarn does not squash. This affects the flexibility and softness of the fabric which in turn affects the *hand.*

It can be seen from this illustration that crimp is related to many aspects of the fabric. It affects the cover, basis weight, thickness, flexibility, softness, and hand of the fabric. When malbalanced it also affects the wear behavior and appearance of the fabric, because the exposed portions tend to wear at a more rapid rate than the rest. The crimp balance is affected by the tensions in the fabric during and after weaving.

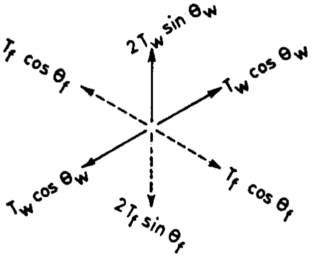
Effect of Tensions

Consider a single cross-over of warp and filling as shown in Fig. 8.9(a) and for simplicity assume that the warp and filling





It may be helpful to consider the above as three planes as shown to the side. The resolved warp tensions act in plane A, the resolved filling tensions in plane C and plane B is that of the fabric



THE RESOLVED FORCES ONLY ARE SHOWN TO THE LEFT

Fig. 8.9(b)

yarns are of the same count and twist. Because of the crimp, the yarn tensions act at various angles to the plane of the fabric and these tensions may be resolved into two directions in the plane of the fabric and one perpendicular to it. The resolved components of the four tensions must balance to give equilibrium. Consider first the components lying in the plane of the fabric. For simplicity assume the tension acting along a given thread is always constant (this is not normally so because of the effects of friction). In the case of the warp direction $T_1 = T_4$ and since $T_1 \cos \theta_1 = T_4 \cos \theta_4$ to give equilibrium in the warp direction, then $\theta_1 = \theta_4$. Since equality of tensions and angles have been assumed, let these be referred to as T_w and θ_w. A similar argument can be applied in the filling direction, therefore T_2 and T_3 can be replaced by T_f also θ_2 and θ_3 by θ_f.

In the direction perpendicular to the plane of the fabric

$$T_1 \sin \theta_1 + T_4 \sin \theta_4 = T_2 \sin \theta_2 + \mathrm{T}_3 \sin \theta_3$$

Whence

$$2T_w \sin \theta_w = 2T_f \sin \theta_f \tag{8.7}$$

Assuming that the crimped yarn is sinusoidal in shape as in Fig. 8.7

$$h = A \sin \frac{2\pi x}{\lambda}$$

$$\frac{dh}{dx} = \frac{2\pi A}{\lambda} \cos \frac{2\pi x}{\lambda}$$

At the point where the yarn intersects the plane of the fabric, $x = 0$ and $\cos (2\pi x/\lambda) = 1{\cdot}0$ therefore $dh\ dx = (2\pi A/\lambda)$ but $dh/dx = \tan\ \theta$. When θ is small $\tan \theta \simeq \sin \theta$. (This is another way of saying $\cos \theta \simeq 1{\cdot}0$; which is true within 10 per cent when the half angle $\theta < 25°$.) Thus for small crimp amplitudes, it is a fair approximation and certainly for the purposes of explanation we may rewrite equation (8.7) as:

$$T_w \tan \theta_w \simeq T_f \tan \theta_f \tag{8.8}$$

Whence

$$T_w \times \frac{2\pi A_w}{\lambda_w} \simeq T_f \times \frac{2\pi A_f}{\lambda_f} \tag{8.9}$$

and

$$\frac{A_f}{A_w} \simeq \frac{\lambda_f}{\lambda_w} \frac{T_w}{T_f} \tag{8.10}$$

In other words, the crimp amplitude is dictated by the tension and spacing of the yarns. If the filling (or the fabric in the filling direction) is kept at low tension whilst the tension in the warp direction is high, then there will be considerable crimp in the filling and very little in the warp. In simple terms, the tension in the warp pulls out the crimp in that direction and in so doing puts more into the filling. This process is called *crimp exchange* (crimp interchange).

Equation (8.10) also shows that the construction of the fabric is important. If there is a high pick density (i.e. the # picks/inch is large or λ_f is small) and a low end density (λ_w is large), then the crimp in the filling will be small and in the warp it will be large unless the tensions are adjusted to compensate for it. This possibility of compensating imbalances in tension by varying the fabric structure or of compensating for the effects of fabric structure by varying the tension is very important. A good understanding of this is essential to the art of weaving.

At the beginning of this section it was arbitrarily assumed that the yarns were all of the same count and twist, but in fact this is rarely so. These factors determine the stiffness of the yarns and, even though the preceding simplified analysis does not show it, the stiffness of the yarns does affect the crimp interchange. Therefore, the equations given are at best no more than an approximation and they should be used with considerable caution; however, it is hoped that they are of help in understanding the process.

If a smooth surfaced fabric is required and the yarns are unequal, then, from purely geometrical considerations, the crimp has to be adjusted so as to bring the crests of the yarns into a single plane. This involves an increase of crimp in the thin yarn and a decrease of crimp in the thick one. Where the twists differ, the amount by which the yarn squashes also differs and this also has to be taken into account. Where ribs are required, the adjustment has to be in the other direction. Bearing in mind that the crimp is related to most other fabric parameters, it will be realized that the matter is complex and is beyond the scope of this book.

Fabric Weight

Generally, the weight of a piece of fabric is the combined weight of the warp and the filling yarns, but if the fabric is in the loom state, allowance must be made for the weight of size material on the warp. Also allowance has to be made for the crimp which changes in finishing. Consider both metric and imperial units.

Let L = length of fabric (meters or yards)
w = width of fabric (meters or inches)
S_w = warp crimp factor
S_f = filling crimp factor
ℓ_w = length of a single warp yarn (meters or yards)
ℓ_f = length of a single filling yarn (meters or yards)
N_w = warp yarn number in cotton count
N_f = filling yarn number in cotton count
n_w = linear density of warp yarn in tex
n_f = linear density of filling yarn in tex
m_w = end density (ends/meter or ends/inch)
m_f = pick density (picks/meter or picks/inch)
w_b = basis weight (g/m^2 or oz/sq. yd.)

From eqn. (8.2a), length of a single warp yarn

$$\ell_w = L(1 + S_w) \text{ meters or yards}$$

Therefore, total length of warp yarns

$$= m_W\, w\, \ell_W = m_W\, w\, \mathrm{L}\,(1 + \mathrm{S}_W) \text{ meters or yards}$$

Total length of filling yarns $= m_f w\ \mathrm{L}\ (1 + \mathrm{S}_f)$ meters or yards

Consider the metric case first.

$$\text{Mass of warp yarn} = \frac{m_W\, w\, \mathrm{L}\,(1 + \mathrm{S}_W)\ n_W}{1000} \text{ gram} \quad (8.11)$$

$$\text{Mass of filling yarn} = \frac{m_f\, w\, \mathrm{L}\,(1 + \mathrm{S}_f)\, n_f}{1000} \text{ gram} \quad (8.12)$$

Mass of fabric, excluding size, is the sum of the above

$$= \frac{w\ \mathrm{L}}{1000}\,(m_W n_W\,(1 + \mathrm{S}_W) + m_f n_f\,(1 + \mathrm{S}_f))$$

Basis "weight" W = Mass of fabric ÷ Area

$$= \frac{1}{1000}(m_W n_W\,(1 + \mathrm{S}_W)\ + m_f n_f\,(1 + \mathrm{S}_f)) \quad (8.13)$$

Now consider imperial units.

$$\text{Weight of warp yarns} = \frac{m_w\ w\ \mathrm{L}(1 + \mathrm{S})}{840\ \mathrm{N}_W} \text{ pounds} \quad (8.11a)$$

$$\text{Weight of filling yarns} = \frac{m_f w\ \mathrm{L}(1 + \mathrm{S}_f)}{840\ \mathrm{N}_f} \text{ pounds} \quad (8.12a)$$

Weight of fabric, excluding size, is the sum of the above but if w is measured in inches (as is normal) then a factor of 36 has to be introduced to calculate the *basis weight* and

$$\text{Basis Weight} = 0.043\ \frac{m_W\,(1 + \mathrm{S}_W)}{\mathrm{N}_W} + \frac{m_f\,(1 + \mathrm{S}_f)}{\mathrm{N}_f} \text{ lb/sq.yd.} \quad (8.14a)$$

or in more normal units,

$$\mathrm{W} = 0.60\ \ \frac{m_W\,(1 + \mathrm{S}_W)}{\mathrm{N}_W} + \frac{m_f(1 + \mathrm{S}_f)}{\mathrm{N}_f} \text{ oz/sq.yd.} \quad (8.14a)$$

Consider a special case in which the fabric has a *square construction,* i.e., the same yarn number for both warp and filling and the same end and pick densities.

$N_w = N_f = N$

$m_w = m_f = m$

In this case the basis weight is given by:-

$$w = 0.69 \frac{m}{N} [(1 + S_w) + (1 + S_f)] \text{ oz./sq.yd.} \qquad (8.15)$$

It must be realized that even if the same yarn number is used for warp and filling, the crimp levels may still be different due to the difference in yarn tension and twist.

Generally speaking, eqn. (8.13) gives the weight of the finished fabric. but it is possible to lose lint which will reduce the weight accordingly. Usually this loss is very small and can be neglected. The loom state basis weight has to be calculated to take into account the amount of size on the warp. Let Z = percentage size pick-up on the warp ÷ 100

Mass of size = eqn (8.11) x Z
or = eqn (8.11a) x Z (8.16)

In metric units, the weight of greige fabric

$$= \frac{w\ L}{1000} (m_w n_w (1 + S_w) (1 + Z) + m_f n_f (1 + S_f) \qquad 8.17)$$

and Basis Weight for greige fabric

$$W_g = \frac{1}{1000} (m_w n_w (1 + S_w) (1 + Z) + m_f n_f (1 + S_f)) \text{ gram/sq meter} \qquad (8.18)$$

in Imperial units, the basis weight for greige fabric

$$W_g = 0.60 \frac{m_W (1 + S_W)(1 + Z)}{N_W} + \frac{m_f(1 + S_f)}{N_f} \text{ oz/sq.yd} \tag{8.18a}$$

Equation (8.14a) is useful when considering finished fabrics and eqn. (8.18) is useful when considering those loom state fabrics which are sold on a weight basis.

Fabric Extension

When fabric is subjected to tension in a single direction, it extends fairly easily until most of the crimp has been removed and then it becomes stiffer. The latter effect is controlled mainly by the character of the yarn. Thus there are two principal mechanisms of extension, the first arising from changes in the fabric structure and the second from changes in the yarn structure. There is no distinct boundary, rather it is a case of a change in emphasis; furthermore, the effect of friction has to be taken into account, but for the present let this be ignored for the sake of simplicity. To show the effect of fabric structure, let the extensibility of the yarn also be ignored. From eqn. (8.2a), the length of a crimped yarn $l = \lambda(1 + S)$, where S = crimp factor = $(\pi A/\lambda)^2$.

After extension let the wavelength = λ_e and the crimp factor be S_e, the length l remains the same, therefore

$$l = \lambda(1 + S) = \lambda_e(1 + S_e)$$

whence

$$\frac{\lambda_e}{\lambda} = \frac{1 + S}{1 + S_e}$$

$$\text{Fabric extension} = \left(\frac{\lambda_e - \lambda}{\lambda}\right) \times 100 \text{ per cent}$$

$$= \left(\frac{\lambda_e}{\lambda} - 1\right) \times 100 \text{ per cent} \tag{8.19}$$

$$= \left(\frac{S - S_e}{1 + S_e}\right) \times 100 \text{ per cent}$$

In other words, the fabric extension is a function of the change in crimp. With inextensible yarns, the initial crimp level would be the limiting extension but, as has been shown earlier, crimp in one direction is only changed at the expense of the crimp in the other direction. For example, if the fabric were subjected to warpwise tension (which tends to straighten out the warp) it could only extend if the crimp in the filling was increased or if the yarns themselves extend. If, for any reason, there was a restraint to prevent the increase in crimp in the filling direction, this would be felt as a change of stiffness in the warp direction. For this reason, behavior when tension is applied in a single direction (*uniaxial load*) is different from behavior when tension is applied in two directions (*biaxial load*). This can be expressed in mathematical terms as follows: From eqn. (8.10)

$$\frac{T_w}{T_f} \cong \frac{A_f \lambda_w}{\lambda_f A_w}$$

$$T_w \cong T_f \frac{S_f}{S_w} \tag{8.20}$$

In other words, when the yarns are in contact and the fabric structure permits free movement, the warpwise tension is a function of the filling tension and the ratio of the crimp factors. When the fabric *jams*, a different situation exists because the crimp can develop no further and the thickness of the yarns prevents any further contraction.

9

WOVEN FABRIC DESIGN

Key words: *abrasion resistance, basket weave, balanced twill, counter, crease resistance, crimp removal, cross-section, crowns, decrimping, design, drape, drawing-in draft, fabric count, fancy rib weave, filling face twill, filling rib weave, filling satins, floats, lifting plan, pattern, reclining twill, reed number, reed plan, repeat, satin, sateen, selvage motion, square construction, square design paper, square weave, steep twill, stitched basket weave; thread diagram, 45° twill, twill weave, warp, warp face twill, warp rib, weave, width in reed, yarn count.*

The fabric weave or design is the manner in which the warp and filling are interlaced. The *pattern* or *repeat* is the smallest unit of the weave which when repeated will produce the design required in the fabric. There are many ways of representing a weave, a most familiar method being to use *square design paper*. The use of *thread diagrams* and *cross-sections* is another effective method of representation. Figure 9.1 shows a thread diagram, warp and filling cross-section and square paper representation of a plain weave.

On the design paper, the vertical rows of squares represent warp ends and the horizontal rows of squares represent filling picks. A mark in a small square indicates that at this particular intersection, the warp end is shown on the face of the fabric with the pick beneath. It is normal to use a filled in square to indicate that the end is over the pick and a blank square to indicate that the pick is over the end.

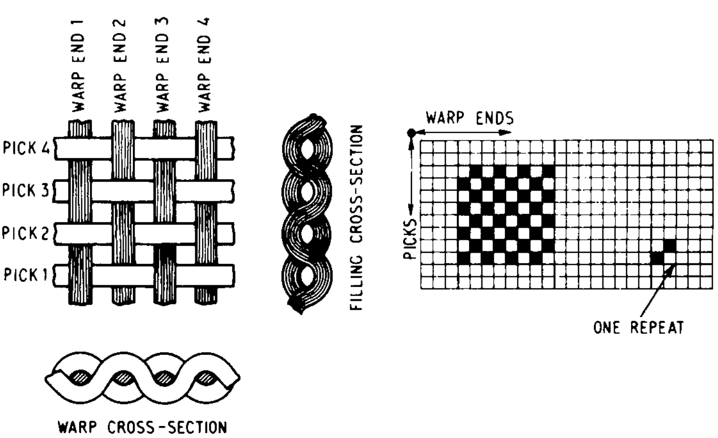


Fig. 9.1. Plain weave

Plain Weave

From Fig. 9.1 it can be seen that the plain weave repeats on 2 ends × 2 picks. The plain fabric comprises a high percentage of the total production of woven fabrics and it can be produced on a loom with 2 harnesses. It has the highest number of interlacings as compared with other weaves and therefore it produces the firmest fabrics.

Ornamentation of Plain Cloth

The appearance of a plain fabric can be changed in many ways, which can be summarized as follows:

1. *The Use of Color*

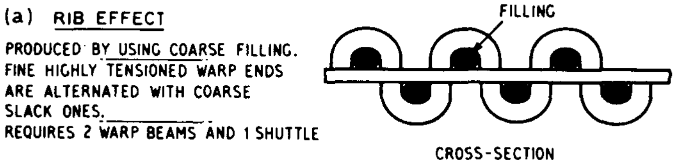
In the warp direction, color stripes are produced along the length of the fabric; in the filling direction, colour stripes are produced across the width of the fabric. When used in both warp and filling directions a check effect is produced.

2. *Changing Yarn and Fabric Counts*

Stripes and check effects can be produced by using different *fabric count* or *yarn count* in one or both directions. Also rib effects can be produced by using different yarn counts and different tensions as shown in Fig. 9.2(a).

3. *Changing the Yarn Twist*

Using combinations of different twist levels and directions in the warp or filling (or both warp and filling), different effects can be produced in the fabric due to the changes in orientation of the fibers, as shown in Fig. 9.2(b). Also different amounts of twist produce different shrinkage characteristics in different parts of the fabric and so change the appearance.


(a) RIB EFFECT

(b) EFFECT OF TWIST

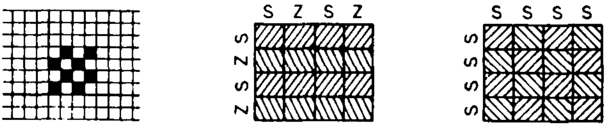
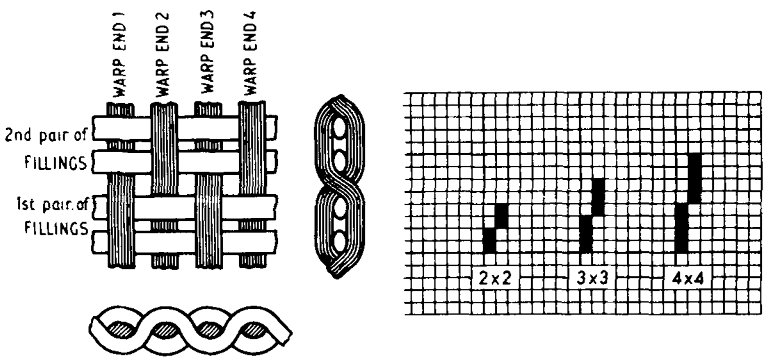


Fig. 9.2. Effect of yarn count and twist on plain weave fabrics

4. *Different Finishing Techniques*

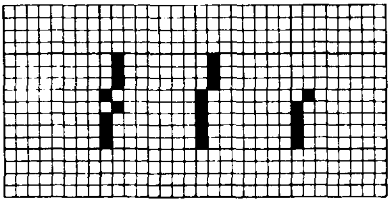
Treatments such as dyeing, mercerizing with caustic soda or coating can change the characteristics of the plain fabric.

5. *Any Combination of the Above*



2x2 WARP RIB

(a) WARP RIB WEAVES



(b) FANCY WARP RIB WEAVES

Fig. 9.3. Warp rib weaves.

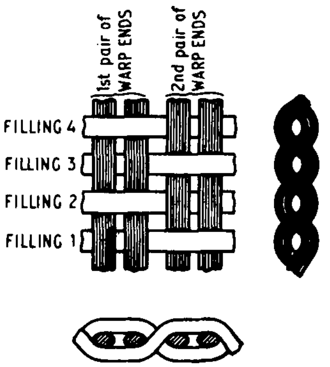
Variations of the Plain Weave

Some fabrics are considered to be derivatives of the plain weave. These are, in effect, extensions of the simple interlacing and, like plain weave, they can be produced on a loom with two harnesses.

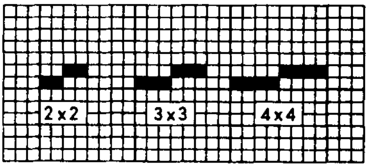
Warp Rib Weave

In this, the extension of the plain weave is in the warp direction, as shown by Fig. 9.3(a); the warp weaves in the same order as in the plain fabric, namely, every two adjacent ends weave opposite to each other. The filling weaves in groups of 2, 3 or more and every group weaves opposite to the adjacent groups; the repeat is always on 2 ends but any number of picks may be involved. The *weave* is denoted by showing the number of picks in the group above and below a line, i.e., as $\frac{2}{2}$ warp rib weave or sometimes as 2 × 2 warp rib weave. Although the weave is called *warp rib* it actually produces ribs in the filling direction. To obtain the best results it is usual to use fine warp and coarse filling in order to show the rib more clearly. The fabrics are normally lighter in weight than plain weave fabrics because of the lower level of crimp. The fabrics are also softer and more flexible than the plain fabrics.

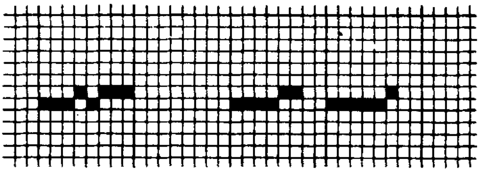
In weaving warp rib weave on a single shuttle loom, it is necessary to use a *selvage motion* to ensure proper binding between the picks and the selvage warp. This is because more than one pick is inserted in one shed and unless the pick is bound at the selvage, the shuttle will pull the pick out of the shed on its second traverse.



2 x 2 FILLING RIB

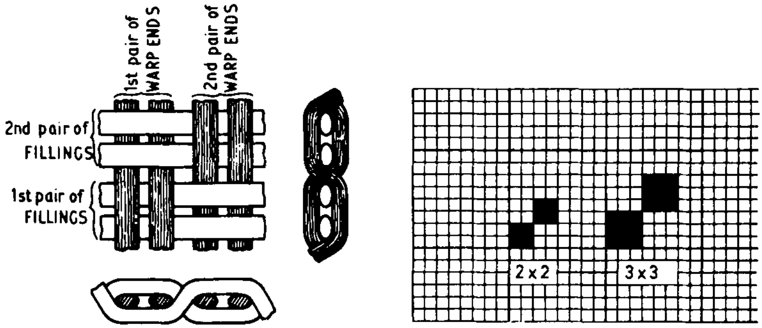


(a) FILLING RIB WEAVES



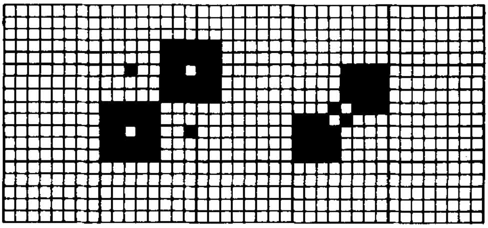
(b) FANCY FILLING RIB WEAVES

Fig. 9.4. Filling rib weaves

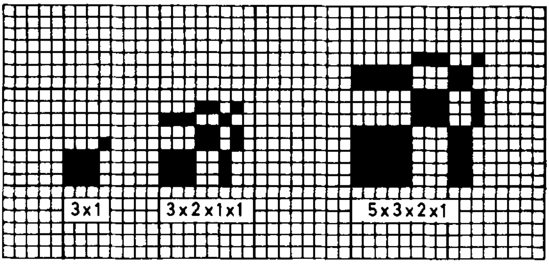


2 x 2 BASKET

(a) REGULAR BASKET WEAVES



(b) STITCHED BASKET WEAVES



(c) FANCY BASKET WEAVES

Fig. 9.5. Basket weaves

Fancy rib weaves can be produced simply by changing the number of picks in the groups, which changes the width of the rib in the fabric as shown in Fig. 9.3(b).

Filling Rib Weave

In this case groups of ends are woven with each group in direct opposition to the adjacent groups. The repeat is always on 2 picks × any number of ends as shown in Fig. 9.4(a). The ribs produced in the fabric run in the direction of the warp. It is usual to use coarse warp and fine filling to emphasize the rib. The fabrics are normally stronger than the plain fabrics because of the low crimp level.

There is no need to use a selvage motion, since there is only one pick inserted in every shed.

Fancy ribs can be produced in the manner already described, but by changing the number of ends in the group, as shown by Fig. 9.4(b).

Basket Weave (Matt Weave)

In this weave the extension is made in both directions so that groups of ends and picks are woven in the same way as single ends and picks are woven in the plain weave. The weave is denoted in the manner used for rib weaves, i.e. as $\frac{2}{2}$ basket or 2 × 2 basket. Fig. 9.5(a) shows the designs for 2 × 2 and 3 × 3 *basket weaves*. The numbers of ends and picks in the repeat are always equal to the addition of the two numbers denoting the weave. Thus a 2 × 2 basket repeats on 4 ends × 4 picks, a 3 × 3 basket repeats on 6 ends x 6 picks and so on. The *weave is square* and is mostly used with *square constructions.*

The fabrics are normally smoother and more flexible than plain fabrics, mainly because of the longer *floats* and fewer number of intersections. As the length of the float is increased more than (say) 1/2 cm, it is desirable to use the stitching shown in Fig. 9.5(b). This *stitched basket weave* produces a much firmer fabric than the regular basket weave.

It is also possible to change the number of ends and picks in the groups to produce fancy basket weaves as shown in Fig. 9.5(c).

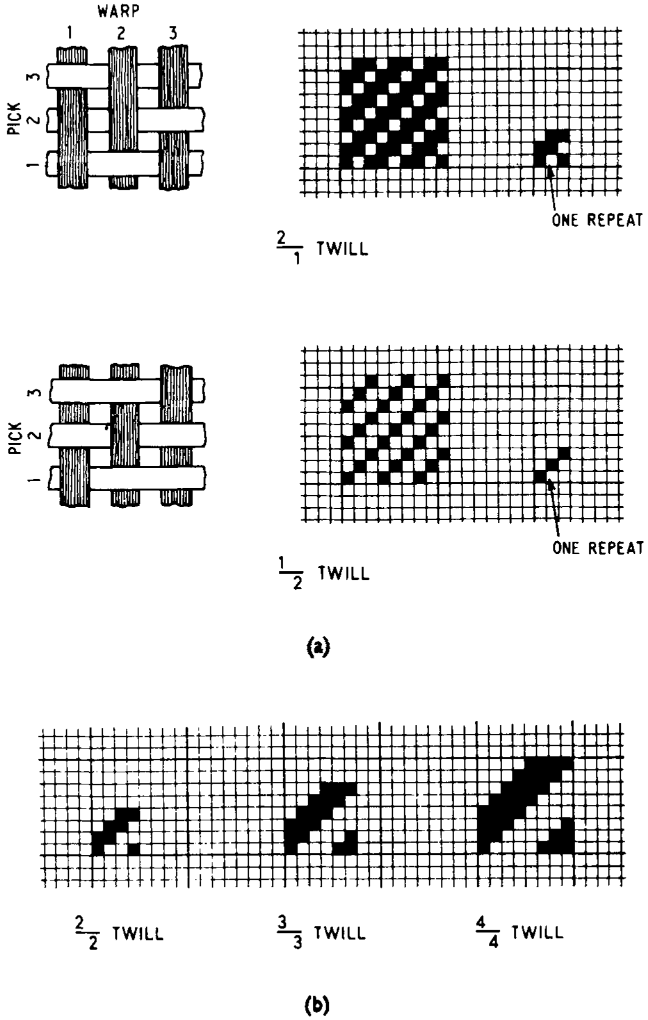
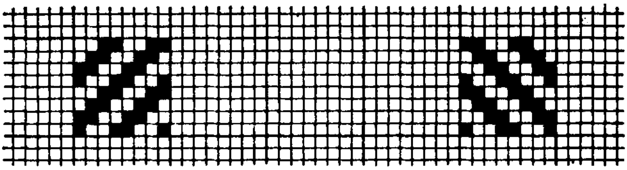
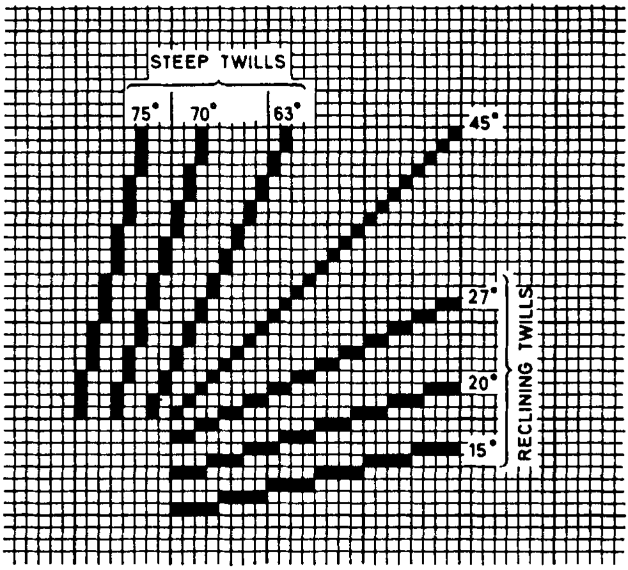


Fig. 9.6.(a) $\frac{2}{1}$ *and* $\frac{1}{2}$ *twills. (b) Balanced twills.*

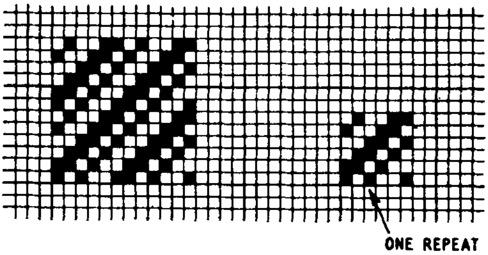
Fig. 9.6.(c) Twill angle and direction and (d) $\frac{2\ 1}{2\ 1}$ *twill shown on page 165.*



$\frac{2}{2}$ R.H. TWILL $\frac{2}{2}$ L.H. TWILL



(c)



$\frac{2\ \ 1}{2\ \ 1}$ TWILL

(d)

In weaving basket weaves, the use of a selvage motion is also necessary to bind the picks at the selvage. Normally the selvage design is different and rib or plain selvage can be used.

With all plain weave derivatives, the fabrics have higher tensile strength, better abrasion resistance and higher tear strength than the same construction in the plain weave. This is mainly attributed to the high degree of freedom for the yarns to move. A rib fabric has a higher tear strength in one direction than in the other direction, due to the grouping of yarns in one direction; a basket fabric has a high tear strength in both directions.

A combination of the plain weave and its derivatives is sometimes used in the fabric to produce a fancy effect with cords or checks which may be of the same or different yarns.

Twill Weave

Twill Weave, the second basic weave, is characterized by diagonal lines running at angles varying between 15° and 75°. A twill weave is denoted by using numbers above and below a line (such as $\frac{2}{1}$ twill which may be interpreted as two up and one down in the shedding sequence). Fig. 9.6 shows some basic twill weaves. At (a) the $\frac{2}{1}$ twill and the $\frac{1}{2}$ twill are shown; these represent the smallest possible repeat of twill weaves, and one is the opposite side of the other. The repeat is always on a number of ends and picks equal to the addition of the two numbers above and below the line denoting the weave.

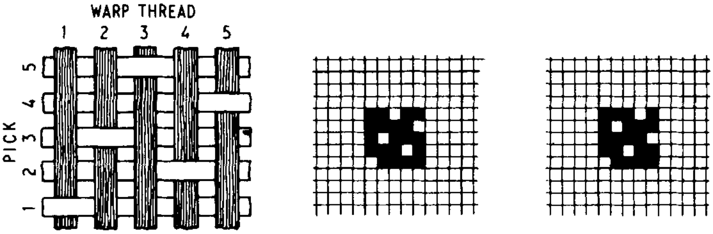
A $\frac{2}{1}$ twill or a $\frac{1}{2}$ twill repeats on 3 ends × 3 picks. If the number above the line is greater than the number below the line, the weave is known as *warp face twill*. If the opposite is true, it is a *filling face twill*. There is a third alternative in which the numbers above and below the line are equal $\left(\text{such as } \frac{2}{2} \text{ twill}\right)$; this is called *balanced twill*. Most twill fabrics are made with warp face weaves. Fig. 9.6(b) shows some balanced twill weaves.

The twill weave is always given a direction; a right-hand twill is one in which the twill line runs from bottom left to top right and a left-hand twill is one in which the twill line runs from bottom right to top left. The angle of the twill is determined by the amount of shift in the points of interlacing. A one pick-one end shift twill weave is called *45° twill*, as shown by Fig. 9.6(c). A twill weave which has more than one pick shift and one end shift is called *steep twill*; if the shift is more than one end and one pick it is called a *reclining twill*. A steep twill will have twill angles more than 45° and a reclining twill will have angles less than 45°, as shown in Fig. 9.6(c). However, the angle of the twill line in the fabric depends on the pick and end densities in the fabric. A 45° twill woven with the same yarn in warp and filling, but with the ends/inch different from the picks/in., will not have an actual twill angle in the fabric of 45°.

Twill weaves can be produced with more than one twill line in the weave. In this case, more than one number is used above and below the line. Fig. 9.6(d) shows a $\frac{2\ 1}{2\ 1}$ 45° right-hand twill. Many variations can be produced by this method of design. Also, there is a vast range of twill weave derivatives which are not covered here. In all these derivatives the twill lines are arranged in different patterns, such as to reverse the direction of the twill or to skip some ends to form broken twill lines.

Satin and Sateen Weaves

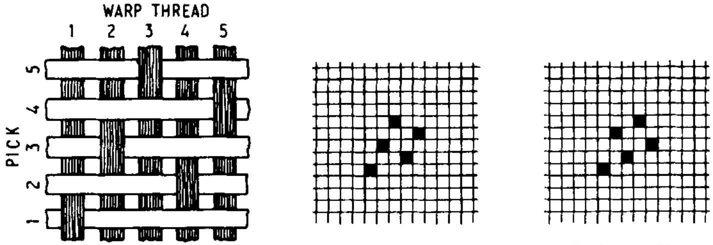
This is the third basic weave, in which the interlacing points are arranged in a similar way to twill weaves but without showing the twill line. The *satin* weave is a warp face weave and the *sateen* is a filling face weave. Sateens are sometimes called *filling satins* weave. Fig. 9.7(a) shows a 5-end (or



2 AS COUNTER

3 AS COUNTER

5-HARNESS WARP SATIN



2 AS COUNTER

3 AS COUNTER

5-HARNESS FILLING SATIN
(SATEEN)

SATIN WEAVES

(a)

5-HARNESS R.H. SATEEN

5-HARNESS L.H. SATEEN

(b)

Fig. 9.7. (Above and opposite). (a) 5-harness satins and sateens. (b) Direction of sateens. (c) 7-harness sateens

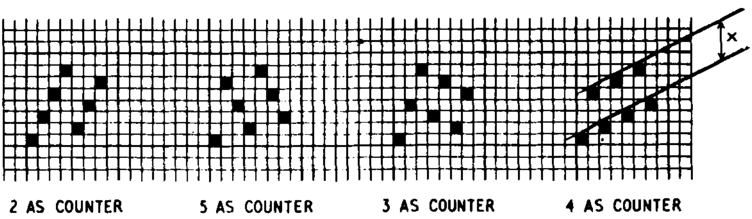


Fig. 9.7. (Above and opposite). (a) 5-harness satins and sateens. (b) Direction of sateens. (c) 7-harness sateens
Note: x = counter

5 harness) satin and 5-end sateen. In this case, the repeat is on 5 ends × 5 picks and it is clear that one design is the back side of the other. There are two different ways of arranging the interlacing points, one by using a *counter* (or move number) of 2 picks and the second by using 3 picks as counter (see Fig. 9.7). It can be seen that in a warp face satin the ends float over all the picks but one in the repeat. The interlacing can be arranged to be in the right-hand direction or in the left-hand direction as shown in Fig. 9.7(b).

For every number of ends and picks in the repeat there is more than one arrangement for the interlacing points. For example, in the case of a 7-end sateen, the possible arrangements are obtained by using counters of 2, 5, 3, and 4, as shown by Fig. 9.7(c). An important condition must be satisfied to produce a so-called regular satin; that is, no interlacing point must touch another. This can usually be achieved by avoiding the use of 1 and its complementary number of ends in the repeat. There are exceptions to this rule, for example, it is impossible to make a regular 6-end satin because the combination of numbers would be 5 and 1, 2 and 4, 3 and 3. In the case of an 8-end satin, the only combination which gives regular satin is 3 and 5, and so on.

Although the satin weave is the back side of the sateen weave produced on the same number of harnesses, it is not true to say that the fabric produced as a satin can be used as sateen. This is mainly because for a satin fabric to be smooth and lustrous, the end density must be higher than the pick density but the opposite is true for sateen fabrics. The sateen fabrics are normally softer and more lustrous than satins, but satins are usually stronger than sateens. In both fabrics, if a heavy construction of filament yarns is used, the fabric tends to be stiff and does not drape easily. However, the length of the float can balance the effect of the construction, but longer floats have disadvantages in that they have an adverse effect on fabric serviceability. Long float satins and sateens are useful in jacquard designing or in combination with other weaves, but are rarely used elsewhere.

Drawing-in Draft, Lifting and Reed Plans

As in engineering, projections which are planar representation of bodies can be used to represent the woven fabric on point paper. These projections are called *design*, *drawing-in draft*, *lifting plan*, and the *reed plan*.

The design represents the manner in which the interlacing between the warp and filling yarns takes place. The drawing-in draft shows the arrangement of the warp yarns on the different harness frames. The lifting (or chain plan) represents the pattern in which the harness frames are lifted or lowered at every pick in the repeat. The reed plan shows the arrangements of the warp yarns in the reed dent. A sketch of a four-harness straight-draw arrangement of warp ends with a two-ends-per-dent reed plan is shown in Fig. 9.8(a) and this is reduced to diagrammatic form in Fig. 9.8(b). The drawing-in draft (D.I.D.) (shown at B) determines the relationship between the design (shown at C) and the lifting or chain plan (shown at A). For example, if harness number 4 has to be lifted on pick number II in the sequence, then the lifting plan must be marked by filling in the square at

P, the arrows indicating the paths by which one arrives at point P.

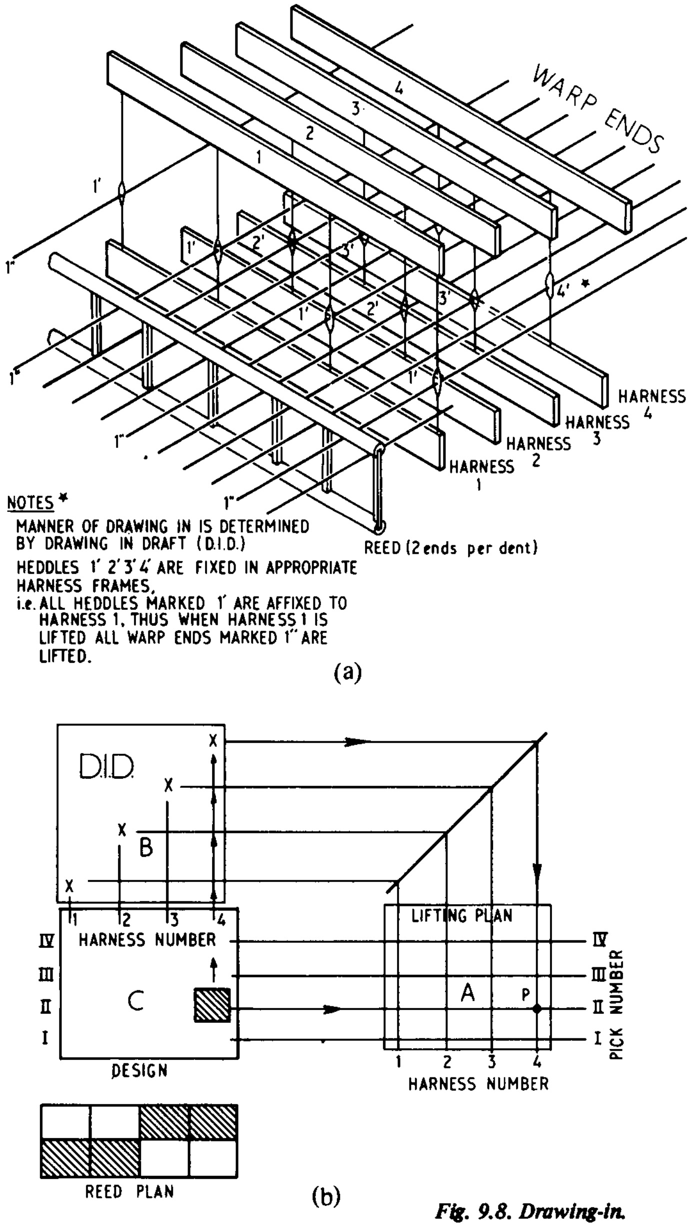
Should the drawing-in draft be straight, then the design and the lifting plan are similar (see Fig. 9.8(c)), but if the drawing-in draft (D.I.D.) be in any other form (e.g. pointed or skip draw), then the lifting plan will be dissimilar to the design. It is then absolutely necessary to make projections similar to those drawn by the arrows in Fig. 9.8(b) to establish the correct relationships between the lifting plan and the design.

Normally, the drawing-in draft is placed either above or below the design with a space in between them. It can be shown by filling in the squares or by using crosses. The lifting plan is usually placed to the right-hand side of the design and it is always based on the filling in of the squares; again, a space between the design and the lifting plan is necessary. The reed plan is normally placed below the design and can be indicated either by filling in squares or by using brackets.

Figure 9.8(c) shows the design, drawing-in draft, lifting plan and reed plan for an 8-end sateen weave. In this case the draft has to be straight, because every end in the repeat is woven differently, and there are eight harnesses. The ends are dented 2 ends/dent. The *reed number* (number of dents/inch or dents/cm) and the end density determine the *width in the reed* (WIR) of the warp.

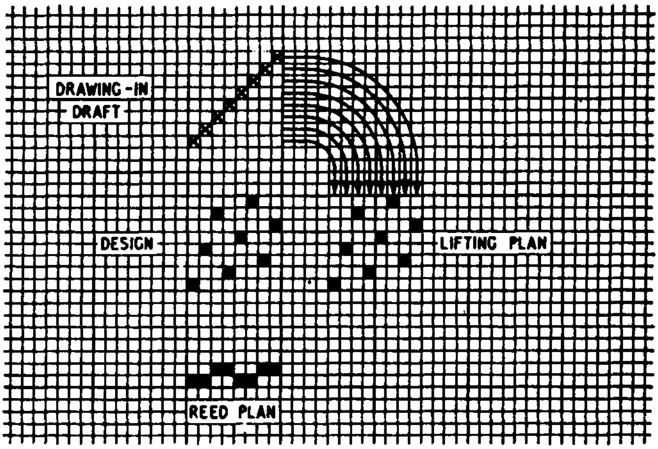
Fig. 9.8(d) is similar to Fig. 9.8(c), but different methods of indication are used. As already indicated, the drawing-in draft can be one of three types depending on the design and the density of the warp. If any two of the projections—design, drawing-in draft, and lifting plan—are given, the third can be deduced from them.

In many cases the selvage design and denting are different from those of the main body of the fabric; they are sometimes included in the representation.

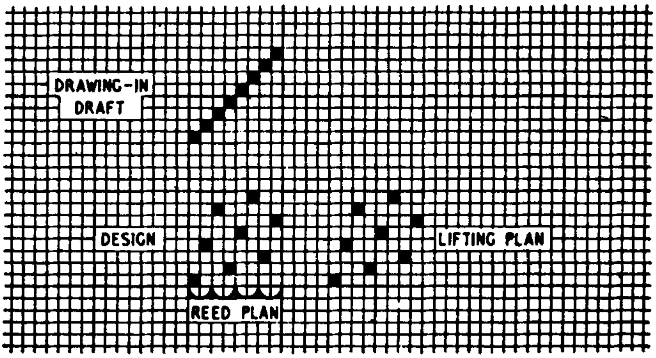


NOTES *
MANNER OF DRAWING IN IS DETERMINED BY DRAWING IN DRAFT (D.I.D.)
HEDDLES 1' 2' 3' 4' ARE FIXED IN APPROPRIATE HARNESS FRAMES,
i.e. ALL HEDDLES MARKED 1' ARE AFFIXED TO HARNESS 1, THUS WHEN HARNESS 1 IS LIFTED ALL WARP ENDS MARKED 1" ARE LIFTED.

Fig. 9.8. Drawing-in.



(c)



(d)

Fig. 9.8. Drawing-in draft, lifting and reed plans

Effect of Woven Fabric Structure on Fabric Properties

The design of a fabric to meet the requirements of a certain end use is a complicated engineering problem. There are many factors involved in the fabric design (such as fiber type, yarn geometry, fabric structure, and methods of finishing) and it is difficult to predict the properties of woven fabrics. However, there are empirical relationships between some of the fabric parameters and the fabric properties. There are also some theoretical relationships (mostly for the plain weave) but theory becomes very complicated when applied to other weaves.

Tensile Strength

The tensile strength of a fabric is a reflection of the strength of the yarn and of the fabric structure. Sometimes, because of the crimp, the fabric strength is less than the strength of twisted yarns; because of the twist in the yarn, the yarn strength is less than the strength of the fibers. However, it is possible to increase the fabric strength over the yarn strength by means of the compacting forces developed in the woven fabric. These can prevent fibers from slipping within the yarn. Other things being equal, plain weave fabrics which have the highest crimp will have the lowest strength.

Extensibility

Equally important to the fabric strength is its ability to extend under load. When the fabric is subjected to tension in one direction, the extension takes place in two main phases. The first phase is *decrimping* or *crimp removal* in the direction of the load. The removal of the crimp is accompanied by a slow rate of increase of the load. The second phase is the extension of the yarn, during which the fabric becomes stiffer, the stiffness depending mainly on the character of the yarn. The more crimp there is in the yarn, the more extensible is the fabric. Therefore, the longer the floats, the less extensible is the fabric.

Surface Friction

Surface friction of the fabric is affected by the crimp and the fabric structure, in addition to the surface friction of the component yarns. Designs which have a high number of intersections in the repeat tend to have high crimp and produce a rough fabric. Long floats, however, produce smooth fabrics with low crimp levels.

Tear Strength

The tear strength of a woven fabric is very important, since it is more closely related to serviceability than is the tensile strength. The behavior of woven fabrics under tearing loads is quite different from their behavior under tensile loading. In the case of tensile loading, all the yarns in the direction of loading share the load; in tear loading, only one, two, or at most a few yarns share the load. The yarn and fabric structures play very important roles in determining the fabric tear strength. The movement of a hairy weak yarn will be restricted during loading, and yarns will be presented to the load one by one; this results in a low tearing strength. Tight constructions will produce the same effect. Loose, open constructions allow more freedom for the yarns to move and group together, thus presenting bundles of yarns to the tearing load; in consequence, the tear strength is high. Designs which have groups of yarns woven together, such as rib weaves and basket weaves will have high tear strengths. Finishing, easy care treatments and coating tend to reduce the tear strength of woven fabrics, especially if they restrict the freedom of movement of the yarns under loading.

Abrasion Resistance

The *abrasion resistance* of woven fabrics is greatly affected by the yarn properties, fabric geometry and construction. The most important factors are the crimp levels and the height of the *crowns* caused by the crimp. The extent to which the crowns are displaced out of the plane of the fabric depends on the weave, yarn number, yarn crimp and fabric count. The greater the number of the crowns per unit area or the greater the area of each crown, the less will be the stress concentration on the crowns, and this leads to higher abrasion resistance. The weave also has a considerable effect on the abrasion resistance of the fabric. Where there are floats, the longer these are, the less restricted are the yarns to move. Also the longer the floats, the larger is the area of contact between the yarn and the abraidant and the higher is the abrasion resistance.

Drape

The *drape* of the fabric is usually defined in terms of the shape or the way in which the fabric hangs down in folds. Bending and shear stiffness have a significant effect on the fabric drapeability. The yarn number, fabric count and the weave are important factors. Heavy fabrics from coarse yarns and dense constructions have poor drape characteristics. Fabrics with long floats in the weave permit the yarns to move freely; this reduces the bending and shear resistance of the fabric, leading to better drape behavior.

Crease Resistance

The *crease resistance* of the woven fabric is affected greatly by the weave. The most important factor is the freedom of yarns and fibers to relax. A plain woven fabric with high fabric count puts a heavy strain on the fibers and limits the recovery of the fabric. The longer the floats, the higher will be the crease resistance of the fabric.

Pilling Resistance

Hairs on the surface of a fabric tend to collect into little balls (pills) and if the fibers are strong, these balls do not break off; this spoils the appearance of the fabric. Low twist yarns are usually hairy and the hairs form sites for the pills to form, especially when strong synthetic fibers are used. Fabric structure plays a part and plain weaves give a higher pill resistance than fabrics with floats, proper crimp balance can minimise the problem for a given structure.

It is apparent that the structure of a woven fabric has a significant effect on fabric properties. It is only possible to engineer the fabric to meet specific requirements by establishing a thorough understanding of the behavior of the fabric in actual use.

10

THE SIMPLE SHUTTLE LOOM

Key words: *auxiliary shaft, bottom shaft, camshaft, closed warp shed, crankshaft, crossed shed, crossing point, dwell, fell, filling insertion rate, flying shuttle, lay, open shed, picking bowls, picking cams, race board, reed, selvage motions, shedding cams, shuttle box, tappets, temples, top shaft, weaving cycle.*

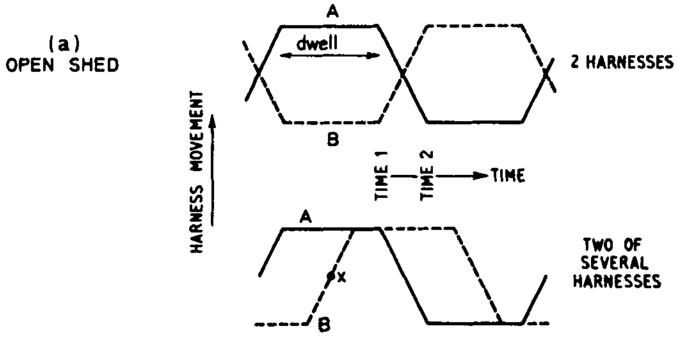
The Weaving Cycle

The functions of the loom (see Chapter 2) are:

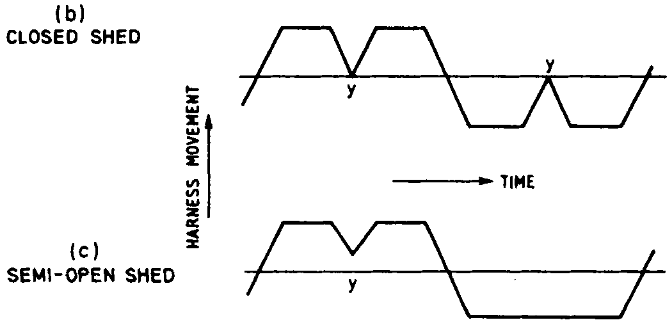
(1) Warpwise control.
(2) Shedding.
(3) Picking.
(4) Beat-up and lay movement.

These functions must be synchronized so that the operations occur in their correct sequence and do not interfere with one another. The relative timing can also affect the nature and quality of the fabric. Consider the case of a two harness loom in which the shedding pattern is very simple. Let the harnesses be designated *A* and *B*; the shedding sequence is then as shown in Fig. 10.1(a). In passing from time 1 to time 2, the sheets of warp become level and at this point (the crossing point) the warp shed is said to be closed. Obviously no shuttle could pass at that time and it is necessary to ensure that it passes while the shed is at least partly open.

More complicated multi-harness shedding patterns are possible but the fundamental concept is similar.


(a) OPEN SHED

Note: change of warp shed B at x would cause ends to go slack or the ends in warp shed A would be over tensioned if wholesale compensation is used


(b) CLOSED SHED

(c) SEMI-OPEN SHED

Note: Only one harness indicated in lower diagrams. Other harnesses can be changed at y and, if compensation is used, uniform tension can be maintained

Fig. 10.1. Types of warp shed (diagrams (b) and (c) are discussed on p. 195).

The transit time of the shuttle

$$t_s = W \div \bar{V}_s$$

where W = effective width of the loom in meters,

$\bar{V}_s$ = average shuttle speed in meters/second,

t_s = transit time in seconds.

Thus the shed has to remain at least partly open for a limited but adequate time and must not open or close at the wrong time. The shed does not have to be fully open at the time of shuttle entry or exit. After the shuttle has passed, it is necessary to rearrange the warps to give the desired fabric structure before the shuttle returns.

There must be a definite time between the completion of one pick and the start of the next. In a shuttle loom, a good deal of this time is spent in stopping the shuttle and then accelerating it in the other direction. Actions other than those relating to picking and checking must also be completed in the same time in a concurrent manner. In theory, the longest of these sets of actions determines the delay time (t_d) but in practice the delay time is determined by the shuttle reversal. Let the average *weaving cycle* time be t_w; since this time varies from one cycle to the next and it is fairly regular over a pair of picks, let the state be defined in terms of $2t_w$. This value $2t_w$ may be defined as the time needed for the shuttle to pass a given point in successive traverses in the same direction. From the foregoing

$$2t_w = t_{s1} + t_{s2} + t_{d1} + t_{d2}$$

where the subscripts 1 and 2 refer to successive picks. The weaving speed is $60 \div t_w$ picks/min, the theoretical filling insertion rate is $\frac{60W}{t_w}$ meters/minute and the actual filling insertion rate is $\frac{60W\eta_w}{t_w}$ meters/minute (where η_w is the weaving efficiency).

It is apparent that the permissible loom speed is a function of the loom width and of the characteristics of the picking and checking mechanisms. It is also affected by other mechanisms.

During time t_d the warp shed has to be changed into a new configuration in order to generate the desired weave, but it is also necessary to position the filling by means of the *reed* in the beating motion. These two actions must be co-ordinated exactly with the weaving cycle. The reed has to be withdrawn rearwards after beating the filling into the *fell* of the cloth and this must be completed (or nearly so) before the next pick can be inserted. The shedding and beating have to be carefully co-ordinated to give the most effective positioning of the filling without undue strain on the warp; hence exact synchronization and proper timing are essential for good weaving.

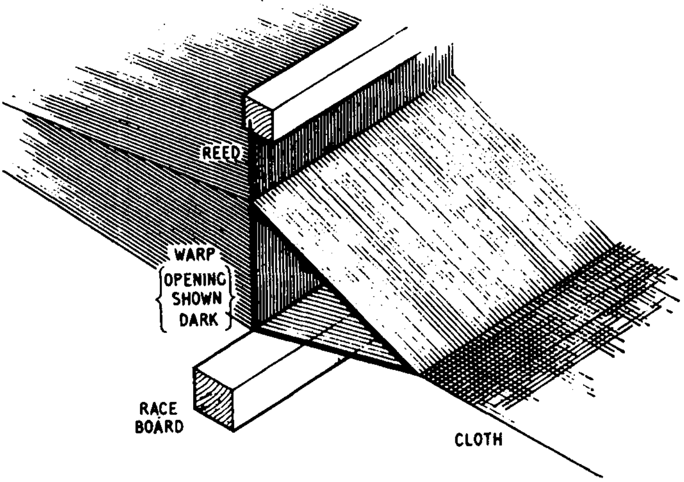


Fig. 10.2. Race board and warp shed

In a shuttle loom, the reed and a so-called *race board* are used as restraints to control the shuttle flight, as shown in Fig. 10.2. The path of the shuttle is important because if it does not enter the *shuttle box* cleanly it will adversely affect the picking and checking, which in turn will affect the whole cycle. If, because of this, the shuttle deviates from its intended path, it might fly out of the loom; this can be very dangerous (such an occurrence is called a *flying shuttle*).

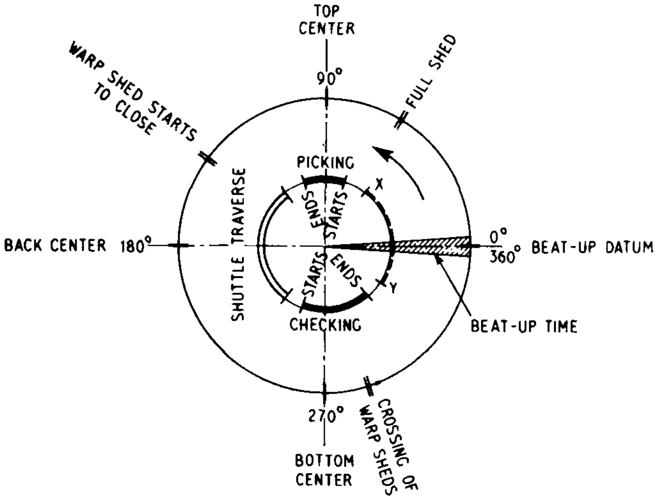


Fig. 10.3. Timing diagram

The beating and shedding cause cyclic tension variations in the warp which, if not controlled, would lead to unacceptable end breakage rates. With high production looms, this is usually controlled by various mechanisms which alter the path of the warp ends so as to relieve the tensions. This too must be synchronized with other mechanisms.

The various mechanisms which have to be synchronized operate in a cyclic manner and they may be described by a timing diagram (see Fig. 10.3).

Mechanisms of Timing

For simplicity, let only the two-harness looms be considered at this stage.

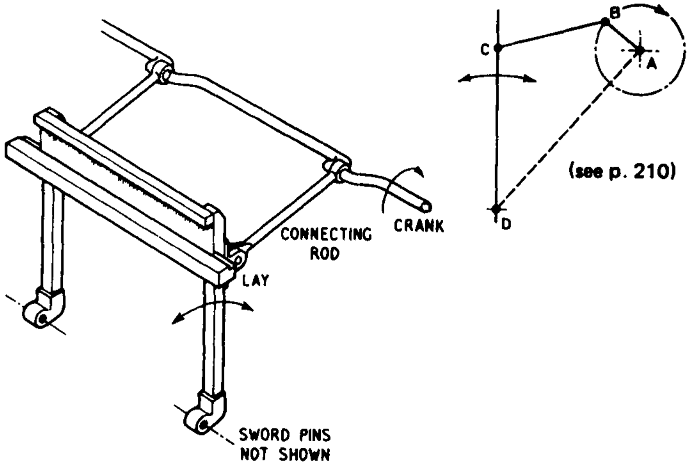


Fig. 10.4. Schematic arrangement of lay mechanism

The *lay* has to operate once per weaving cycle to beat up the newly inserted lengths of filling. During one weaving cycle, a given harness moves from the up to the down position or vice versa. The whole shedding cycle (i.e. from top position to bottom position and back) takes two weaving cycles to complete, thus there must be two drives, one of which operates at half the speed of the other. A loom has two picking mechanisms, one on each side. Each operates every other weaving cycle and therefore it is driven from the same shaft as the shedding motion.

In the normal loom there is a main shaft (or *top shaft* or *crank shaft*) which operates the lay mechanisms as shown in Fig. 10.4. The main shaft is connected by means of gearing or other toothed drive to a second shaft called a *cam shaft* (or *bottom shaft*). This cam shaft drives the shedding motion by means of *shedding cams* (or *tappets*) as shown in Fig. 10.5; it also operates the picking mechanisms by means of *picking cams* (or *picking bowls*) together with various linkages (a typical system is shown in Fig. 10.6).

For more complicated weaves it is necessary to use a

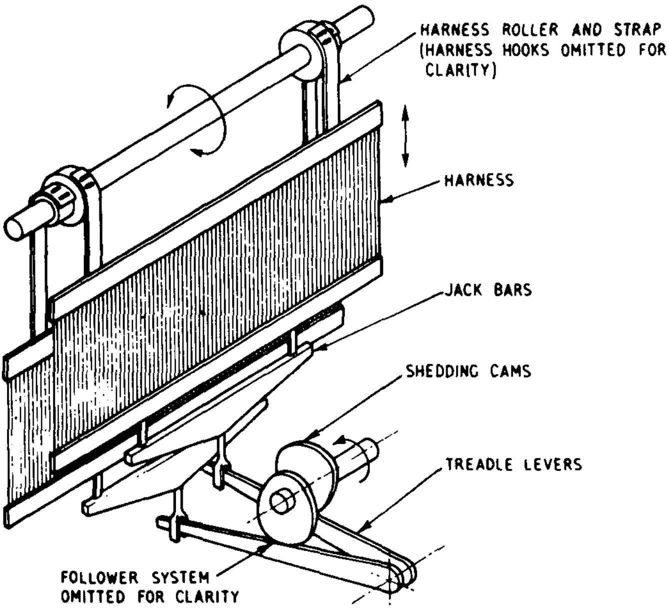


Fig. 10.5. Schematic arrangement of shedding mechanism.

large number of harnesses because of the complex shedding pattern and a separate shaft is usually required for the shedding cams (this is termed an *auxiliary shaft*). For the most complex weaves it is necessary to use a different type of loom but this need not be discussed here.

Timing

Let the point at which the reed reaches its most forward position be the datum. In other words, this point will be represented as O° crank angle and the other mechanisms can be related to this. One complete revolution of the crank shaft is one weaving cycle and this can be represented as 360° of movement.

For convenience the datum will be referred to as beat-up, even though this occupies a finite angular displacement. A typical set of timings is given in Fig. 10.3 but actual timings depend upon the design of both loom and fabric and there

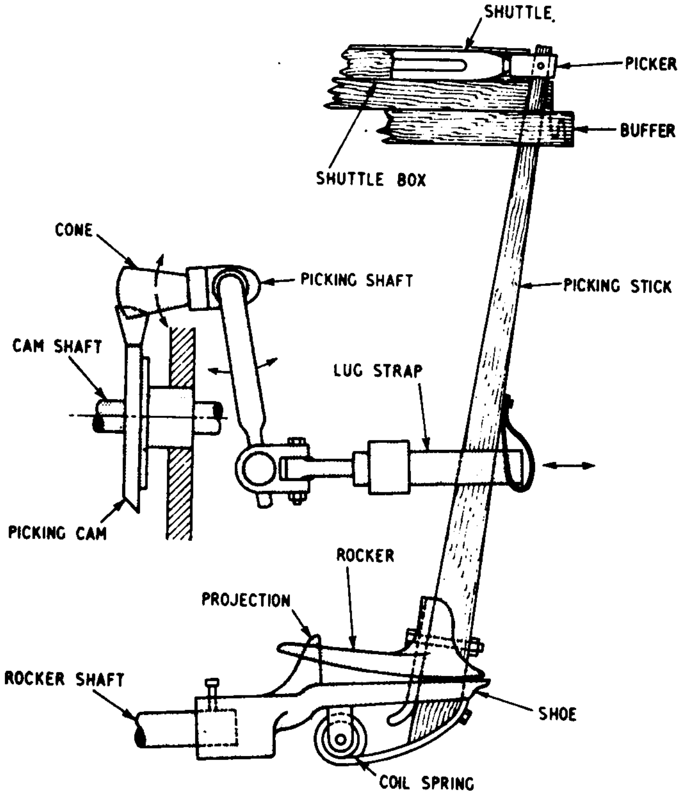
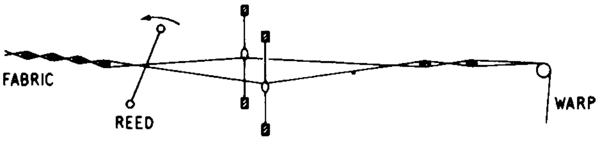
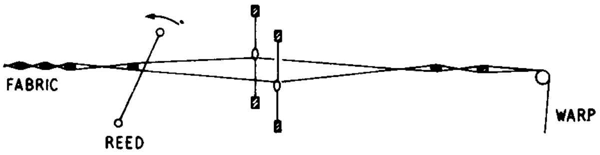


Fig. 10.6. Cone underpick mechanism.

is no unique timing diagram. In the diagram the shuttle movement is related to one circle and shedding to the other. The motion of the lay is a continuous harmonic motion which is directly related to the crank angle. Let the shedding motion be considered first in relation to beat-up. Beat-up is intended to force the filling into its proper position in the fabric by a sort of wedge action and it is exceptional for beat up to take place at the time the warp sheets cross. With



(a) BEATING ON CLOSED SHED



(b) BEATING ON OPEN SHED

Fig. 10.7

staple fiber warp yarns, it is normal to beat up on a *crossed shed* as shown in Fig. 10.7(a), whereas with filament warp it is more normal to beat up on an *open shed* as shown in Fig. 10.7(b). For illustration, the harness movements for the former case are shown in Fig. 10.1(a); it is normal that beat up takes place on a crossed shed, and that the shuttle enters and leaves with the shed partly open. The *dwell* is controlled by the cam profile and must be such as to permit passage of the shuttle for the particular width and speed of the loom.

Consider next the shuttle motion. The shuttle starts from rest at about 80° after beat up and then must be accelerated up to speed, which takes a definite time. It has to change from zero to some 15m/sec (35 mph) after travelling less than 30 cm (1 ft). This imposes high stresses on the mechanism and usually it is necessary for this phase to occupy some 20–30°. After transit, which normally takes some 150°, the shuttle has to be stopped in a like distance and time. The balance of the time (XY in Fig. 10.3) is available to permit the automatic changing of the quill.

The question of the position at which the loom should stop is relevant. It is desirable that it should stop at back center so as to give the best access to the warp shed. It is necessary to stop it before the crossing of shed to permit repair without fault in the fabric. Once the shed is crossed and there is a warp break, the repair will give a wrong shedding for the end unless the loom is turned back, which is undesirable.

It is essential to stop the loom before beat-up to permit the repair of broken filling yarns which otherwise would be beaten into the fabric and probably cause damage.

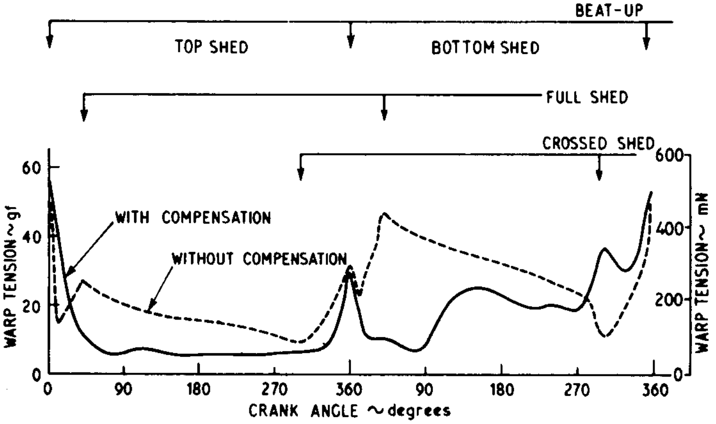


Fig. 10.8. Typical warp tension diagrams.

Interaction between the Textile Material and Loom Parts

The action of shedding causes the length of the warp to vary; this, in turn, causes the warp tension to vary. In the absence of any compensating motion, the tension would vary in sympathy with the harness motion. Thus there would be a tension cycle somewhat similar in shape to the shedding diagram shown in Fig. 10.8. In practice, this is reduced

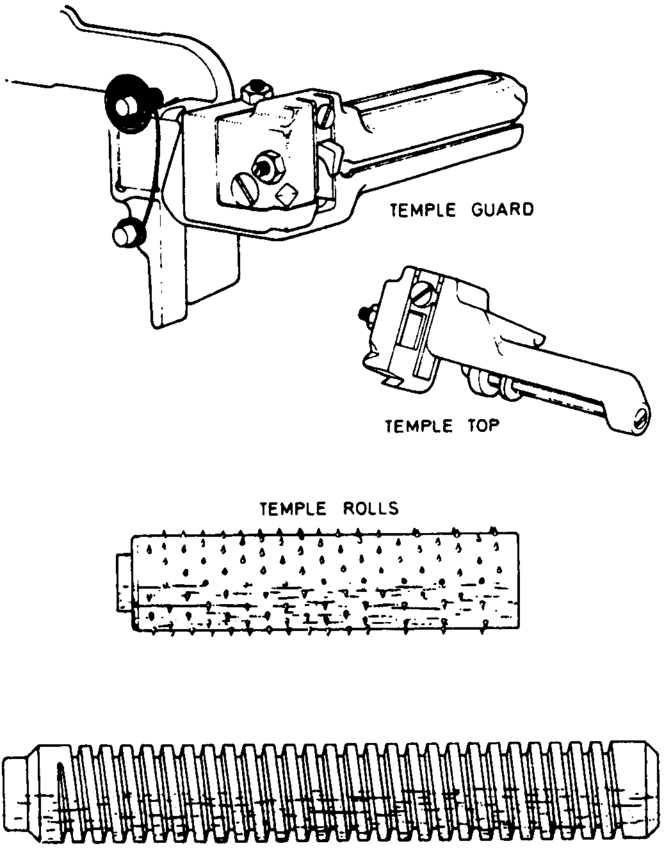
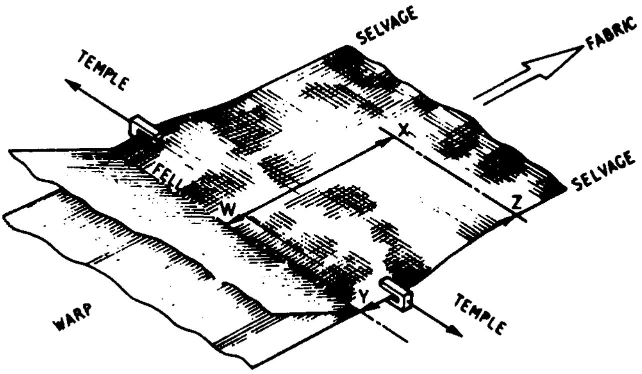


Fig. 10.9. Temple parts.

by having a synchronized compensating motion which reduces the tension peak to give a tension diagram similar to that shown in Fig. 10.8 (full line).

Superimposed upon this is a tension pulse arising from beat-up. For a very light open fabric this pulse is small, but with a heavy dense fabric the pulse can be very large.

There is crimp interchange between warp and filling which is a function of the respective tensions (see Chapter 8). To get a good crimp balance, it is necessary to apply a tension in the filling direction. It is not possible to do this prior to beat-up and therefore the whole fabric has to be tensioned. This is achieved by using *temples*, of which there are numerous types; a fairly common one is shown in Fig. 10.9.



DISTANCE $\overline{YZ}$ > DISTANCE $\overline{WX}$
DUE TO FILLINGWISE SHRINKAGE

Fig. 10.10. Action of temples.

For several reasons, the warp tensions vary from the center to the selvages. Firstly, the shuttle entering or leaving the shed rubs the outermost yarns, causing local peaks in tension; this effect is commonly controlled by using *selvage motions* or separate heddles for the selvage warp ends. Secondly, the crimp in the yarn causes a widthwise contraction of the fabric after leaving the temples. The path length of the outermost warp threads is therefore longer than the central ones (see Fig. 10.10). In addition, it is normal to alter the fabric construction at the selvages to give a durable fabric and this alters the crimp behavior, which in turn affects the tension in the yarn. This can cause damage and increase the end breakage rate, and it may occur in such a way as to cause irregular local damage which spoils the appearance of the fabric.

The frictional forces arising from the movement of the filling during beat-up can play a significant part. With filament yarns which have a high coefficient of friction, the forces generated in trying to beat-up on a crossed shed would cause very high end breakage rates. Friction between the warps and the reed wire, heddle wires, lease rods, drop wires and shuttle can also cause end breaks.

Generally, the action of the machine on the material is more important than the action of the material on the machine. Under normal conditions the material has relatively little direct effect on the performance of the loom, but since the loom can certainly affect the cloth, it is necessary to understand each of the component systems thoroughly if the best is to be obtained from the loom. The following chapters deal with these component systems.

11

SHEDDING AND BEATING

Key words: *baulk, beating, beat-up, bumping, cam, clear shed, closed shed, comber board, complete shed, connecting rod, crank, cylinder, dobby, dobby head, dobby loom, double-lift dobby, drawstrings, feelers, fell, float, grate, griffe, harness, heddle, hook, incomplete shed, jack, jammed fabric, knives, lay, lay sword, lift, lingoes, mails, needle, neck, open shed, pattern chain, peg, punched card, reed, semi-open shed, shed, shedding, shedding diagram, single-lift dobby, spindle, unclear shed, under-cam loom.*

The Interrelationship between Shedding and Beating

From a design point of view, *shedding* and *beating* are interrelated. Referring to Fig. 11.1, it is apparent that the shed opening $(H_1 + H_2)$, the distance B and the angles β_1 and β_2 are related as follows:

$$H_1 = B \tan \beta_1$$

$$H_2 = B \tan \beta_2$$

In a symmetrical system, $H_1 = H_2$, which implies that $\beta_1 = \beta_2$ and $h_1 = h_2$. For ease of reference, let these be referred to as H, β, and h, respectively; also for simplicity let only the simple symmetrical case be considered.

In general

$$h = \text{b} \tan \beta \qquad (11.1)$$

It might be thought that the angle β should be as small as possible so as to reduce the *lift* of the *harnesses* (i.e. to reduce H), since this would reduce the strain on the warp.

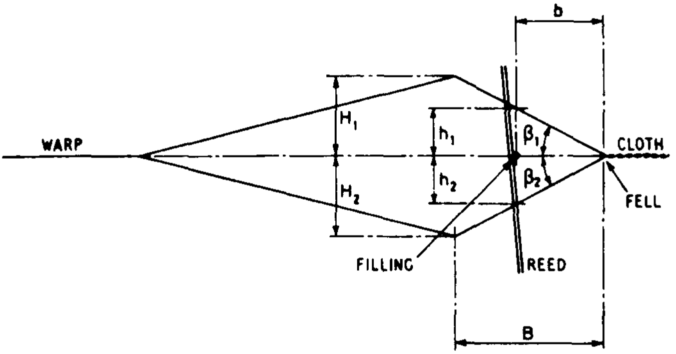


Fig. 11.1. Geometry of warp shed

A reduced lift would also make the mechanism easier to design and operate. However, if β is made too small, the warp sheets will not open properly and some ends are likely to catch up; such an obstructed opening is called an *unclear shed.* In such a case, there is a strong likelihood that the shuttle will rub the protruding warp end and cause it to break. Thus an unclear shed can lead to unacceptable increases in end breaks. Furthermore, the distance traveled by the *lay* in beating the filling into the *fell* of the cloth is a function of β. The lay and associated parts are heavy and appreciable amounts of energy are required to move them quickly over considerable distances; this affects the motor size and efficiency. Also the movement of such large masses gives rise to undesirable cyclic speed changes in the loom.

If the distance the lay moves is b_a, and b_s is a constant, then

$$b_a = b_s + b$$

but

$$b = h \operatorname{cotan} \beta$$

therefore

$$b_a = b_s + h \operatorname{cotan} \beta$$

$$= b_s + \frac{hB}{H} \qquad (11.2)$$

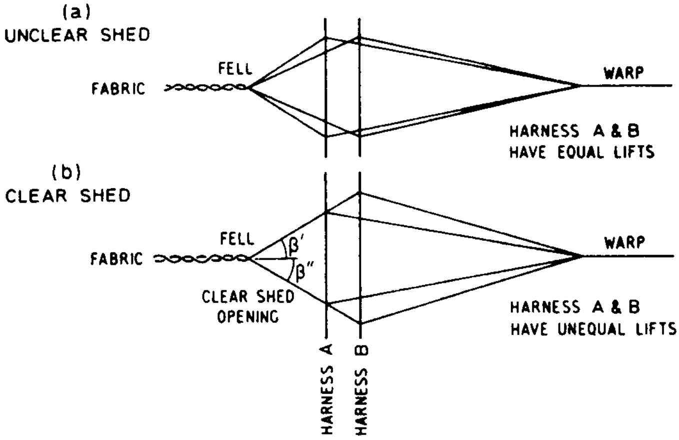


Fig. 11.2. Shed openings.

From eqn (11.2) it can be seen that if the harness lift H is made small, keeping the other parameters on the right-hand side constant, then the lay movement b_a must be increased in order to permit the shuttle to enter. The height of the front wall of the shuttle controls h and is itself controlled by the diameter of the quill which fits in the shuttle. This, in turn, involves the economics of weaving because a small quill has to be changed frequently and handling costs tend to go up as the size goes down. Also, every time a quill is changed there is a potential fault. Good machine design can minimize this potential but it cannot eliminate it completely. Hence for several reasons, the distance b must be limited and a balance has to be struck between the harness lift H and the lay movement b_a. It is desirable that h be as large as possible but that H and b should be as small as possible; clearly it is impossible to reconcile these requirements and a compromise has to be made. The art of achieving the best compromise is beyond the scope of this book.

Shed Forms

If the shed is unclear, as shown in Fig. 11.2(a), it is possible for the shuttle to cause many end breakages and it is usually desirable to keep the angle β the same for all ends in order to produce a *clear shed.* This requires an adjustment to the movements of the various *heddles* unless they can all exist in a plane at a fixed distance from the fell of the cloth. This is an impossible condition for a normal loom because the harnesses must be at different distances from the fell in order to permit their independent movement. To maintain a clear shed, the angle β has to be kept constant and to do this each harness must be given a slightly different lift from its neighbors; in fact, the lift must be proportionate to the distance of the harness from the fell. Thus the differences depend upon how closely the harnesses can be packed; if there are many harnesses, the differences can be large.

For certain looms operated by drawstrings (Fig. 2.7), positive movements which involve the direct drive of the elements occur only in one direction and deadweights return the shed to the lower position. In these cases the shed opening is rarely symmetrical and angles β_1 and β_2 are dissimilar; in fact β_2 can be very small in some cases. Such a system gives a so-called *incomplete shed.* The most common case of shedding, called a *complete shed,* is as shown in Fig. 2.8; the sheds are driven in both directions.

The timing of the opening of the fully open shed is important. Various systems have been designed to compensate for the change in warp length in shedding and so minimize the variations in warp tension (see Chapter 10). These systems operate on all warp ends, and if some ends are left in position whilst others are moved, the compensation will act on some more than others; this may cause some ends to go slack and some to be over-tensioned. The slackness might enable entanglements to form and the high tensions could lead to end breaks; the variations in tension

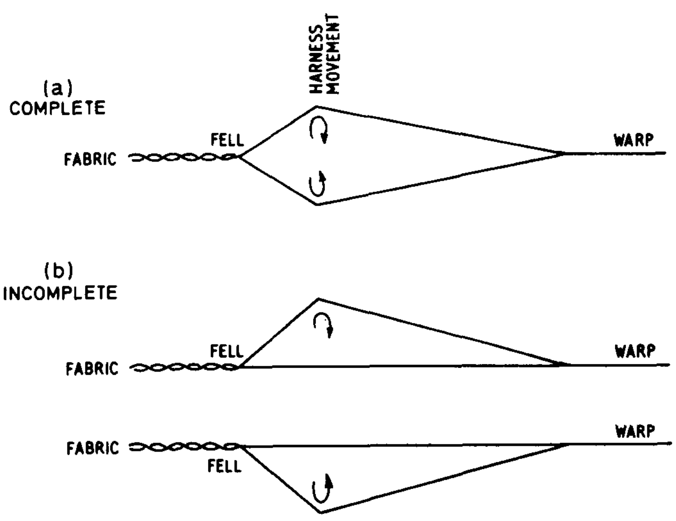


Fig. 11.3. Shed forms.

would also affect the fabric structure. In the simple case, where the shed is changed only as dictated by the fabric weave, the *shedding diagram* might be as shown in Fig. 10.1(a). Where compensation is used, the corresponding shed must be adjusted to avoid the difficulties cited; the diagram might be as in Fig. 10.1(b). The former is called an *open shed* and the latter a *closed shed*. It is also possible for the shed to be asymmetrical, in which case the shedding has to be adjusted to give minimum tensions and a *semi-open shed* is used, as shown in Fig. 10.1(c).

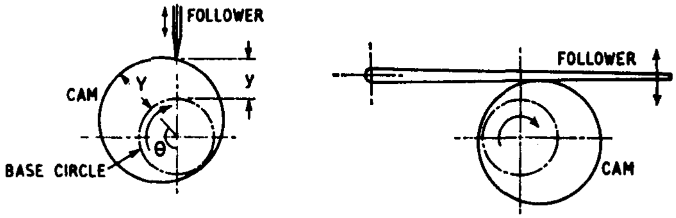
Shedding Motions

The lift of the heddles can be achieved by using *cam* or *dobby* operated harnesses or by *drawstrings* and each has its own limitations. Leaving aside all mechanical differences, it is useful to consider the operational limitations. Most cam systems tend to be inaccessible and it is sometimes inconvenient and time consuming to change the weave, especially with complex fabric designs. With such complex weaves (which need many harnesses), a change can involve replacement of some or all of the cams, which is a fairly lengthy process. Occasionally, alterations can be made by varying the cam-shaft speed in multiples so as to avoid cam changes. The most important advantages of the cam system are that the design permits a relatively high speed and the system is inexpensive. Some of the operational inflexibility of the cam loom can be circumvented by good organization if there is a sufficient number of looms at the disposal of the manager.

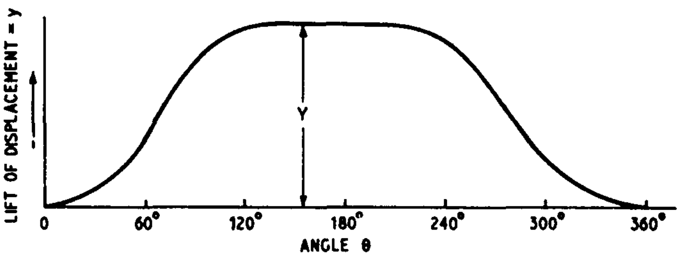
Moving to the other extreme, a Jacquard loom is very flexible as far as the weave is concerned because it is possible to control single ends if so desired. Fabric designs can be changed merely by inserting a series of punched cards into the *pattern chain*. However, the production rate is very low and consequently these looms are used only for complex weaves. The Jacquard heads are expensive and therefore there is considerable incentive to find cheaper ways of producing patterned fabrics, especially if the required pattern is not too complex.

Intermediate between the Jacquard and the cam looms is the *dobby loom*; this loom is one on which small geometric and regular figures can be woven. Originally a dobby boy sat on top of the loom and drew up the warp as required to form the pattern. This function has now been automated and a device which replaces the dobby boy has become known as a *dobby head*. The origin of the word dobby is obscure.

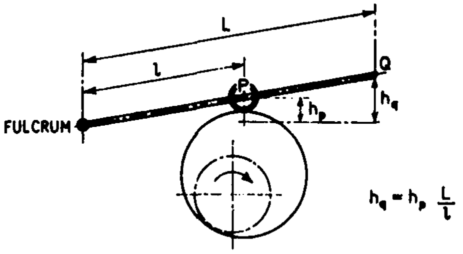
The inaccessibility of the multiple *under-cam* system limits the design possibilities. One solution is to bring the cams to the side of the loom where they are more accessible. This permits an increase in the number of harnesses from about eight to about sixteen, but the system tends to be cumbersome. It is an obvious advantage to miniaturize the system so that the drive to the harnesses is triggered by an actuating device rather than being driven directly. This, in fact, is what a dobby head does; instead of a cam and lever system, a peg or some other discontinuity in a pattern chain triggers the appropriate shed changes. The pattern chain determines the



(a) RADIAL FOLLOWER (c) ROCKER FOLLOWER



(b) LIFT DIAGRAM



(d) ROCKER FOLLOWER WITH EXTENDED ARM AND ROLLER FOLLOWER

Fig. 11.4. Simple cam systems

weave. The variety of patterns and the ease of change is increased considerably. Against this must be set a slight decrease in the maximum permissible operating speed; this arises because of the excessive stresses set up in the dobby head when it is operated over the maximum safe speed.

To understand some of the restrictions, it is necessary to consider some elements of cam design. First, an explanation may be given in terms of a cam with a radial knife edged follower, even though this is a gross oversimplification. Referring to Fig. 11.4(a), the rotation of the cam causes the follower to lift along a radius and its vertical position is determined by the angle θ; the lift diagram is shown in Fig. 11.4(b) where any ordinate refers to the corresponding radial distance between the base circle and the outside operating surface of the cam. The relationship between these two parameters is linear, but if the follower does not move along a radius or if a knife edged follower is not used, this linear relationship no longer holds. Since practical cam systems do have nonlinear relationships, the actual cam shape is dissimilar to the lift diagram and this implies that cams from different systems are not interchangeable. In practice, interchanges are possible in many cases but care has to be taken in this respect, especially where high performance systems are involved.

If the case of the simple system, it is possible to have a rocker follower (Fig. 11.4(c)) which will give a lift diagram similar to the one previously mentioned, providing the distance l is adequate. If the arm is extended as in Fig. 11.4(d), the point Q will move a greater distance than the point P but the shapes of the respective displacement diagrams will be similar. The lift at Q

$$= \text{(the lift at } P) \times \frac{L}{l} \qquad (11.3)$$

With a given mechanism, it is possible to alter the position of Q with respect to P and thereby change the lift at Q. If the harnesses are connected at Q, then the lift can be adjusted as required by altering either L or l and the varying lifts that are needed to give a clear shed can be obtained by this means without having to have a wide range of cams.

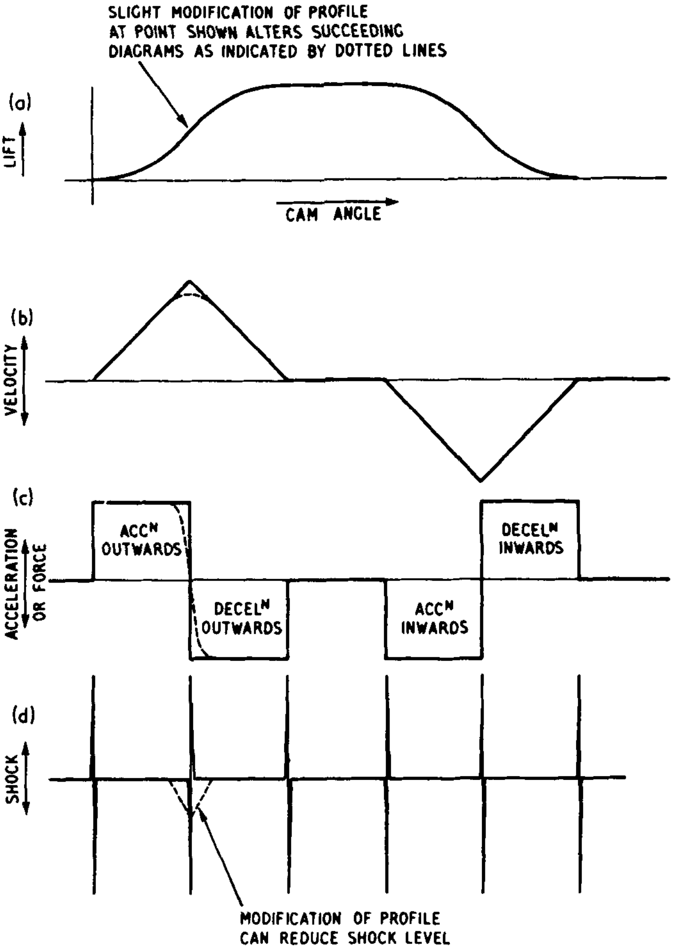


Fig. 11.5. Lift diagram with corresponding velocity, acceleration and shock diagrams.

A rocker follower which operates about a fixed fulcrum would cause the point Q to move in an undesirable arcuate path but if the fulcrum is allowed (or caused) to move to compensate, a desirable straight lift can be obtained. A similar problem exists in picking and since it is so important in that context, the matter will be dealt with under that heading.

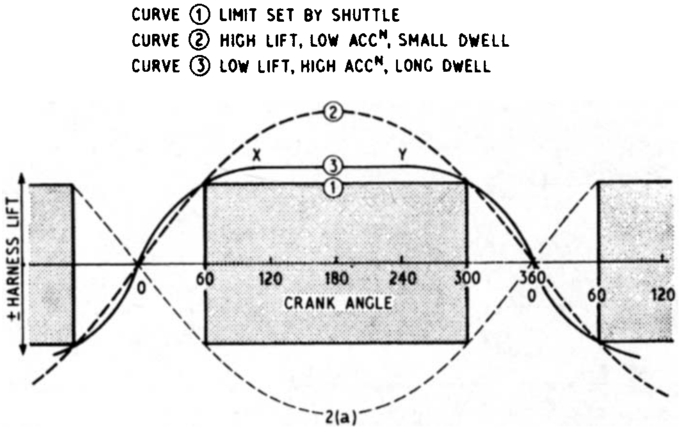


Fig. 11.6 (a) Shedding diagrams and shuttle interference. N.B. Sheds are not always symmetrical

A lift diagram such as that shown in Fig. 11.5(a) implies that the corresponding velocity diagram will have steep portions, which in turn implies an acceleration as shown in Fig. 11.5(c). A high acceleration acting on a mass will produce a large force, and a sudden change in acceleration produces a shock which will produce noise and vibration. Thus the cams must be designed to minimize these forces as well as the shocks, and the faster the loom runs the more important this becomes. (In mathematical terms, if the lift is h, the harness velocity is $\partial h/\partial t$, the acceleration is $\partial^2 h/\partial t^2$ and the shock level is proportional to $\partial^3 h/\partial t^3$.) Suppose the dimensions of the shuttle and the timing dictate that the harness lifts should lie outside the shaded area shown

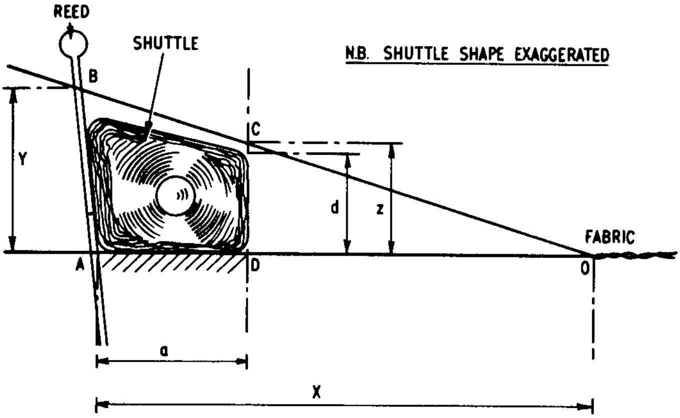


Fig. 11.6 (b). Shuttle interference at C.

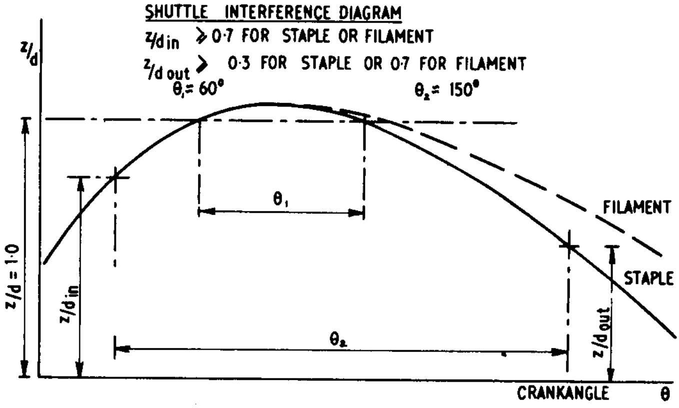


Fig. 11.6 (c).

in Fig. 11.6; in such a case there are several alternative solutions. The acceleration can be minimized by using a curve such as 2, but this would be at the expense of an increased harness lift (which would strain the warp ends and lead to increased breakage rate). It is also possible to maintain the dwell between *Y* and *X* as shown in curve 3, but this would be at the expense of generating extra forces in the mechanism (which might limit speed). Thus a compromise is usually needed, but the band of acceptable solutions will narrow as the picking rate increases and, of course, high picking rates are preferred. The solution also depends upon several other factors; for instance, with a closed shed there are some rather rapid changes which generate high forces and it is not usually possible to operate a closed shed as fast as an open one.

The warp shed opening (Z) may be calculated from the similar triangles OAB and OCD shown in Fig. 11.6(b).

$$z = Y(1 - a/x)$$

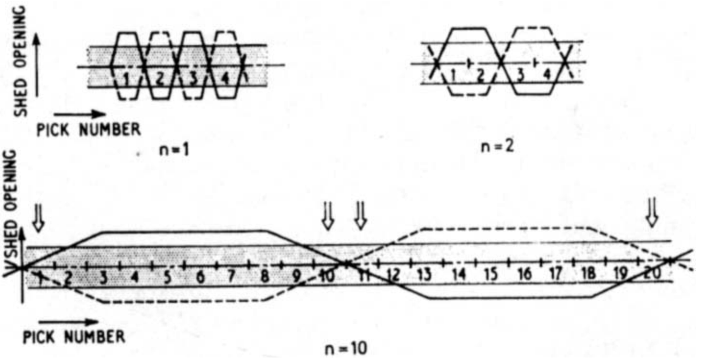
The warp shed opening needed to clear the shuttle at point C as it traverses the loom depends upon the lay position and the dimensions of the shuttle. Should the warp shed fail to clear the shuttle, there will be a degree of warp abrasion especially at the selvages. However, it is common practice to accept a degree of shuttle interference for the sake of increased productivity as will be explained later.

For example, consider a case where a loom runs at 200 picks/min, the shuttle velocity is 20 m/sec (66 ft/sec) and the crankangle over which the shed is open sufficiently for the shuttle to pass without shuttle interference is 80°. The loom speed is (200 x 360)/60 = 1200 degrees/sec. Hence the warp shed is open for 80/1200 = 0.06666 sec and, in this time, the shuttle travels 20 x 0.06666 = 1.3333 meters. The width of fabric that could be woven without shuttle interference is 1.333 $-\ell_{sh}$ (where ℓ_{sh} is the effective length of the shuttle). Thus if ℓ_{sh} is 0.3 meters, the maximum fabric width would be 1.0333 meter if shuttle interference were completely eliminated. Any attempt to weave wider fabric would lead to a tendency for warp abrasion and this would get worse as the width increased. Similarly with speed, if the speed were increased to (say) 250 picks/min, the loom speed would be 1500 degrees/sec, the shed opening time 0.053 sec and the shuttle would travel 1.0666 meter in this time; thus the maximum width would decrease from 1.0333 to 0.7666 meter for the particular timing and shuttle speed. Thus it can be seen that any increase in speed or width (both of which tend to increase productivity) can only be achieved at the expense of shuttle interference. All the factors are closely related and are NOT independent variables.

By suitably shaping the shuttle, the effects can be minimised. It is usual to make the front wall height (d) less than the back wall height (the wall in contact with the reed is larger), and the shuttle edges are rounded. Also the shuttle ends are pointed, which reduces the effective shuttle length (ℓ_{sh}) and by these means it is possible to carry the largest possible quill (shown dotted in Fig. 11.6 (b)) for the minimum amount of shuttle interference.

Even when all these precautions are taken, the avoidance of all shuttle interference would unnecessarily restrict productivity. Because of the smooth pointed ends to the shuttle, it is quite possible to allow the shuttle to enter a warp shed which is too small but opening. It is also possible to allow the warp shed to close on the departing shuttle. The extent of these interferences depends mainly upon the warp yarns. A typical warp shed opening diagram is given in Fig. 11.6(c) and it will be observed that the crankangle interval ($\Delta\theta$) is much enlarged by permitting a controlled amount of shuttle interference. For typical staple yarn $(Z/d)_{in} > 0.7$ and $(Z/d)_{out} > 0.3$, whereas with most filament yarns $(Z/d)_{in}$ and $(Z/d)_{out}$ are both greater than 0.7. Limited adjustments to $\Delta\theta$ can also be obtained by varying the loom timing.

In practice, knife edged followers are not used. A knife edge would wear too rapidly and it is usual to use a roller



NB. Shaded areas indicate minimum shed opening to permit passage of shuttle. Interference indicated by arrows in the case of n=10

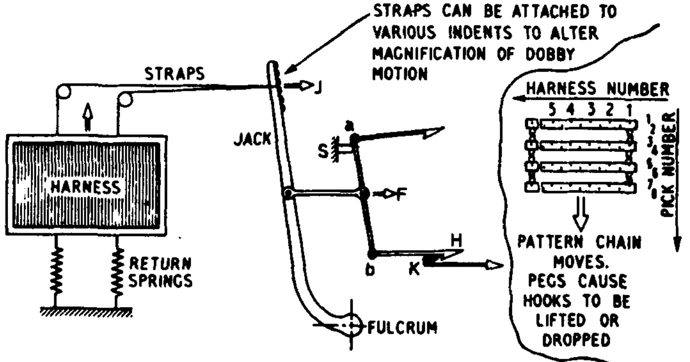
Fig. 11.7. Shedding diagrams from one given cam.

follower as shown in Fig. 11.4(d). The roller is limited in its ability to follow the cam surface when there are very rapid changes in profile; for instance, a roller cannot produce a vee-shaped lift diagram because the roller surface cannot make contact with the apex of the vee. The larger the roller or the sharper the vee, the less will be the conformity. The diameter of the roller thus determines, in part, the profile of the cam and this is another reason why care should be taken in interchanging cams between different sorts of looms.

A gear train is normally used to connect the crankshaft and the camshaft to maintain proper synchronization. In one shedding cycle, the harness remains up for one dwell period and down for the other. With a plain weave, two picks are inserted in this time and the camshaft has to rotate at half the crankshaft speed. If 4 : 1 gearing were used, two picks would be inserted with the harness in the up position and two in the down position. If $2n$: 1 gearing were used there would be n picks inserted between changes. Such a procedure is used to make twills and other structures which require *floats*, but there are limitations. Consider an extreme case; let $n = 10$ and let the cam profile shown earlier be used. As shown in Fig. 11.7, the changeover of the shed would still be in progress at the time that picks number 1, 10, 11, 20, etc., should be inserted. The shed would be insufficiently open to allow the shuttle to pass and it would be impossible to weave unless the cam profile were changed to give a very rapid shed change. Such a profile could only be run at a diminished speed.

With a given fabric structure, the pattern repeats even though it might only be one up, one down. Whatever the pattern, the gear ratio should be equal to the number of picks per complete repeat. For example, with a plain weave the repeat is over 2 picks and the gear ratio is 2 : 1. For a 2 × 2 basket weave, the repeat is over 4 picks and the gearing ratio is 4 : 1.

To simplify matters, normal fabrics woven on a cam loom are usually restricted so that all cams are similar but merely displaced in terms of their relative angular position. When the fabric structure is changed it is sometimes necessary to



IF HOOK (H) IS DROPPED, MOVEMENT OF KNIFE (K) IS TRANSMITTED TO (F), STOP (S) ACTS AS FULCRUM TO LINK a b, MOTION (F) IS MAGNIFIED BY JACK ACTING AS A LEVER, CAUSING (J) TO OPERATE THE HARNESS VIA THE STRAPS

Fig. 11.8. Basic dobby motion. Not to scale. Certain parts omitted for clarity

change cams, gearing or both; therefore, accessibility to these parts is important.

Dobby Shedding

The cams used in a cam loom fulfill two functions, namely:

(1) To position the harnesses as required from time to time
(2) To transmit the power needed to cause the desired movement.

In a dobby mechanism, these functions are separated, with the result that the actuating mechanism can be very much lighter in construction and much more compact and accessible. These improvements permit the production of more complex weaves under normal mill conditions without the sacrifice in productivity that follows the use of a Jacquard loom. The Jacquard loom is used primarily for weaves which are too complex for the dobby loom.

Basically, the dobby mechanism consists of two sections; one section is concerned with power transmission, the other with the connection and disconnection of the harnesses to and from the power source at the appropriate time. The latter device may be regarded as a sort of mechanical equivalent to an electrical switch. On the power side of the switch, there is a permanently connected set of moving *knives* which reciprocate along fixed paths. As shown in Fig. 11.8, there are hooks (*H*) which hinge on a *baulk* (*ab*); when these hooks are lowered, they engage the knives and move with them. In one mode, the stop (*s*) acts as a fulcrum and thus the movement of the knives causes the central link to move, which in turn causes the *jack* to move. The motion is magnified by the lever action of the jack and is transmitted to the harnesses. The connection and disconnection of the hooks is caused by *needles* or *feelers* which contact the pegs in the pattern chain.

Other modes are possible. Figure 11.9 shows four modes,

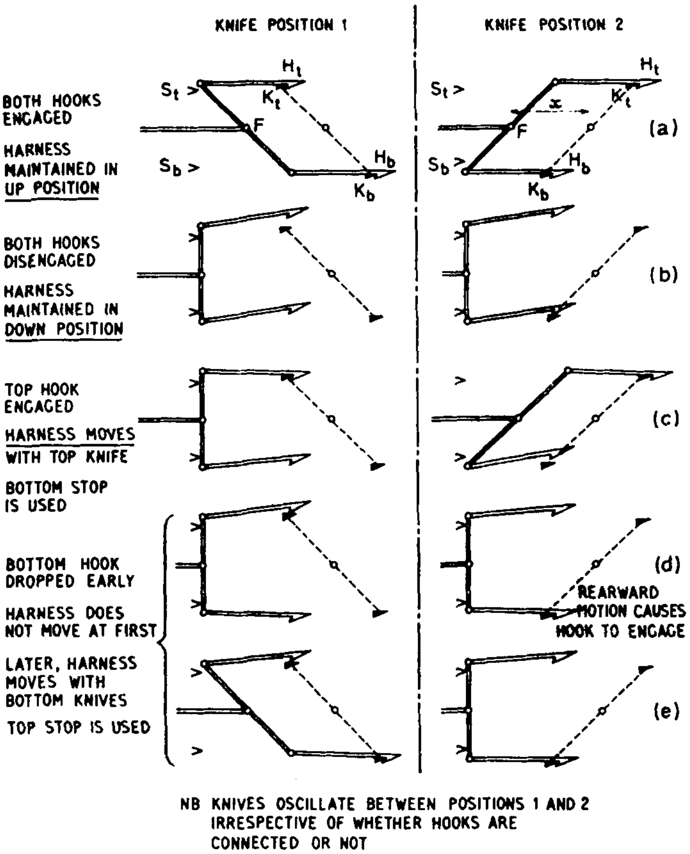


Fig. 11.9. Different modes of action of a dobby.

the knives being shown in each of the extreme positions. When both hooks are engaged, the baulk merely seesaws about point F and the harnesses are maintained in the up position. When both hooks are disconnected, the baulk is held against both stops and the harnesses are maintained in the down position. When one hook is disengaged, the harness will move up and down in sympathy with the other knife. It is the practice to lift the rearward knife because at that time the appropriate portion of the baulk is held by the stop and the hook can be raised without damage. A hook can be dropped at any time, but there may be a time lag before it latches into proper sequence as shown in sections (d) and (e) in Fig. 11.9.

By altering the distance x (Fig. 11.9(a)), it is possible to operate with semi-open sheds. Therefore it is possible to obtain any desired shedding diagram by having two sets of pegs, hooks, and knives per harness; this is known as a *double lift dobby*. It is also possible to use a single set, but *single lift dobbies* are now comparatively rare.

Single Lift Jacquard

Pattern cards are presented to a four-sided "*cylinder*" in such a way that every card fits one side (Fig. 11.10). Every card on the chain represents one pick in the weave. Thus the cylinder speed of rotation is one-quarter that of the loom crankshaft. The cylinder moves away from the needles, rotates one-quarter of a revolution to present a new card and then moves again towards the needles. A hole on the card indicates that the corresponding hook has to be lifted. The movement of the needle through the hole, under spring pressure, causes the hook to be ready to engage with the knife. The knife therefore lifts the hook during its upward movement, which in turn lifts the cord attached to the hook. The ends passing through the heddles (or mails) attached to the hook will then be lifted. When no hole faces the needle, it will be pushed by the card against the spring and the hook will be kept away from the knife.

In order to prevent the rotation of the hook, the lower end is bent and passes through a narrow slit in the *grate*. When the hook is not engaged with the knife the bent end rests on a *spindle* which controls the lower position of the warp yarns.

The capacity of a Jacquard head is indicated by the number of hooks (each hook has one needle). The single-lift Jacquard discussed here is the simplest and gives the necessary basic

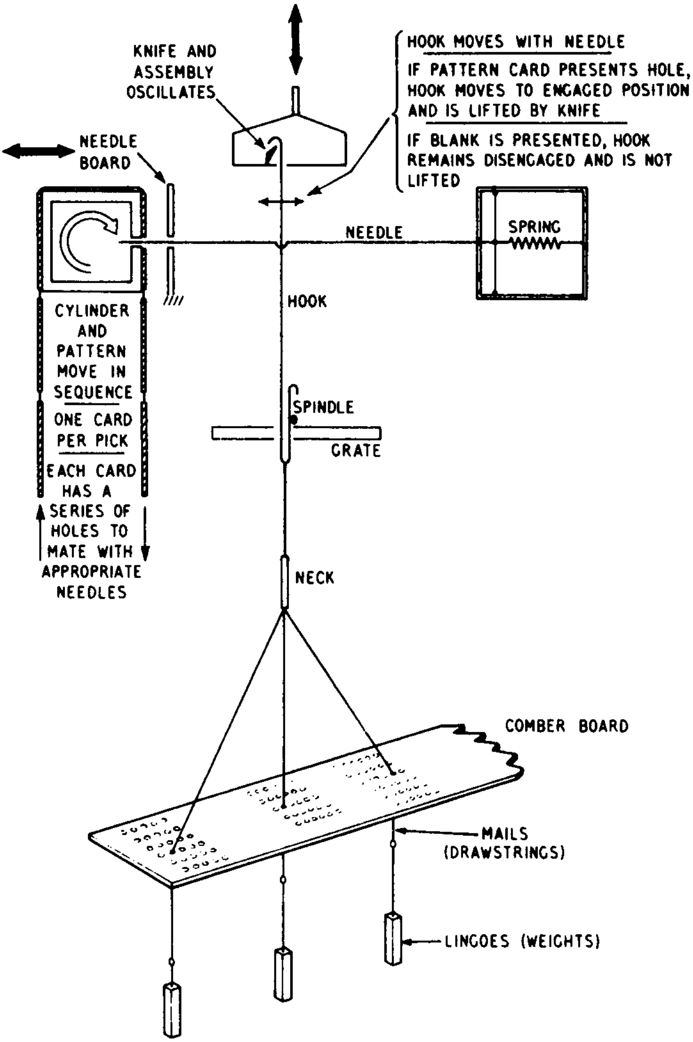


Fig. 11.10. Single lift Jacquard

principle of Jacquard operation, but there are also double lift Jacquards of a variety of designs which are more complex; these are beyond the scope of this book. Suffice it to say that double lift machines usually have two cylinders (one on each side of the needles), two card chains, and no spring box.

Selvage Motion

In the case of Jacquard and dobby looms there is no problem in weaving the selvage, which in all cases has a design different from the weave in the body of the fabric. With cam looms, however, the situation is different, since the number of harnesses is limited. In this case, it is necessary to use a separate shedding motion for the selvage yarns. In its simplest form, the selvage motion uses two pairs of small frames with heddles, one on either side of the loom. These frames get their motion from eccentrics or cams fixed on the loom camshaft, or on a separate shaft. The most common weaves used for the selvage are plain, 2 × 2 rib or 2 × 2 basket weaves.

Beating Motions

The Motion of the Lay

A lay mechanism is shown in Fig. 10.4. It will be seen that the mechanism is in reality a four bar chain in which the loom frame forms the link AD. The link AB is the *crank*, the link BC is the *connecting rod* and the link CD is the *lay sword.* As the crank AB rotates, it causes the point C to oscillate and if the reed is attached to the link CD (or an extension of it), it, too, will oscillate as required. If the crankshaft is geared to the camshaft (and auxiliary shaft where appropriate) in the proper manner, then the essential synchronism is achieved.

It is highly desirable that the lay should stay in the back position as long as possible so as to give the shuttle more time to pass. This requires that the lay should move in a fairly complex harmonic motion. To understand this it is necessary to analyze the mechanism. To simplify the motion, it is possible to assume that the point C moves along a straight line rather than along an arc (as the radius *CD* is always large compared to *AB*, this is a reasonable assumption). For the purposes of explanation, let it be further assumed that the line of action of *C* passes through *A* and that the loom speed remains constant. Let

r = length of crank
l = length of connecting rod
h = instantaneous perpendicular distance of *B* from line *AC*
θ = crank angle relative to inner dead center (in radians)
ϕ = inclination of connecting rod to *AC* (in radians)
x = displacement of lay from the beginning of its stroke
v = velocity of lay
$= dx/dt$
f = acceleration of lay
$= d^2x/dt^2$
ω = angular velocity of crank in radians/second

Displacement $x = l + r - l\cos\phi - r\cos\theta$

$$= r(1 - \cos\theta) + l(1 - \cos\phi) \qquad (11.4)$$

but $h = r\sin\theta$

$$= l\sin\phi$$

therefore $\sin\phi = \frac{r}{l}\sin\theta$

By Pythagoras $\cos\phi = \sqrt{1 - \sin^2\phi}$

$$= \frac{r}{l}\sqrt{\left(\frac{l}{r}\right)^2 - \sin^2\theta}$$

Substitute in eqn. (11.4)

$$\frac{x}{r} = 1 + \frac{l}{r} - \cos\theta - \sqrt{\left(\frac{l}{r}\right)^2 - \sin^2\theta}$$

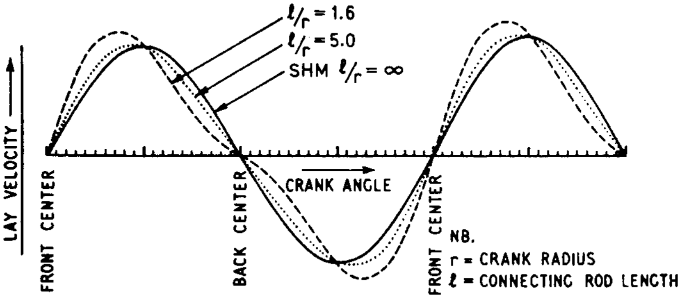


Fig. 11.11. Effect of short connecting rod

but if $$D^2 = \left(\frac{l}{r}\right)^2 - \sin^2\theta$$

$$x = r\left(1 + \frac{l}{r} - \cos\theta - D\right)$$

Differentiating $$v = \frac{\mathrm{d}x}{\mathrm{d}t}$$

$$= \frac{\mathrm{d}x}{\mathrm{d}\theta} \cdot \frac{\mathrm{d}\theta}{\mathrm{d}t}$$

$$= \omega \cdot \frac{\mathrm{d}x}{\mathrm{d}\theta}$$

$$= \omega r\left(\sin\theta + \frac{\sin 2\theta}{2D}\right)$$

$\sin^2\theta$ is small compared to l^2/r and it is a close approximation to write $D = l/r$, whence

$$v \simeq \omega r\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right) \tag{11.5}$$

TABLE 11.1

Effect Of Varying the Connecting Rod Length

l/r	*Connecting Rod*	*Type of Movement*	*Type of Fabric*
Greater than 6	Long	Very smooth with low acceleration forces	Fine cotton Silk Continuous filament
Between 6 and 3	Medium	Smooth	Medium density cottons
Less than 3	Short	Jerky with high acceleration forces	Heavy cottons Woolen

Figure 11.11 shows a series of curves for various values of l/r. It will be seen that as the connecting rod is made shorter there is an increased deviation from the pure sine wave (the sine wave represents simple harmonic motion or SHM). This is another way of saying that the lay lingers in the back position because of the shortness of the connecting rod, and it is this which is used to advantage in the loom.

There is a limit to the amount of deviation which can be achieved because as $l \to r$ the mechanism becomes unworkable; when $l = r$, the crank and the connecting rod could spin round a common center and the lay would not move at all. In fact, when the connecting rod is made too short, the system will jam and it is normal for $l > 2r$.

The value of l/r used in a loom depends upon whether a smooth action is required or whether an impulsive jerky type of beat-up is needed; this in turn depends upon the fabric to be woven and the width of the loom. A fine delicate fabric should not be roughly handled, whereas a coarse staple yarn may require a sharp beat to be effective. With a wide loom, the shuttle transit time is long; this leaves less time for the other functions and therefore the beat-up has to be short if the loom speed is to be kept up. For example, l/r for a 45 in. loom might be 4, whereas for an 85 in. loom it might be as low as 2. The range of values for various conditions is shown in Table 11.1.

Generally, the long connecting rod enables a light loom construction to be used whereas the short connecting rod demands a heavy construction which adds to the weight of the reciprocating masses and further increases the forces. To understand how the high accelerations arise, it is necessary to differentiate eqn. (11.5).

The lay acceleration

$$\begin{aligned} f &= \mathrm{d}v/\mathrm{d}t \\ &= \omega \,.\, \mathrm{d}v/\mathrm{d}\theta \\ &= \omega^2 r\left(\cos\theta + \frac{r}{l}\cos 2\theta\right) \qquad (11.6) \end{aligned}$$

It will be noted that pure SHM would give an acceleration of $\omega^2 r\cos\theta$ and the difference caused by the short connecting rod is $\frac{\omega^2 r^2}{l}\cos 2\theta$. An infinitely long connecting rod would make the difference zero and the movement would be SHM; however, if $l/r = 2$, the peak accelerations will be more than 50 per cent higher than with SHM. (When $\theta = 0$, 180°, 360°, etc., both $\cos\theta$ and $\cos 2\theta = 1.0$; thus the portion of eqn. (11.6) in brackets becomes $1 + \frac{1}{2}$, i.e. only slightly less than the maxima which occur at angles slightly different from those quoted. With SHM the maximum value is 1·0.) Since force = mass × acceleration, and since the lay is relatively massive, these differences are important because the forces can become very large.

The foregoing has been developed on the basis of several simplifying assumptions, but even in the more complex cases, there are similar results; however, any further such mathematical development is beyond the scope of this book.

The Beating Action

The motion of the *reed* positions the filling, but in so doing it has to push against frictional forces imposed by the

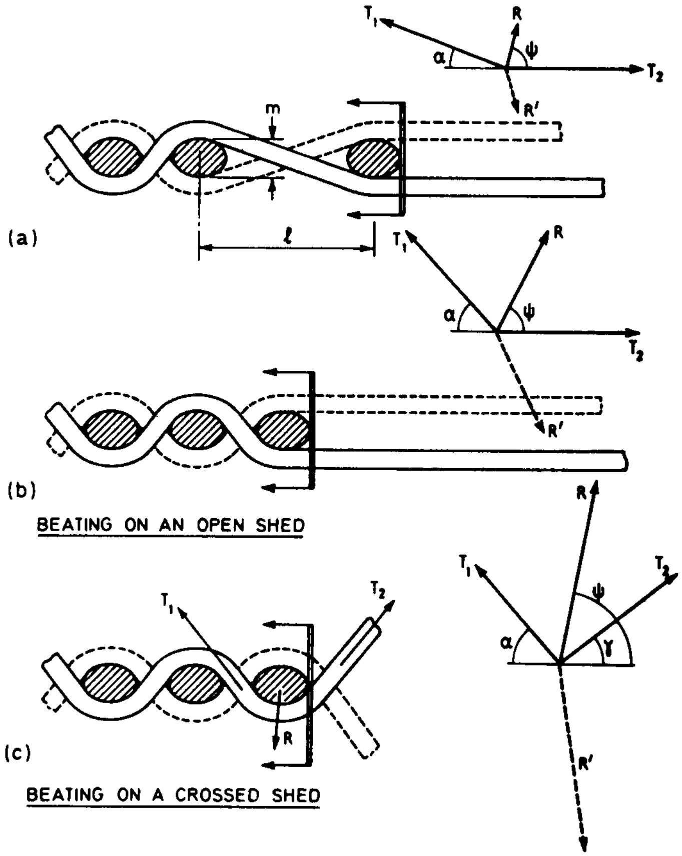


Fig. 11.12. The forces in beating

warp. The magnitude of these forces depends on the coefficient of friction between the warp and filling, as well as the reaction between them (this reaction arises from the interlacing).

Consider a filling yarn about to be moved towards the fell of the cloth as illustrated in Fig. 11.12. The yarn tensions on a single end are as shown on the right-hand side of the diagram. In addition, there are other reactions from the opposite interlacings as indicated by R'. As the filling is moved towards the fell, the angle α steepens, the magnitude of R and R' increases and ψ moves away from 90°. When moved far enough into the fell, the angle ψ becomes so acute that the filling would be squeezed out if it were not restrained. There is a critical value for ψ which is determined by the coefficient of friction. Thus the minimum pick spacing which can be obtained by beating on an open shed is determined by the coefficient of friction between filling and warp.

When beating on a crossed shed, γ is more nearly equal to α and there is a smaller tendency for the filling to be squeezed out. Hence closer pick spacings can be obtained.

Let the general case illustrated in Fig. 11.12(c) be considered. The force needed to move the filling over a single warp end consists of two parts; the first is a component of the reaction R resolved in the direction of beating, and the second is a frictional component which also has to be resolved in the same direction.

The force needed to cause the filling to slip $(F) = \mu R$ and this acts perpendicularly to R; thus the resolved component is $F' = \mu R \sin \psi$.

Resolving the direct forces vertically,

$$R \sin \psi = T_2 \sin \gamma + T_1 \sin \alpha \qquad (11.7)$$

therefore $$F' = \mu T_2 \sin \gamma + \mu T_2 \sin \alpha$$

Resolving the direct force horizontally (in the direction of beat)

$$T_2 \cos \gamma - T_1 \cos \alpha = R \cos \psi \qquad (11.8)$$

Beating force/warp end

$$F'' = R \cos \psi + \mu R \sin \psi \qquad (11.9)$$

$$F'' = T_2 \cos \gamma - T_1 \cos \alpha + \mu R \sin \psi$$

Substitute for $R \sin \psi$ and we get

$$F'' = T_2(\cos\gamma + \mu\sin\gamma) - T_1(\cos\alpha - \mu\sin\alpha)$$

but from Amontons' law of wrap friction

$$T_1 = T_2 e\beta$$

$$\text{where } \beta = -\mu\,[\pi - (\alpha + \gamma)]$$

therefore

$$F'' = T_2\{(\cos\gamma + \mu\sin\gamma) \text{ -}Ke^{-\mu(\alpha+\gamma)}(\cos\alpha - \mu\sin\alpha)\} \tag{11.10}$$

When the angle γ is small, as it often is, then eqn. (11.10) can be simplified as follows

$$F'' = T_2\{1 \text{ -}Ke^{-\mu\alpha}(\cos\alpha - \mu\sin\alpha)\} \tag{11.11}$$

If further approximation is tolerable then this can be reduced to $F'' = 2\mu(\sin\alpha)T_2$ or even to $F'' = 2\mu\alpha T_2$.

Bearing in mind that the angle α is determined by the crimp levels, the yarn dimensions and the pick spacing, it will be realized that the beat-up forces are affected by them too. Also, the tension T_2 is affected by the beat-up and, as demonstrated above, the beat-up force is also a function of T_2; this is another reason why it becomes progressively more difficult to beat up as the filling is pushed into the fell of the cloth. Indeed, too heavy a beating action to achieve a close pick spacing will produce a condition known as *bumping*; here the whole beat-up force is taken by the warp and the fabric ahead is temporarily relieved of tension. Bumping usually indicates a *jammed* fabric; that is, one which cannot have a closer pick spacing due to its construction.

Referring again to Fig. 11.12(a), it will be seen that the angle α is fixed by the dimensions m and l. At the beginning of beat-up, l is long and α is small but as the process proceeds, l gets shorter with the result that α becomes more acute. Hence, as beat-up proceeds, the beating forces increase until the lay is reversed or the bumping condition is reached (see

Fig. 10.8). Because of this, it is important to set the loom properly to prevent undue stress; high stresses lead to increased ends down and consequent loss of production. Also it is possible to damage the machinery, particularly if it is designed only for light fabrics.

12

SHUTTLE PICKING AND CHECKING

Key words: *Alacrity, binder, buffer, checking, coefficient of restitution, controlled binder, kinetic energy, lug strap, natural frequency, nominal movement, overpick loom, picker, picking, picking stick, picking cam, pitch, roll, shuttle box, shuttle box length, simple harmonic motion (SHM), stick checking, underpick motion, yaw.*

The Energy of Picking

To accelerate a shuttle to the necessary speed in the very short time available requires that considerable amounts of energy should flow in that short time. This means that there has to be a source of energy as near to the shuttle as possible, with as little intervening mass as possible. Such masses impede the flow of energy and make it more difficult to accelerate the shuttle. In the conventional loom, a transient source of energy is the picking stick itself; this is normally made of wood, which is a very resilient material capable of storing remarkable amounts of strain energy. The primary source of energy is the electric motor, but the energy is transmitted through a cam/linkage system which has considerable inertia. Without the resilient stick to store energy at appropriate times (i.e. with a perfectly stiff mechanism), such a cam/linkage system would be unsatisfactory. If sufficient energy were transmitted to give adequate acceleration, the forces generated in some parts would be above the safe working limits and failures would occur.

A conventional system works, in the first part of the operation, by causing the drive end of the mechanism to start with little or no motion by the shuttle and picker. This is achieved by the action of the *binder* which temporarily restrains the shuttle. During this first phase, various parts of the mechanism are strained (especially the *picking stick*) and strain energy is built up. During the subsequent phase, the direct motion of the drive end continues but the shuttle now moves. The direct motion and that due to the sudden unbending of the picking stick are superimposed to give a very rapid acceleration. There is a sort of whiplash effect, which is extraordinarily effective in producing the acceleration required without producing unacceptably high stresses in the mechanism.

The Motion of the Shuttle during Acceleration

The force applied to the shuttle is proportional to its mass and the acceleration involved (i.e. force = mass × acceleration). For a given shuttle, it is necessary to restrict the acceleration if the limiting force is not to be exceeded. The limiting force is determined by the strength and durability of both the shuttle and the propulsion mechanism. In this respect it is the peak acceleration that is important (rather than the average value), and this peak should be kept as low as possible. On the other hand, to get a high loom speed it is necessary to have a high average acceleration. These requirements clash, but the conflict can be lessened by making the ratio of peak to average acceleration as low as possible. This implies that the shuttle displacement curve should be parabolic, as shown in Fig. 12.1. This can be explained in mathematical terms as follows.

Let

$$x = at^2 + bt + c \tag{12.1}$$

where a, b, and c are constants and the eqn. (12.1) describes a parabola

t = time ($t \propto \theta$ approx.)

θ = angular position of crankshaft

x = position of shuttle from some reference

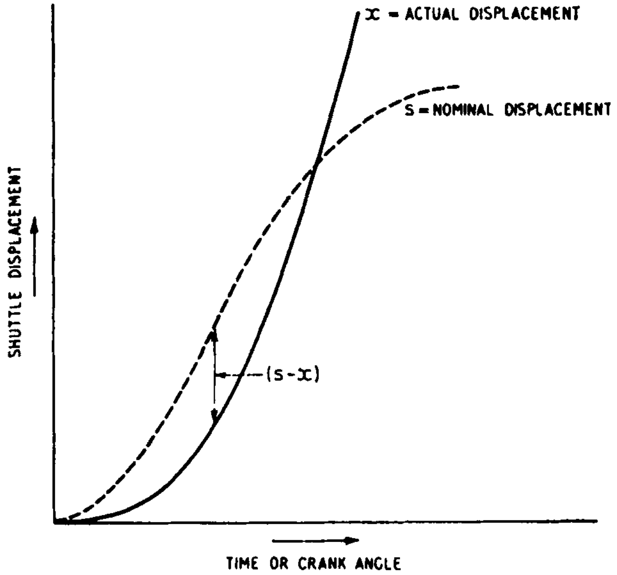


Fig. 12.1. Shuttle displacement

Differentiating

$$\text{shuttle velocity} = \dot{x} = 2at + b$$
$$\text{shuttle acceleration} = \ddot{x} = 2a = \text{constant}$$

where $\dot{x} = dx/dt$

$\ddot{x} = d^2x/dt^2$

Under these circumstances, the ratio of peak to average is unity, which is the lowest possible value; this means that for a given loom speed, the shuttle acceleration (and the force applied) will be the lowest possible.

The force pulse applied to the shuttle in this case will be rectangular, similar to that shown in Fig. 11.5; the steps in force levels are likely to create unwanted shocks which lead to the production of noise and vibration. To reduce shocks, it is necessary to round off the flanks and this implies that the displacement curve has to depart a little from the simple parabola.

The accelerating distance x is of some importance. From space considerations, it ought to be as short as possible, but from force considerations it ought to be as long as possible. Bearing in mind that there are geometric limitations in any picking mechanism and that the maximum forces acting on the shuttle arises elsewhere, it is usual to make x about 20 cm (8 inches). This determines the *shuttle box length* as well as the difference between the loom and fabric widths.

The motion of the picker is never geometrically similar to the shape of the *picking cam*; however, to overcome this in the present discussion, let the cam shape be defined by the motion of the picker, it being recognized that the actual cam shape has to be modified to take into account the geometry of the linkage.

There is another and very important factor to be considered. The picking stick and other parts deflect under the loads encountered under running conditions; it is necessary, therefore, to make another modification to the cam profile if the actual shuttle motion is to approximate to the parabolic ideal. If the loom is turned over very slowly with no shuttle, there will be little or no load on the system; it will behave as if the components were perfectly stiff. Let the movement obtained like this be referred to as the *nominal movement*. The actual movement, obtained under normal running conditions, differs greatly from this because of the deflections of the various components in the system (see Fig. 12.1).

Assuming the system to be perfectly elastic:

$$\text{force} \propto \text{acceleration}$$

but also

$$\text{force} \propto \text{deflexion}$$

therefore

$$\text{acceleration} \propto \text{deflexion}$$

or in symbols,

$$\ddot{x} = n^2 (s - x) \qquad (12.2)$$

where n = a constant which is known as the *alacrity*
$\ddot{x}$ = shuttle acceleration
$(s - x)$ = elastic picker displacement
s = nominal displacement of picker
x = actual displacement of picker

Equation (12.2) is mathematically identical to that for simple harmonic motion. This implies that the picking stick with its various associated masses is in fact a vibratory system which has its own particular *natural frequency*. This vibratory motion, which is superimposed upon the applied motion derived from the cam, is fairly heavily damped so that it scarcely carries over from one pick to another; nevertheless, it is very important in determining the behavior of the picking system as a whole.

In a normal loom, it is necessary to apply an average force F_s to the accelerating shuttle for a time t_s at the beginning of each pick. Since it is required that the strain energy be released in the time t_s, it is most desirable that the natural frequency should be such that at least a quarter cycle of vibration should be completed in the time t_s. Since the alacrity is proportional to the natural frequency (which in turn is a function of the mass and elasticity of the system), the foregoing really fixes the flexibility of the picking system for a given shuttle weight. In a typical case, the force F_s might be of the order of 50kg (110 lb), the time over which this force has to be applied (i.e. t_s) might be some 0.02 sec and the relative deflection of the picker might be over 5 cm (2 inches); the natural frequency might be about 20 c.p.s., which is equivalent to an alacrity of about 120/sec.

The energy stored in deflecting the stick by the stated amount might represent as much as a quarter of that needed to propel the shuttle at the required speed. The strain energy released at the appropriate time gives that extra impulse that makes the system so effective. If the stiffness of the system is too low (i.e. the alacrity is too low), the propulsion phase of the pick will be completed before all the energy has been released and this will reduce the effectiveness of the system. If the system is too stiff, the energy is released too quickly and the energy is largely dissipated in noise and useless vibration. Thus it is important that the picking mechanism be properly designed to meet the requirements of the particular loom working with its particular shuttle at its particular speed. Of course there is some band of tolerance and it is, for example, possible to speed up a loom to some degree without redesigning the picking system; to get the best possible advantage, however, it is worth making sure that the design is reasonably adequate in this respect.

Another factor must be considered. The rest position of the shuttle determines the amount of energy that is built up and this in turn determines the shuttle velocity. In normal weaving, this rest position varies from pick to pick and therefore the shuttle velocity also varies. The arriving shuttle tends to bounce away from the picker and to leave a gap just before picking starts. The size of the gap is dependent on the arrival velocity of the shuttle; thus there is an unstable situation which is characteristic of most looms. The instability is made worse by certain other factors (such as the torsional oscillation of the bottom shaft) but these other factors are rather difficult to control without redesigning the loom; consequently, they will not be further discussed here. The gap, however, can be controlled; for example, a good controlled buffer or other device can return the stick and the shuttle to their proper starting positions and thus eliminate some of the instability. A smoother running loom tends to be more efficient in all senses and it is usually worthwhile to eliminate the causes of irregularity.

It was suggested earlier that a parabolic motion was usual and that this would produce a rectangular force pulse on the shuttle. Equation (12.2) suggests that the value $(s - x)$ is proportional to the force applied to the shuttle;

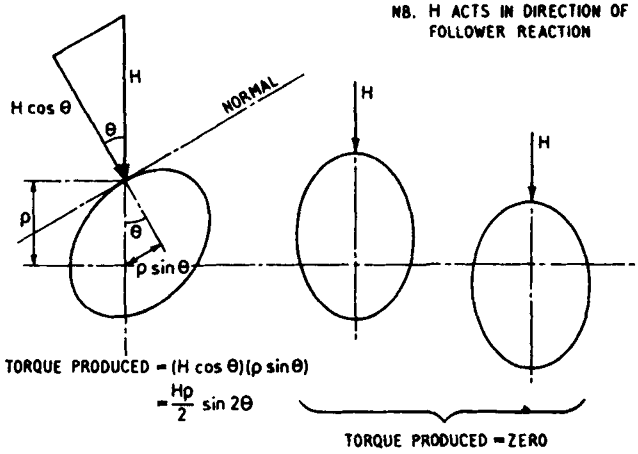


Fig. 12.2. Varying mechanical advantage of a cam

however, Fig. 12.1 shows this to be untrue. One reason for this is that the alacrity is not a constant; it varies from time to time within the cycle. The alacrity is dependent on the mass-elastic behavior of the whole system and this means that the driving shafts and linkages are all involved to some extent. The cam and follower in this system act as a link which transmits some of these effects to a varying extent dependent on the angular position of the cam. Referring to Fig. 12.2, it will be seen that when the follower is climbing the flank of the cam, forces may be transmitted either way through the system. When the follower is at either extreme; no such transmission is possible; rotation of the cam causes no movement of the follower and a force exerted on the follower merely tends to dent the surface of the cam. In fact, the extent of the force transmission depends on the local angle between the cam surface and the follower and thus it varies from time to time. Hence the effect of the bottom shaft, and other systems connected to it, is not constant.

Where the drive to the cam is stiff, this is not of great significance, but where the drive is flexible, the effect can be quite noticeable.

In the normal loom, the driving motor is located to one side, the motion being carried to the other side by shafts. In picking, it is necessary to have a cam system on either side of the loom; one is driven by a short stiff shaft and the other by a long flexible extension of that shaft. This affects the behavior quite markedly and it is usual to fit unlike cams, i.e. the cam at the end of the flexible shaft is modified to take the difference into account. This is a further reason for care being taken with cams. Even with the modified cam profiles, picking is frequently uneven and must be adjusted to give equal "strengths" of picking by altering the position of the *lug strap.*

Parallel Motions

If a picking stick were to swing about a simple fulcrum at one end, the other end would move in an arc; however, the shuttle moves in a straight line. The older *overpick looms* (which have mechanisms such as that shown in Fig. 12.3) solve the problem by constraining the picker by guides and allowing the motion of the strap to compensate. Some looms with an *underpick* motion also have guided pickers, and in this case the picker can slide on the picking stick to achieve the necessary compensation. A different approach is to use a curved foot (Fig. 12.4) or an equivalent linkage to cause the stick to lift as it rocks, and to do so in such a way that the free end of the stick moves in a straight line. In this way it is possible for the picker to be attached firmly to the free end of the stick. It is essential, however, that the stick should be properly restrained so that it cannot lift except as desired. One consequence of an unsuitable lift is that the shuttle may be projected in a wrong direction and fly out of the loom; this is highly dangerous. An unsuitable lift might also damage adjacent mechanisms such as the quill changing device.

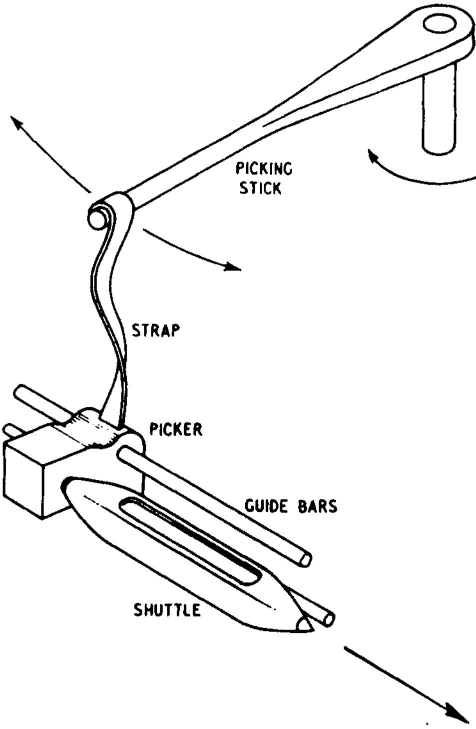
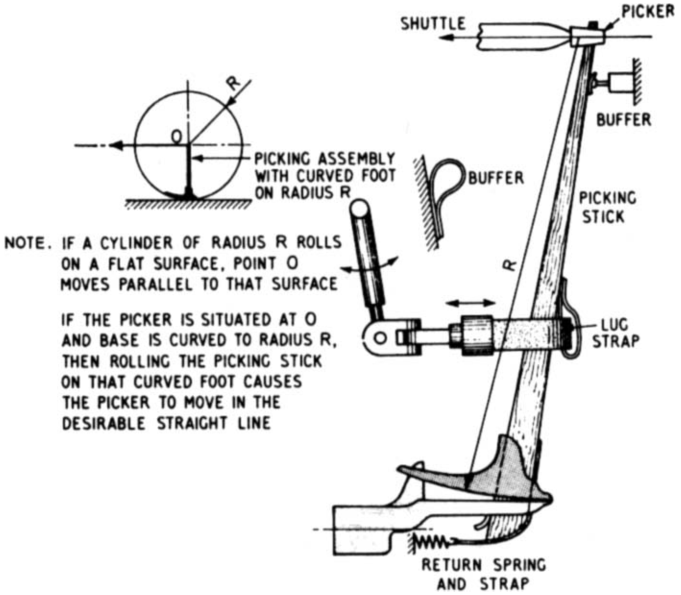


Fig. 12.3. Overpick loom picking mechanism

Stick Checking

At the time that the shuttle leaves contact with the picker, the picking stick has completed its task but it still possesses appreciable *kinetic energy*. This energy has to be dissipated before it can be returned to its starting position in readiness for the next pick from that side. The simplest way of doing this is to place a resilient buffer in the path of some portion of the stick, but this produces a heavy concentrated load at the impact point. Furthermore, the load caused by the decelerating stick is distributed on either side of the impact point, with the result that there is severe bending as the stick tries to wrap itself round the *buffer*. When it is realized that the kinetic energy possessed by the stick just before checking is about the same as that possessed by the shuttle, and that it is decelerated in a fraction of the time that was spent in accelerating the system, it will become evident that the forces involved must be very large. The highest stress levels in the picking stick are encountered at this time, stick failures occur most frequently at this time and stick damage builds up due to the impacts met during this phase of the stick motion. The stick vibrates within its own length and a number of unintentional movements are generated; the stick is usually thrown backwards and forwards within the



NOTE. IF A CYLINDER OF RADIUS R ROLLS ON A FLAT SURFACE, POINT O MOVES PARALLEL TO THAT SURFACE

IF THE PICKER IS SITUATED AT O AND BASE IS CURVED TO RADIUS R, THEN ROLLING THE PICKING STICK ON THAT CURVED FOOT CAUSES THE PICKER TO MOVE IN THE DESIRABLE STRAIGHT LINE

Fig. 12.4. A normal underpick motion with a curved foot

constraints of the linkage and it may also lift. These movements can cause subsidiary damage; more important, they cause considerable noise and vibration through the whole loom.

Shuttle Checking

After the shuttle has traversed the warp shed and has left its trail of filling behind, it too has to be decelerated very rapidly. It is not possible to use a check as severe as that used for the stick, as this would cause the yarn to move on the quill (which would make it impossible to unwind properly and would lead to loom stops). The system almost universally used is shown in Fig, 12.5. The *binders* (swells) rub on the incoming shuttle and the frictional force slows down the shuttle but does not stop it. The final braking action is obtained as the shuttle collides with the picker, which at that time is backed with a suitable buffer. The binders are not very effective as a brake but they do serve another purpose (see page 220); they rarely remove more than about 20 per cent of the kinetic energy from the incoming shuttle.

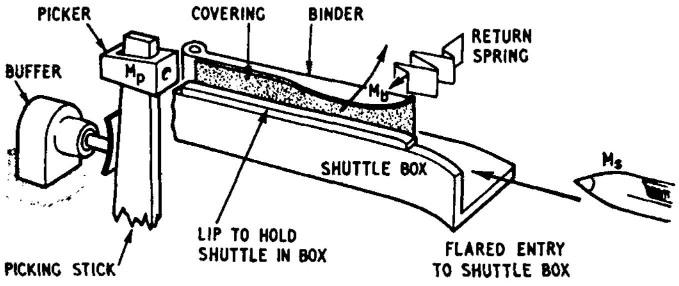


Fig. 12.5

At the risk of considerable oversimplification, conside the following theoretical model. To avoid the difficulties of asymmetrical loading of the shuttle, let the binder be split into two equal parts and let one part act on one side of the

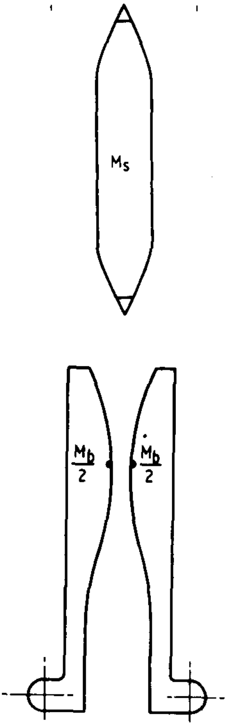


Fig. 12.6. Theoretical model

shuttle and the other on the opposite side as shown in Fig. 12.6. Furthermore, let both portions of the binder act in the same way so that at any given time they both have the same velocity. Let subscripts *s* and *b* refer to shuttle and binder, respectively.

In general,

$$\text{force} = \text{mass} \times \text{acceleration}$$

Retarding force acting on the shuttle

$$= F_s = M_s \times \mathrm{d}V_s/\mathrm{d}t$$

Also $$F_s = \mu(F_b' + F_b'')$$

but $$F_b' = F_b'' = F_b$$

and $$F_b = \tfrac{1}{2}M_b \times (\mathrm{d}V_b/\mathrm{d}t)$$

Therefore $$M_s \times \mathrm{d}V_s = \mu M_b \times \mathrm{d}V_b \qquad (12.3)$$

This equation has the same form as that which describes the collision of two bodies traveling along the same line of action, except the two masses are M_s and μM_b instead of their real values. Using the classical solution to the simple collision problem and defining the *coefficient of restitution* (e) as the ratio $(V_s' - V_b')/V_s$, we may formulate the change in shuttle velocity as follows.

(N.B. the superscripts refer to the stated quantities just after impact and V_s is defined below.)

$$\frac{\mathrm{d}V_s}{V_s} = \frac{(1+e)\mu M_b}{(M_s + \mu M_b)} \qquad (12.4)$$

where e = the coefficient of restitution
μ = the coefficient of friction
M_s = the mass of the shuttle
M_b = the mass of the binder
$\mathrm{d}V_s$ = the change in shuttle velocity
V_s = the velocity of approach of the shuttle

Apart from the somewhat sweeping assumptions made, the coefficient of restitution is not a constant and if there is vibration present, it can vary with conditions (between 0·2 and 0·6). For the present purpose, this is of no great importance since the equation is much more sensitive to changes in μ and M_b. There is only a limited range for the coefficient of friction; therefore, the binder mass is seen to be the most important factor.

Experimental work has demonstrated that changing the nature of the binder covering has little effect. Traditionally, the covering was leather and this provided durability and a reasonably high coefficient of friction against the wood of the shuttle. Attempts to replace leather by materials of different coefficients of friction sometimes yielded strange results. For instance, substituting a steel strip for the leather produced a more effective check even though the coefficient of friction was reduced; this was because the mass of the binder was increased and this more than compensated for the change in frictional character of the surface. Resilient backings altered the time of contact between the binder and shuttle and thereby decreased the average pressure, but this had little or no effect on the amount of energy extracted from the shuttle.

In the normal system, the remaining kinetic energy in the shuttle has to be dissipated by striking the picker attached to the picking stick at the arrival side of the loom. Apart from the energy extracted by the buffer, the impact with the picker and its associated masses causes energy to be dissipated. In fact, this is the classical impact case and eqn. (12.4) can be rewritten as

$$\frac{\mathrm{d}V_s}{V_s} = \frac{(1 + e)M_p}{(M_s + M_p)} \tag{12.5}$$

where M_p is the mass of the picker and associated masses. Other symbols are as for eqn. (12.4).

Since M_s and M_p are roughly of the same magnitude, the change in shuttle velocity is very large; it is possible for the change to be as high as 70 per cent of the arrival velocity. This may be compared to a normal change of about 20 per cent caused by the binders. Some of the energy of the approaching shuttle (but not all of it) is converted into kinetic energy in the picker and its associated masses. This energy is dissipated by the buffer and the stick is brought to rest only to suffer another blow from the shuttle. However, this blow is a light one and has little significance. If the loom is set correctly with a good buffer, the separate actions just described may merge into one continuous action. A typical checking characteristic is given in Fig. 12.7 and this also shows the acceleration for comparison. It also shows the loss in velocity during transit across the warp shed. The mass M_p is significant and an increase in mass could give a more rapid checking action but any change in M_p will alter the alacrity; thus there is little chance of securing a gain in this

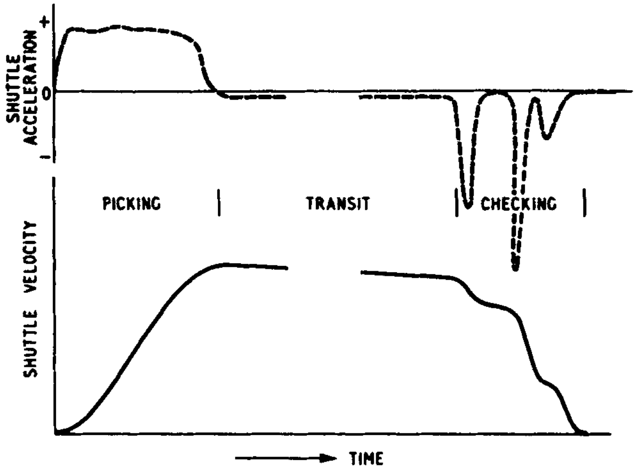


Fig. 12.7. Variation of shuttle velocity during one pick

direction. Furthermore, the checking distance is important. Most of the shuttle deceleration is confined to the last inch or so of its travel. The shuttle was accelerated over a distance of several times this, hence the forces involved in shuttle checking are considerably larger than in picking. The acceleration (or deceleration) of the shuttle has to be limited to prevent damage to the yarn on the quill. As loom speeds rise, this problem becomes more acute.

The shuttle is a projectile whose path is not subject to exact restraint. The path is not linear, because of the movement of the lay. To this must be added the effects of contact with the reed, lay and warp. It is normal for the shuttle to *roll*, *pitch* and *yaw* (see Fig. 12.8) as it passes across the warp shed. Consequently, the shuttle rarely enters a shuttle box cleanly; often it enters obliquely with the result that appreciable transverse forces are generated. Measurements have shown that these can be as much as ten times the worst force acting along the path of the shuttle. These forces can be very damaging to the yarn on the quill and sometimes even to the shuttle. Careful setting of the picking mechanism can minimize this difficulty. In particular, the path of the picker can be very important and any tendency for it to rise during picking will cause the shuttle to deviate from its intended path. Hence, the parallel motions described earlier are seen to be very important.

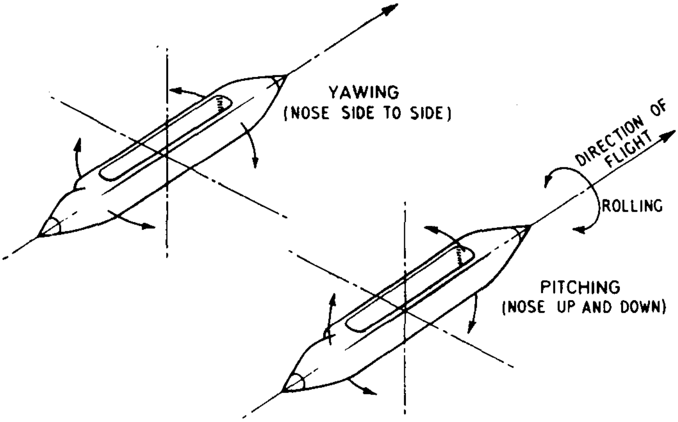


Fig. 12.8. Shuttle movements during flight

An interesting concept in checking is to use multiple binders so that the shuttle is retarded in steps. This distributes the load and instead of a single blow to reduce the shuttle speed before it collides with the picker, it is possible to have several lesser blows. The shocks arising from these lesser blows are more tolerable than those from the single one. An established variant of this is to use a *controlled binder* system comprising two units. One of these acts independently like the normal binder and the other has a variable spring pressure which can be applied or released at various times in the weaving cycle. Although its main purpose is to control the shuttle during picking, the auxiliary binder also helps in checking.

13

AUTOMATION AND CONTROLS

Key words: *back rest, barré, battery, beam ruffle, bobbin loaders, box chain,* 2 x 1 *box motion, box motion, bunch, bunter, center filling fork, change gear, cloth roller, dagger, direct take-up, drop wire, droppers, feeler, filling transfer mechanism, fork, frog, give-way, hammer lever, knock-off device, knock-off motion, let-off motion, loose reed, magazine, midget feeler, multiplier chains, negative-feedback, negative let-off, pawl and ratchet, pick-and-pick, pick at will, pinned, positive let-off, protector feeler, raceboard, risers, semi-positive let-off, sheath, sinkers, side filling fork, smash, stop motions, stop rod finger, take-up roller, temples, tin fillets, transfer latch, unifil, warp stop motion, well, worm and wheel.*

In a loom there are many mechanisms to control the warp and fabric tensions, fabric width and color pattern in the filling direction. There are also some automatic protection devices such as warp and filling *stop motions.* One very important mechanism on the loom, which gives the loom the adjective "automatic", is the *filling transfer mechanism.*

Warp Let-off Motions

The function of a *let-off motion* is to apply tension on the warp yarns to help form a clear shed. The tension also has to be high enough to develop the forces required between the warp and filling to form the cloth. The tension ratio between the warp and filling has to be correct, otherwise the crimp levels are improperly balanced; this affects the appearance of the cloth. The let-off motion applies the tension by controlling the rate of flow of warp yarns.

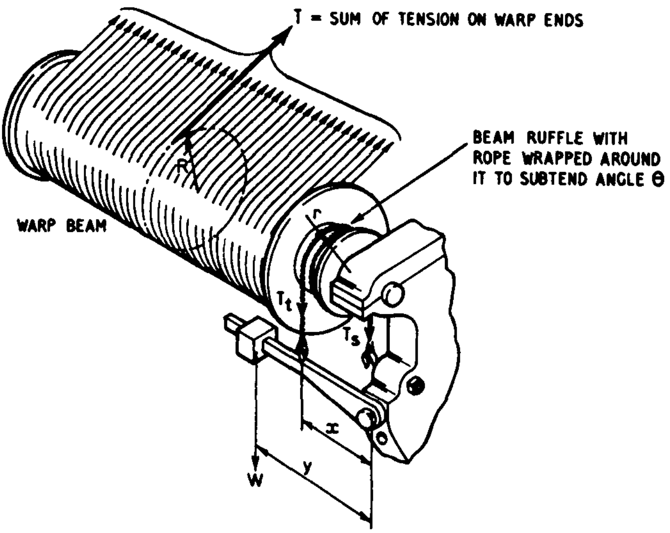


Fig. 13.1. Negative let-off ;not to scale.

There are three different types of let-off motions, namely:

(1) Negative.
(2) Semi-positive.
(3) Positive.

1. *Negative Let-off*

In this case the pull of the warp is purely against friction forces in the let-off motion. To demonstrate the principle of negative let-off, let the simple non-automatic mechanism shown in Fig. 13.1 be considered. The tension of the warp is regulated by the friction between chain or rope and the *beam ruffle.*

Taking moments about the center of the beam

$$T \times R = (T_t - T_s) \times r \tag{13.1}$$

and by Amontons' law

$$\frac{T_t}{T_s} = e^{\mu\theta} \tag{13.2}$$

where μ = coefficient of friction between the chain or rope and the beam ruffle.

θ = the angle of lap

Taking moments about the hinge O of the lever:

$$T_t \times x = W \times y \tag{13.3}$$

$$\therefore \qquad T_t = W\frac{y}{x} \tag{13.4}$$

Substituting for T_t and T_s in eqn. (13.1)

$$\therefore \qquad T = \frac{r}{R} T_t \left(1 - \frac{T_s}{T_t}\right)$$

$$= \frac{r}{R} \times W\frac{y}{x}(1 - e^{-\mu\theta})$$

$$= K\frac{Wyr}{xR} \tag{13.5}$$

$$\text{i.e.,} \qquad T \propto \frac{1}{R} \tag{13.6}$$

This means that the tension of the warp increases as the radius of the warp on the beam is reduced. This cannot be allowed in practice and the increase in tension must be balanced by moving the weight towards the fulcrum O, to reduce the distance y. Therefore, the condition needed to maintain a constant warp tension is that

$$\frac{y}{R} = \text{constant} \tag{13.7}$$

The movement of the weight can be either manual or automatic. In modern looms, only negative let-off motions of the automatic type are used. In this case, the weight is not moved along the lever, but the lever is fixed in a different way such that any change in tension causes a change in the moment applied.

2. *Semi-Positive Let-off*

In the case of negative let-off the warp is pulled off the beam and the tension is regulated by slippage in a braking system. In a positive let-off, the beam is driven through a positive mechanism where no slippage takes place. This latter type of mechanism is seldom used and in most cases the tension is controlled by a mechanism driving the warp beam, which allows a certain loss of motion (or slippage) whenever the tension increases. Basically these are crude *negative-feedback* automatic-control systems which are related to controls such as are used in autoleveling during sliver production. These mechanisms are sometimes considered positive, but in reality they are semi-positive.

Figure 13.2 shows an example of a semi-positive let-off motion. The warp beam is driven through a *worm and wheel*

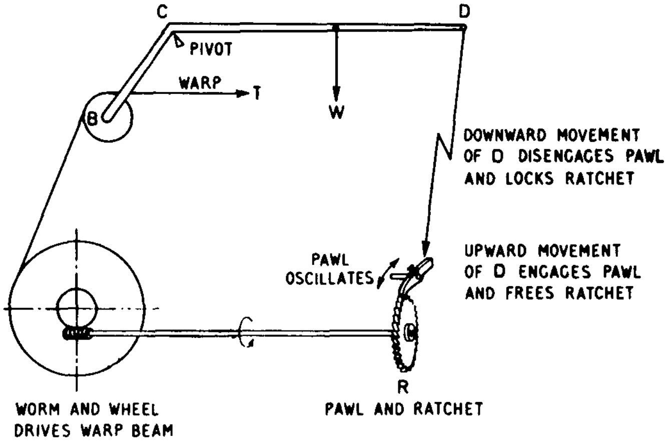


Fig. 13.2. Semi-positive let-off

which are turned by a *pawl and ratchet* (*R*). The warp passes over a moveable *back rest* (*B*). If the warp tension is reduced, the back rest is moved up under the influence of the weighted lever (*CD*). The motion is transmitted through levers to a *sheath* which locks the movement of the ratchet wheel and disengages the pawl until the tension increases again to the normal level under the influence of the cloth take-up. If the tension increases beyond normal, the back rest is lowered, which causes the sheath to be moved away from the ratchet wheel; the let-off is restarted and overfeeds slightly, causing the tension to drop. The tension remains nearly constant between limits, and does not depend on the warp diameter on the beam.

There are many semi-positive let-off mechanisms designed to control the warp tension and it is beyond the scope of this book to discuss all of them.

Fabric Take-up Motions

As the picks are inserted, the point of fabric formation has to be moved and, to maintain the same pick spacing, the rate of movement must be kept constant.

The fabric commonly follows one or other of two paths. These are used in the direct and indirect take-up systems, as shown in Fig. 13.3. In the indirect system, at (a) and (b) the fabric is passed over a *take-up roller* before being wound over the *cloth roller*. The cloth roller of (a) is driven through friction between it and the take-up roller. This is suitable for spun yarn fabrics, since the friction does not produce a critical defect in the fabric. In the case of the indirect motion at (b), the cloth roller is negatively driven and is kept away from the take-up roller; this makes this type of motion suitable for the more sensitive continuous filament yarn fabrics. One of the advantages of this system is the possibility of cutting the fabric and removing the cloth roller without stopping the loom.

The motion shown at (c) is known as "*direct take-up*"; the fabric is wound on the cloth roller directly with a press

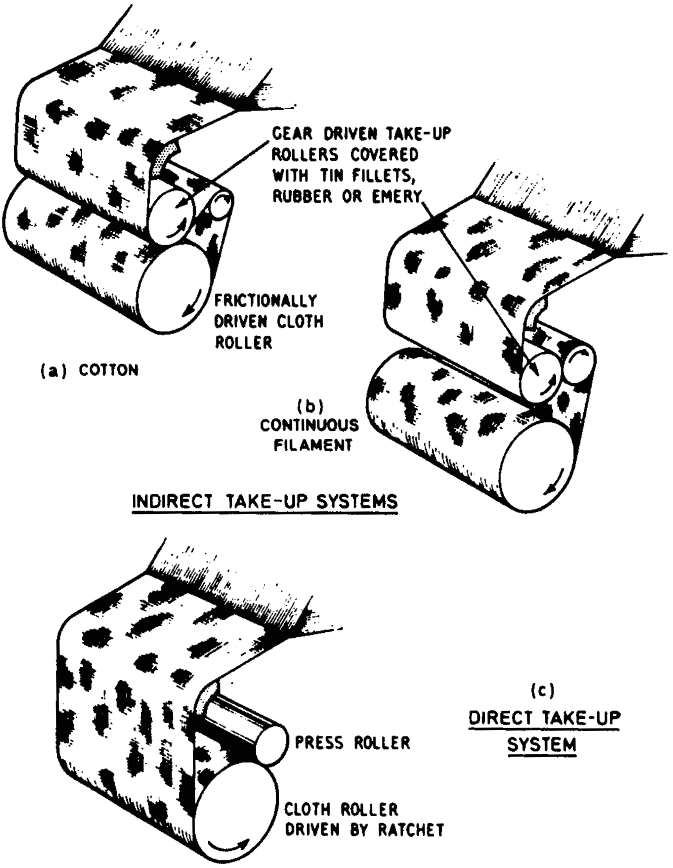


Fig. 13.3. Cloth take-up systems.

roller. The drive of the cloth roller is of the negative type so as to reduce the rotational speed as the diameter of the cloth on the roller increases. For this reason, the indirect take-up motions are normally considered positive whereas the direct motions are considered negative.

The take-up rollers are normally covered by *tin fillets* or rough rubber to increase the grip between the roller and the fabric. Also, the take-up roller is usually driven through a gear train which reduces a single movement of the pawl to the distance between two successive picks in the fabric. If the commercial range of pick densities is considered to be between 8 and 40 picks/cm (20 and 100 ppi), the distance moved by the cloth or take-up roller is between ¼ and 1¼ mm/pick (0.01 and 0.05 inch/pick). This movement is very small and a gear train of 5 or 7 wheels must be used to allow for the large reduction in movement and to provide for the changing of the pick density of the fabric. This is normally achieved by changing only one gear, called the *change gear*, in the train.

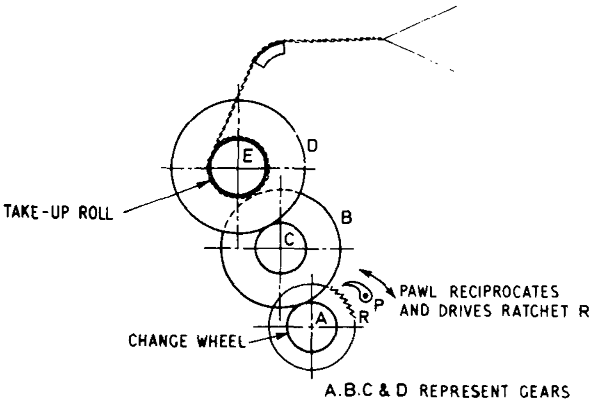


Fig. 13.4. Five wheel take-up system

Figure 13.4 shows a 5-wheel take-up mechanism in which the ratchet wheel (*R*) is moved the distance of one tooth by the oscillating pawl (*P*) for every pick. The pawl gets its movement from the lay mechanism. If *R* is the number of teeth on the ratchet wheel, one revolution of the ratchet wheel corresponds to *R* picks inserted into the fabric.

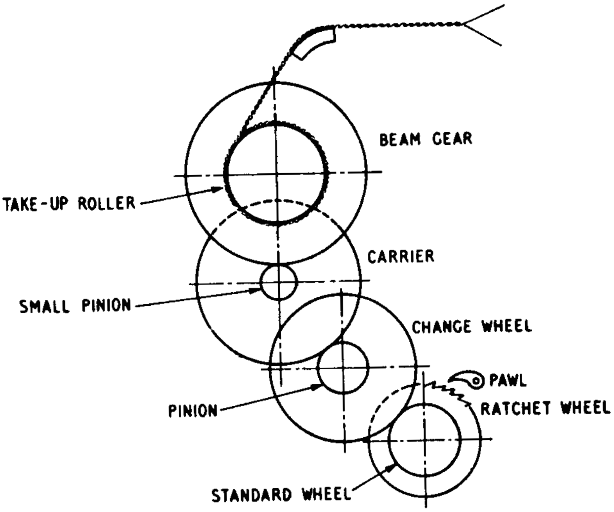


Fig. 13.5. Seven wheel take-up system

The length of cloth taken-up for every revolution of the ratchet wheel = $(A/B) \times (C/D) \times$ circumference of take-up roller (E).

Pick density = Picks inserted ÷ Length of Fabric Taken-up

$$= \frac{R}{(A/B) \times (C/D) \times \text{circumference of } E}$$

$$= R \times \frac{B}{A} \times \frac{D}{C} \times \frac{1}{\text{circumference of } E}$$

A is the number of teeth of the change wheel. The other gears usually are not changed. Therefore,

$$\text{Pick density} = \frac{\text{constant}}{A}$$

Due to fabric contraction after leaving the loom, the pick density in the fabric is normally increased by 1·5–2 per cent. This has to be taken into account when designing the gear train so that,

$$\text{Pick density} = \frac{\text{constant}\,(1 + K)}{A} \qquad (13.8)$$

where K = percentage contraction ÷ 100.

Many looms use a 7-wheel gear train similar to that shown in Fig. 13.5, in which case the change wheel is a driven gear instead of a driving wheel (as in the 5-gear train). The pick density is then given by

$$\text{Pick density} = (\text{constant} \times \text{change wheel teeth})(1 + K) \qquad (13.9)$$

In this case, the gear train is usually designed so that the number of teeth on the change wheel is equal to the pick density. This means that the constant, after taking contraction into consideration, is equal to unity.

A very important point to be considered in the design of a take-up motion is the effect of imperfections in the cutting or mounting of the gears. Any eccentricity in a gear in the train produces cyclic variation in pick spacing which produces a defect in the fabric known as *barré*. If the spacing of the bars is either less than 2 mm or more than 25 cm, the effect is not readily seen in the fabric. Thus, in a well-designed take-up motion, the length of fabric woven during a full rotation of any gear in the train should be less than 2 mm (0.1 inch) or more than 25 cm (10 inches).

Figure 13.6 shows the Shirley take-up motion which was designed to satisfy this condition. The length of fabric woven for every rotation of the standard wheel *A* for a cloth of 25 picks/cm (60 ppi) is about 1.7 mm (0.07 inches). The length of fabric woven for one revolution of the carrier wheel B is 1.4 mm. Every rotation of the worm wheel E produces 25 cm of fabric. In this mechanism, also, the number of teeth on the change wheel is equal to the pick density. The minimum number of teeth on the change wheel to satisfy the previous condition concerning barre is 32. This good characteristic of the mechanism was made possible through the use of a worm and wheel with a speed reduction of 150:1.

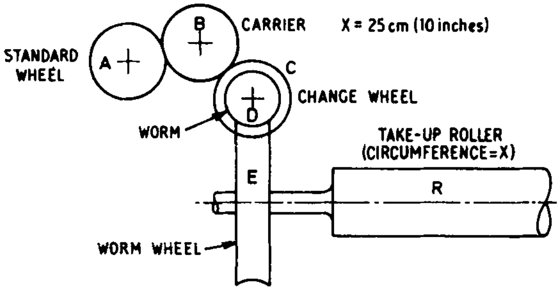


Fig. 13.6. The Shirley take-up.

Transverse Fabric Control

Due to the crimp in the filling yarns, a component of the tension exists in the filling direction (see Fig. 8.9). This force tends to bring the ends closer together, causing a contraction in fabric width. The contraction is exaggerated by the increase of warp tension or stiffness and also by increasing the twist in the filling yarn. When this contraction is allowed to be excessive, high frictional forces are created between the reed and warp yarns near the selvage. This, apart from affecting the fabric quality, also increases the warp breaks near the selvage and in turn reduces the weaving efficiency. To control the fabric width and maintain proper crimp levels for warp filling, the fabric has to be pulled at the selvages in the direction of the filling. This is done by using *temples* similar to those shown by Fig. 10.9. There are many types and designs of temples, but they all perform a similar function.

Warp Stop Motions

One of the important automatic protective devices on the loom is the *warp stop motion.* The main function of this motion is to stop the loom, in a very short period of time, when a warp yarn breaks. This helps to maintain the quality of the fabric, and to reduce the time to repair the breaks, thus improving weaving efficiency. Both considerations have a direct effect on the economics of the process.

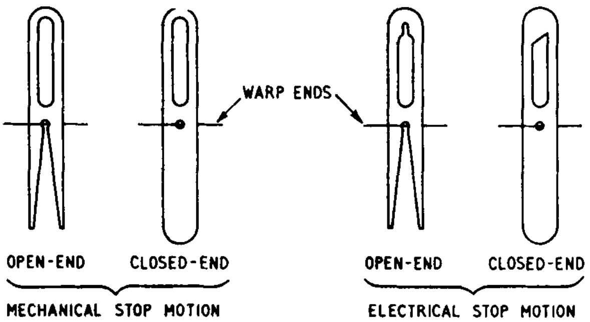


Fig. 13.7. Typical drop wires.

There are two types of warp stop motions, viz. mechanical and electrical. In both cases a *feeler* or *drop wire* is used for each warp end. The ends are drawn through the drop wires prior to weaving or they may be placed on the warp yarns on the loom. The drop wires (or *droppers* as they are sometimes called) have to be thin, because so many must be fitted across the width of the loom. Typical designs are shown in Fig. 13.7. The droppers used for both mechanical and electrical stop motions are basically similar, but may show slight differences. They are either open-ended or closed. The open-end dropper can be placed or "pinned" on the yarn without threading, but the closed-end droppers are better secured to the yarn.

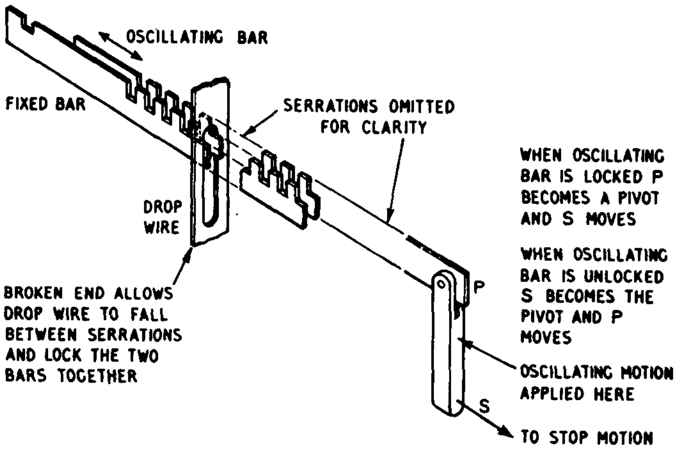


Fig. 13.8. A typical mechanical stop motion

The usual mechanical stop motions consist of two serrated bars, as shown in Fig. 13.8. One of the bars slides to and fro continuously with respect to the other. The droppers are held clear of the bars by the warp yarn. If a warp end breaks, the drop wire falls between the serrations and locks the two bars together. The movement of the drive is transmitted to a *knock-off motion*, i.e. it operates a device which stops the loom, usually by causing the starting handle to be moved to the "off" position. The principle of using a lightweight device to insert a link in a power mechanism to initiate an operation requiring considerable force is very common in weaving.

Electrical warp stop motions, which have been in use for many years, are to be found on most modern looms. Two bars are used as electrodes connected to a transformer and a magnetic *knock-off device*. When a yarn breaks, the wire drops and completes the electrical circuit. The current passing through the circuit operates the magnetic knock-off device which stops the loom.

The loom must stop very quickly before the lay moves forward to beat the filling, otherwise the weaver will have to reverse the loom for one complete revolution to remove the filling; this is necessary if the repaired warp end is to have the correct interlacing. The effectiveness of the braking system may be increased by disconnecting the clutch, so reducing the inertia of the system which is to be stopped.

Filling Stop Motions

Filling stop motions usually have a feeling device in the form of a *fork*. In some cases the fork is placed at the side of the reed and clear of the warp (*side filling fork*), and in other cases the fork is placed at the center of the warp (*center filling fork*). The side fork systems feel the filling every other pick, whereas center fork systems feel the filling every pick.

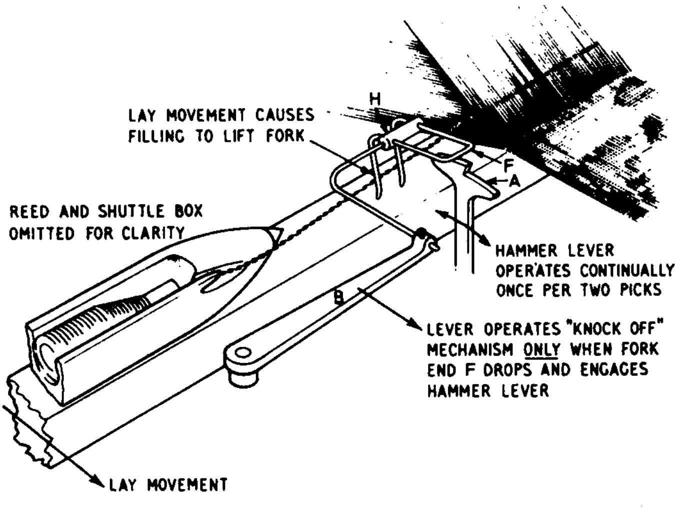


Fig. 13.9. Typical side filling fork mechanism

A typical filling fork mechanism is shown in Fig. 13.9. The forward movement of the reed during beating pushes the filling yarn forward. The yarn acts on the fork (*F*) which is hinged at the point (*H*) causing the bent end to be lifted, and this permits the loom to continue running. If the yarn is broken or the quill is exhausted, the fork stays with the bent end downward and this engages an oscillating *hammer lever* (*A*) which takes the fork lever (*B*) backwards. The fork lever then knocks the loom starting handle to the "off" position. The hammer lever gets its movement from a cam on the loom camshaft. This motion is robust and simple and its only disadvantage is its failure to feel every pick. One way of overcoming this is to use two side fork mechanisms, one at each side of the warp.

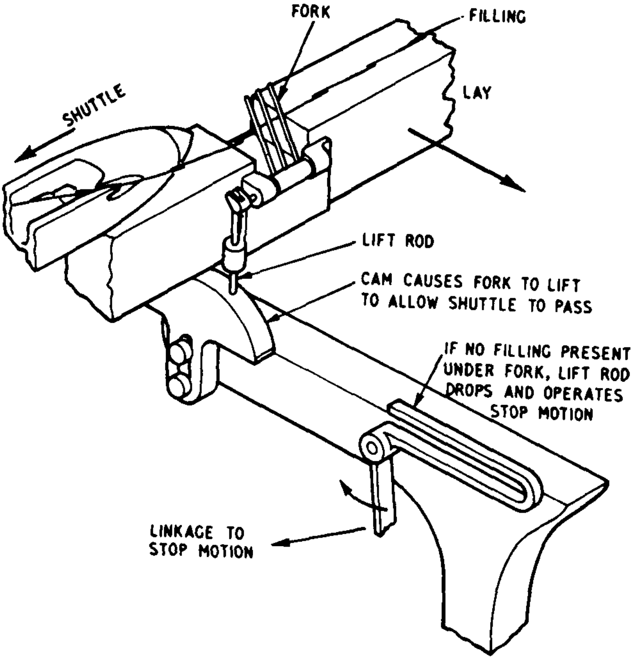


Fig. 13.10. Center fork stop motion

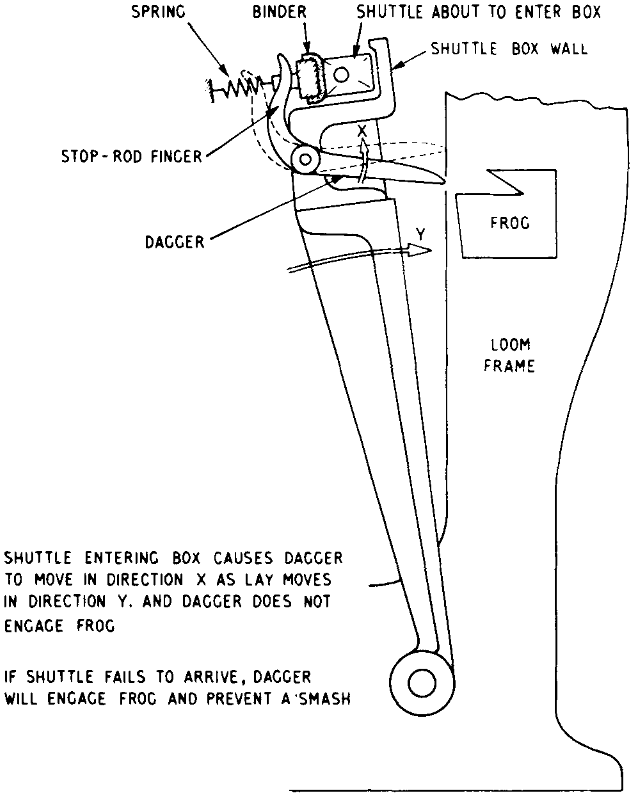


Fig. 13.11. Warp protector motion.

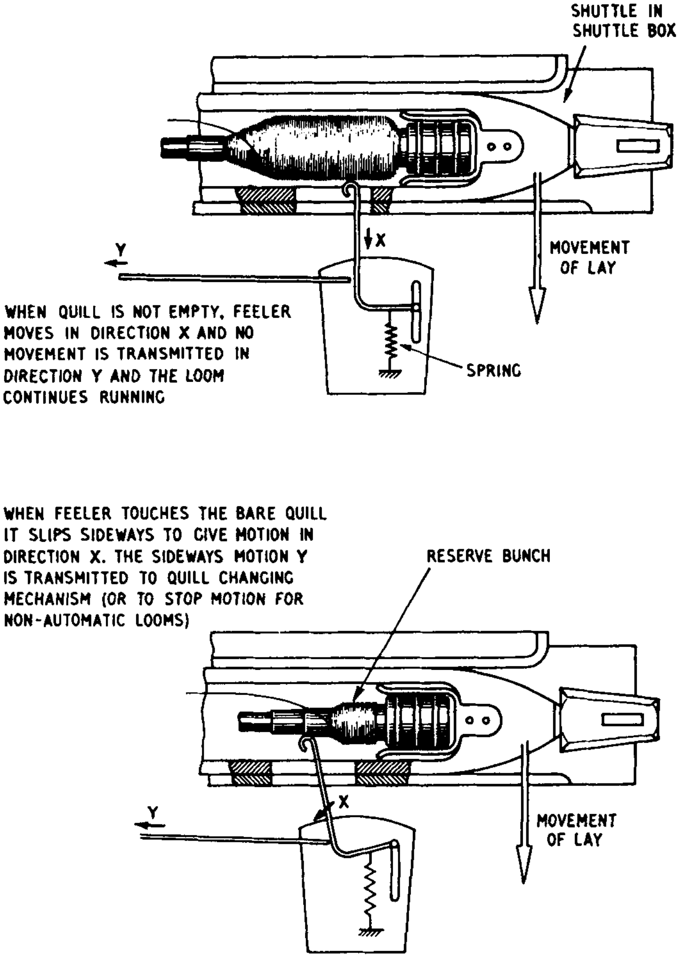
The center filling fork stop motion is more complicated and difficult to set. Several designs of center fork motions are available, but they are all basically the same. A *well* or channel is cut at the center of the *raceboard*. The fork is mounted on a bracket fixed to the front of the lay. Before the shuttle passes, the fork is raised clear of the shuttle. After the passage of the shuttle, the fork is lowered, and if the filling yarn is present the fork is prevented from dropping into the well and the loom is permitted to continue running. At a certain crank angle the fork must be withdrawn to allow the filling to be beaten into the fell of the cloth.

If no yarn is present, the fork drops quickly and operates the movement to stop the loom before the beating action is started. This simplifies repair and saves time. Figure 13.10 shows a typical system; in this case, if the filling yarn is not present, the dropping of the fork operates the knock-off device and the loom stops.

Warp Protector Motion

This motion is used on all conventional looms to stop the loom when the shuttle does not arrive at the shuttle box at the proper time. This action protects the warp for, if the loom continued to run, the reed would beat against the shuttle and cause damage to a large number of warp yarns as well as to the reed and shuttle (this is called a *smash*).

Two techniques are used. In the first, the reed can swing backwards when it meets a resistance greater than the normal reaction of beating-up (such looms are known as *loose reed looms*). In the second, a mechanism connected to the binders is used to knock off the loom when the shuttle fails to arrive at the proper time. The principle of operation of such a mechanism is shown in Fig. 13.11. When the shuttle arrives in the shuttle box, the binders move outwards by the impact of the shuttle. The outward movement of the binder produces a similar movement in the *stop rod finger* causing the *dagger* to be lifted to clear the *frog*, and the lay continues to move forward for beat-up. If the shuttle is late, the dagger comes in contact with the frog, which is moved; the movement is transmitted to the knock-off mechanism, which stops the loom. Contact with the frog results in a very severe deceleration to the system and the parts involved must be extremely rugged.



WHEN QUILL IS NOT EMPTY, FEELER MOVES IN DIRECTION X AND NO MOVEMENT IS TRANSMITTED IN DIRECTION Y AND THE LOOM CONTINUES RUNNING

WHEN FEELER TOUCHES THE BARE QUILL IT SLIPS SIDEWAYS TO GIVE MOTION IN DIRECTION X. THE SIDEWAYS MOTION Y IS TRANSMITTED TO QUILL CHANGING MECHANISM (OR TO STOP MOTION FOR NON-AUTOMATIC LOOMS)

Fig. 13.12. Mechanical weft feeler

Filling Transfer Motions

Automatic filling supply is the principal feature of an automatic loom. Two main types of mechanism are used. In the first type, the whole shuttle is replaced. In the second type (which is now the most common) only the quill or bobbin is replaced; the exhausted quill is knocked out and replaced by a full one in the very short time that the shuttle is stationary in the shuttle box. Further discussion is limited to the *bobbin changer* type of transfer.

The mechanism is composed of three components; a feeling device, a transfer mechanism with associated linkage and a magazine or other quill storage.

The feeling device can be one of three types; mechanical, electrical or photo-electrical. The feeler detects the difference between the yarn surface and the base surface of the quill tube. It is usual to have a "*bunch*" of yarn on the quill not detected by the feeler and this allows sufficient yarn reserve to carry over between detection and transfer. Figure 13.12 shows the most commonly used mechanical feeler, the "*Midget*" *feeler*. When the filling yarn on the quill is down to the *reserve bunch*, the feeler blade comes in contact with the smooth surface of the quill and slides sideways rather than lengthways. This movement is transmitted to the transfer mechanism (this is fixed on the magazine side of the loom which is normally remote from the feeler).

In the case of electrical feeler, when the two probes merely touch the yarn, no transfer takes place; when the yarn runs down to the reserve bunch, the probes come in contact with the metal tube and complete an electric circuit. This passes current through an electromagnetic relay which initiates the quill transfer.

The photo-electrical feeler consists of a photocell and a lamp. The light beam incident on the quill does not pass through to the cell until the yarn on the quill is down to the reserve bunch. When this happens, the cell induces a voltage and current passes through an electric circuit which initiates the change.

In the case of the mechanical feeler, a linkage between the feeler and the transfer mechanism is needed to connect to the *magazine* or *battery*. This linkage usually consists of a shaft which rotates through a small angle to transmit the initiation of the change to the mechanism. Electrical and photo-electrical feelers do not need this type of linkage, since the initiation is transmitted by electric circuits.

The magazine can be of the rotary or the vertical stationary types. The first type is the most commonly used on single shuttle automatic looms, whereas the second type is more popular on multi-shuttle automatic looms. The magazine is normally mounted on one side of the loom in such a position as to be above the shuttle box when the lay is at front center.

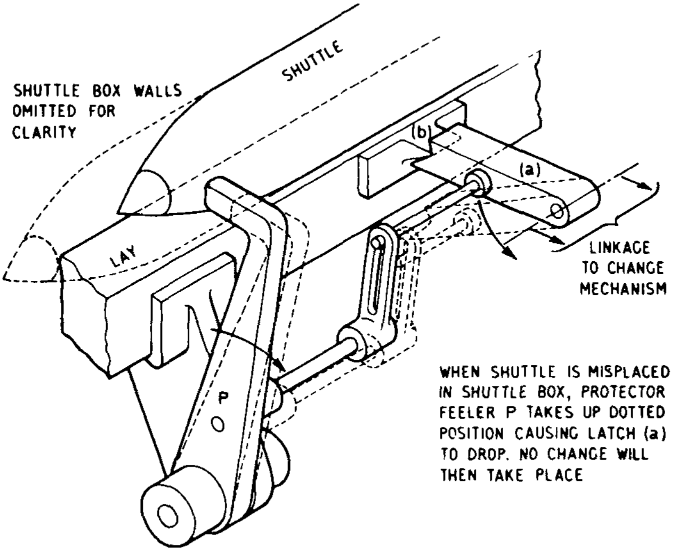


Fig. 13.13. Protector feeler for change mechanism

When the quill is exhausted, the feeler slips to one side and turns the shaft connecting the components of the mechanism. When the shuttle reaches the magazine side, a *protector feeler* moves forward to the mouth of the shuttle box. If the shuttle is not properly positioned, the protector is knocked away by the shuttle and the loom continues running without filling transfer. On the next pick the same procedure takes place, and if the shuttle is not properly positioned the same happens until the yarn is completely exhausted and the loom is stopped. If the shuttle is in the proper position, which is normally the case, the *transfer latch* (*a*) (Fig. 13.13) is then lifted and locked with the transfer hammer. As the lay moves forward to beat the filling, the *bunter* (*b*) engages the latch (*a*), turns the hammer about its fulcrum and presses a quill into the shuttle, pushing the empty quill out through the bottom of the shuttle. The backward movement of the lay returns all the parts to their normal position and this causes the magazine to rotate through an angle just enough to position a new quill under the hammer.

The movement of the shuttle from the magazine side partly threads the yarn, the threading being completed when the shuttle is picked from the other side. The end of the yarn from the old quill is cut by a cutter fixed at the temple and the end from the new quill is cut by the shuttle eye cutter.

In multi-shuttle looms, several shuttles are used, either for mixing of filling yarns to prevent barré or for the use of color. In the first case, where a 2 × 1 *box motion* is used to insert two picks from each shuttle; a rotary magazine is normally used. When color is introduced, a rotary multi-color magazine can be used, but it is preferable to use a stationary magazine. Every color of filling is stacked separately, as shown in Fig. 13.14. There are many designs for the filling transfer on multi-color magazines.

The main difference between multi- and single-color magazines is that a color selecting device, working in connection with the box motion, is used. Also provision is

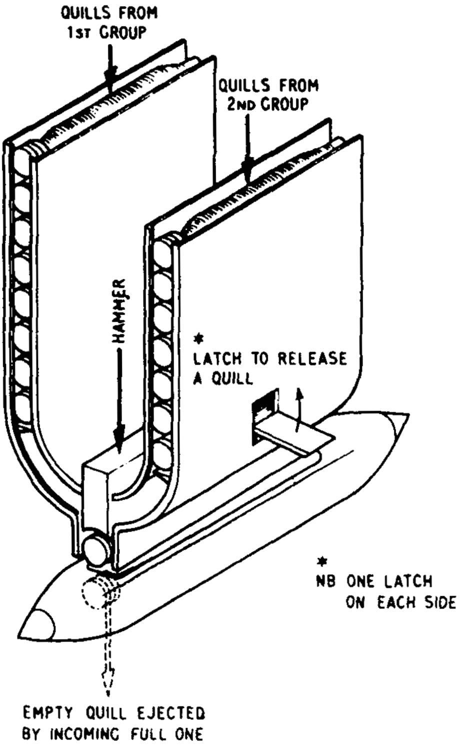


Fig. 13.14. U quill magazine

made to store the signal for transfer, if box changing takes place before the shuttle which has the empty quill is picked to the magazine side. In this case, the indication of the need for transfer is made by a feeler fixed at the magazine side.

In a weaving mill, the supply of quills to the magazine is normally done manually. This task involves the employment of labor to move the quills from winding rooms to the looms and keep supplying bobbins to magazines. This is a costly process, and it also makes the mixing of quills unavoidable. Two systems have been developed to minimize the labor cost and prevent mixing of quills. The *bobbin*

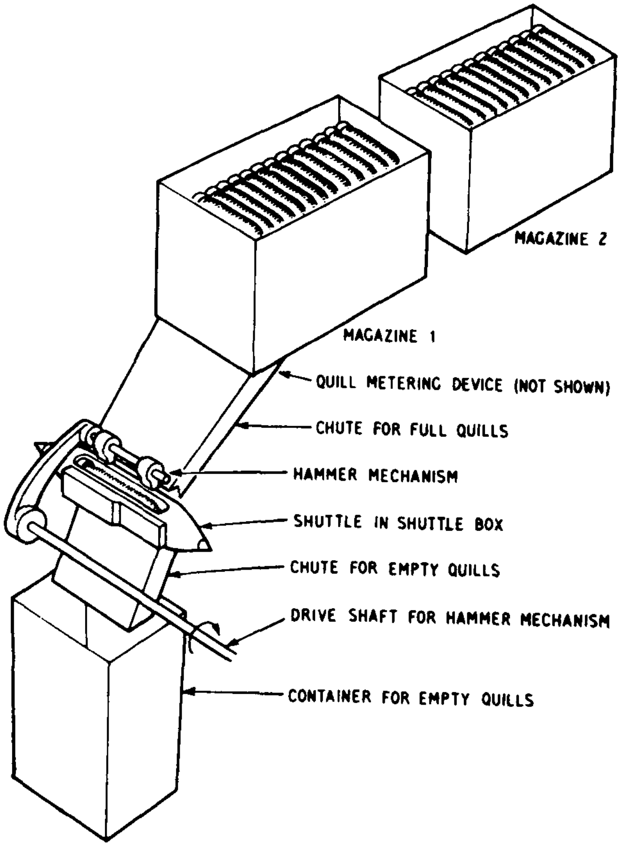


Fig. 13.15. Simplified bobbin loader system. (End finder, cutters and waste systems omitted for clarity)

loader uses containers to hold up to about 100 quills each and these are stacked during winding. Two containers are placed on the loom to act as magazines; one of these is active and the other is a reserve. When the first is exhausted, the second takes its place and a new full container is placed in position (see Fig. 13.15).

The second system which uses a winder at the loom, is known as the *Unifil*. In this case the filling yarn is supplied to the loom in the form of a large cone. The partly empty bobbins are stripped and returned to the winding position by a conveyor belt, as shown in Fig. 13.16. This system is advantageous in preventing barré caused by the mixing of quills, especially with filament yarns. Also, the system eliminates the need for quill winding machines and saves labor cost in transporting and supplying magazines. The use of Unifil also saves capital cost on quills since the number

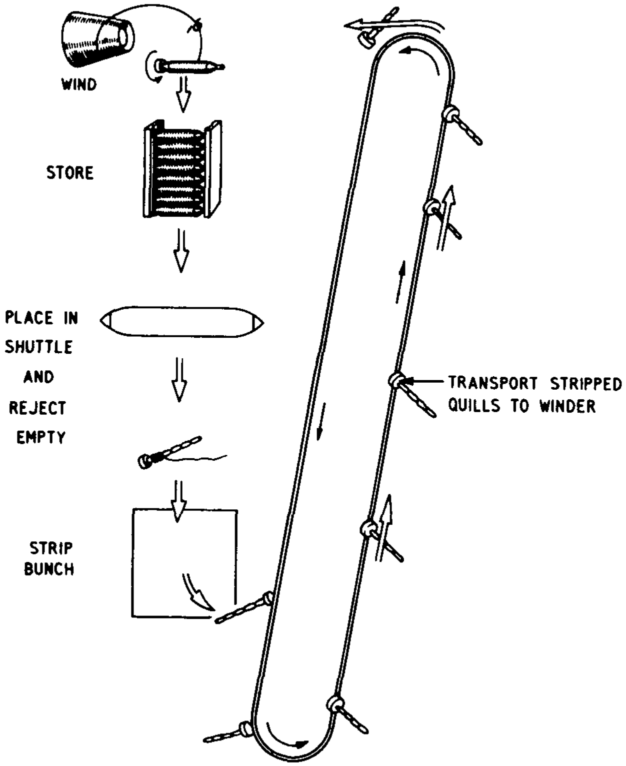


Fig. 13.16. Flow cycle for Unifil

of quills used is very much reduced. Unifil has a definite economic advantage in the case of coarse filling, because the rate of consuming quills is very high. On the other hand, it may not prove to be economical in the case of fine filling; the cost of the unit is considerable and it lies idle for a large proportion of the working time because the frequency of change of the quills is reduced. In many cases a compromise between cost and other advantages has to be made. The system is limited to single filling yarn color.

Multi-shuttle Looms

In the production of solid color fabrics, a single shuttle loom is normally used with one shuttle box on either side of the loom. With some fabrics, especially when filament yarn is used in the filling, two shuttles are used for the mixing of filling to prevent barré defects. In this case the loom must have at least two shuttle boxes on one side. If there is one box on the other side, the loom is usually denoted as a 2 × 1 loom. In this case every shuttle is used alternately for two picks.

If two or more colors are used in the filling, an equivalent number of shuttles must be used to give a series of looms with the appropriate number of shuttle boxes on one side. These are known as 2 × 1, 4 × 1, etc., looms. If multi-shuttle boxes are used on one side only, the maximum number of colors used is equal to the number of boxes on that side. In this case, the number of picks inserted from any color must be an even number, since the shuttle must be brought back to its box before any box changing can take place.

It is possible to have several shuttle boxes on each side of the loom and such looms are denoted as 4 × 4, 2 × 2, and 4 × 2 looms. They are sometimes used to permit the use of more colors and odd numbers of picks from each color; they are known as *pick-at-will* or *pick-and-pick* looms. The maximum number of colors used is equal to the number of boxes of the loom minus one.

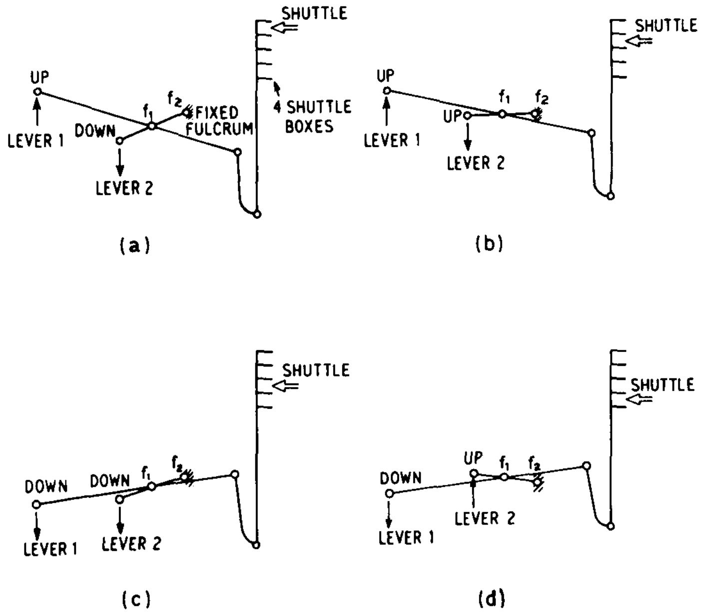


Fig. 13.17. Four-box motion in each of its positions

The most common mechanism used is the 4 × 1 box motion. This mechanism uses two levers to produce a compound movement at the box rod. This movement depends on which lever is moving and about which fulcrum the levers are moving. Lever 2 (Fig. 13.17) moves about the fixed fulcrum f_2 to move fulcrum f_1 on lever 1. The levers are usually moved by means of cams which are gear driven from the loom camshaft. When movement is required, clutches are engaged to cause the appropriate cam (or cams) to rotate sufficiently to cause the lever system to take up one of the configurations shown in Fig. 13.17 according to the demands of the pattern.

The control for selecting any particular box is initiated by a pattern chain which contains movable protuberances called *risers* and other links without protuberances called *sinkers*. A normal *box chain* has two rows, side by side, in which these risers can be fitted. There are four combinations in which the risers can be installed and these are translated into the appropriate lever settings by using a system of feelers and linkages. The combinations are:

	Row 1	*Row* 2
Combination 1	R	S
Combination 2	R	R
Combination 3	S	R
Combination 4	S	S

where R = riser and S = sinker.

To prevent these chains becoming unduly long where many picks are required in sequence from a single bobbin, it is usual to use *multiplier chains.* Consider first a single multiplier chain with one row of sinkers and risers similar to those used in a box chain. If there are x risers in succession on the multiplier chain, then the box chain is held stationary until these have passed (during which time $2x$ picks have been inserted). When the next sinker in the multiplier chain arrives, the box chain continues until it is again interrupted by a riser in the multiplier chain. It is usual to have two chains in the multiplier system which can be used in combination and this gives a range of multiplying possibilities. The two multiplier chains are both driven together (the pattern chains being stopped). One multiplier chain consists of all risers except one and the other chain consists of all sinkers except one. The pattern chains are only started when the odd riser in the one multiplier chain coincides with the odd sinker in the other. The multiplier chains are then stopped until a signal from the pattern chain causes the multiplier chains to restart and the pattern chains to stop.

If the multiplier chains each have different numbers of links, then they behave as a single long chain of $(N_1 \times N_2)$/H.C.F. as shown on page 262.

(N.B.: H.C.F. = highest common factor).

If chain no. 1 moves through z revolutions, and it contains N_1 links, then zN_1 pass during this time. If chain no. 2 contains N_2 links, then it moves zN_1/N_2 revolutions. Assuming that $N_1 = an_1$ and that $N_2 = an_2$, then

chain no. 2 moves through $\frac{z\,a\,n_1}{a\,n_2} = \frac{z\,n_1}{n_2}$ revolutions.

For proper registration, the odd riser has to coincide with the odd sinker, and starting from a proper registration, it is necessary for chain no. 2 to move a whole number of revolutions before registration can occur again. In other words, zn_1/n_2 must be a whole number. If n_1 and n_2 are prime numbers, then the requirement can only be met when $z = n_2$. In this case, $z\,N_1$ links pass but $z = n_2 = N_2/a$ and therefore a repeat occurs after every $(N_1 N_2/a)$ links pass. (Note: *a* is the H.C.F.). During the time these links pass, twice this number of picks are inserted. It is quite normal for the pattern lengths to be measured in picks and in this case the repeat is given by $[(M_1 M_2)/a]$ where M_1 and M_2 are the number of picks in each chain. The arrangement of colors in the shuttleboxes must satisfy two conditions; firstly, the color which appears most often should be placed in the top box, and secondly, skipping from box 1 to box 4 should be avoided because this puts more strain on the mechanism.

With all box motions, a safety device must be incorporated to prevent breakage of parts should the boxes jam. A *give-way* is normally built into the mechanism to allow relative movement between the parts in an emergency; this prevents further movement until the fault has been rectified.

14

POWER, ENERGY AND VIBRATION

Key words: *Alacrity, amplitude, back rest, beat effect, bottom shaft, buffer, capacitor, centroid, clutch, crank, damping, damping coefficient, damping pad, dynamic equivalence, dynamic magnifier, dwell, elasticity, electrical slip, equilibrium position, excited, fell, flywheel, forcing frequency, four bar chain, harmonic, induction motor, lay, lint, mass-elastic system, (mass) moment of inertia, natural frequency, offset, picker, power factor, radius of gyration. reed, resonance, rocking shaft, shuttlebox, simple harmonic motion, stiffness, structure-borne vibration, sword, synchronous speed, time constant, torque, torsion, vibration.*

The Loom as an Integrated Mechanism

The functions of a loom are interconnected and interrelated. Action at one place produces reactions elsewhere. These actions and reactions are correlated in the first part of this chapter.

Speed Variations

In a loom, it is necessary to use a great deal of reciprocating motion of heavy parts and these motions can involve considerable impulsive loading. Thus it is desirable to make the rotational parts heavy (to act as flywheels) and the reciprocating parts light. If the rotational parts are made too heavy, the loom will be slow to start and this is likely to cause cloth faults. These faults arise because the first few picks are not beaten and shedded in quite the same way as the rest. One solution to the problem is to insert a *clutch* between the loom and the drive. The motor may have a considerable *flywheel* attached to it because it does not matter much if the motor is slow in starting if it is not connected to the loom. Connecting the loom to a relatively massive motor/flywheel assembly causes the motor to slow down only slightly and the loom to come up to speed very rapidly. The situation is rather like the collision between two bodies as described in the section on checking in Chapter 11; instead of linear motion, the present case has rotary motion. The heavier the flywheel (strictly, the greater the *moment of inertia*) the more quickly will the loom be brought up to speed but also the greater will be the load on the clutch. The clutch limits the extent to which this can be carried, and the loom dictates how far it is desirable. A heavy duty loom requires more stabilization than a light silk loom.

Cyclic variations in loom speed are caused mostly by the reciprocating motions. Shedding has some effect and picking induces a sharp pulse once per pick, but the most important effect of all arises from the *lay* movement. The lay and all its

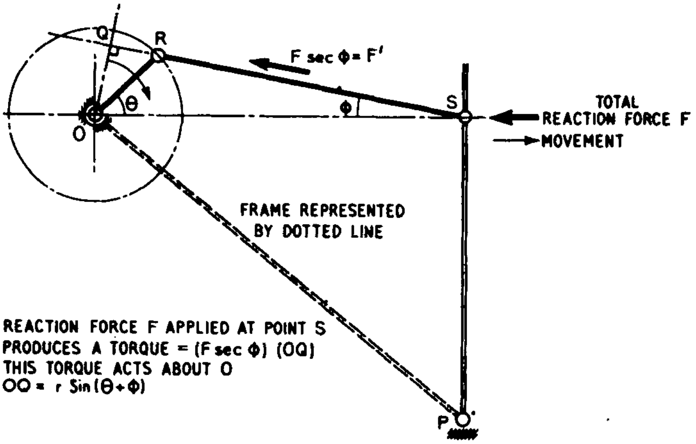


Fig. 14.1. Schematic diagram of crank/lay system

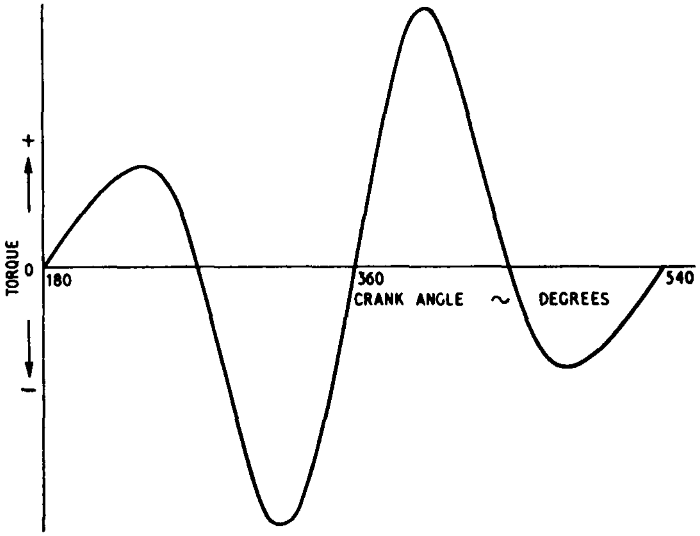


Fig. 14.2. Theoretical torque characteristic of lay drive mechanism. N.B. Bearing friction and windage ignored

associated parts may be regarded as a single large mass acting at the *reed*. This mass (M) is subject to the acceleration described by equation 11.6, i.e.,

$$f = \omega^2 r \left(\cos\theta + \frac{r}{l}\cos 2\theta\right) \qquad (14.1)$$

The force generated by this acceleration $(F)' = M \times f$. As shown in Fig. 14.1, the torque needed at the crankshaft to produce this force $(T) = F' \times r \times \sin(\theta + \phi)$. The angle ϕ is small compared to θ; therefore, an approximate expression for the *torque* is as follows:

$$T = Fr\sin\theta$$

$$= Mfr\sin\theta$$

$$T = M\omega^2 r^2 \sin\theta \left(\cos\theta + \frac{r}{l}\cos 2\theta\right)$$

$$= \frac{M\omega^2 r^2}{2}\left(\sin 2\theta + \frac{r}{l}(\sin 3\theta + \sin\theta)\right) \qquad (14.2)$$

It will be noticed that the torque required is proportional to the equivalent mass of the lay and the square of the loom speed and *crank* radius. This means that the peak torque (which determines the motor size) depends on these parameters. A graph of eqn. 14.2 is given in Fig. 14.2. It will be seen that the torque required to drive the lay oscillates and is sometimes negative; this means that the lay might sometimes drive the motor by virtue of its own inertia. There is a strong double angle component (sin 2θ) which is referred to later.

When it is realized that the mass M may be as much as 200 kg (400 lb) and the maximum acceleration may be up to about 3 g, it will be seen that the force transmitted by

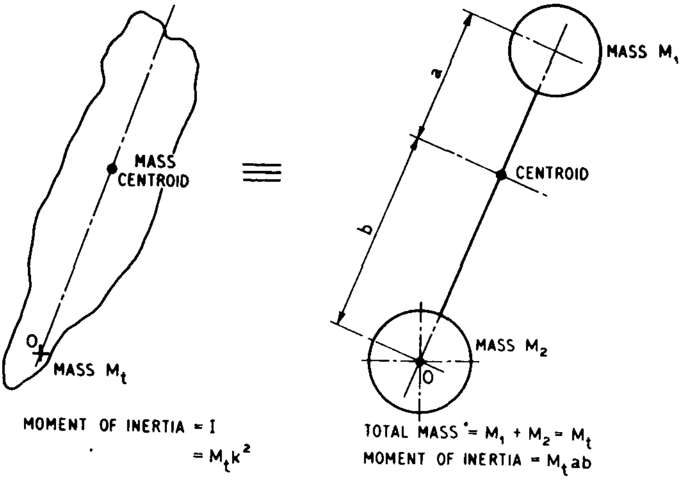


Fig. 14.3. Dynamic equivalents

the connecting rods could be up to 600 kg (i.e. roughly ½ ton). This emphasizes the importance of the lay mass.

In reality, the mass M is not a single mass concentrated at a point, but is distributed over the lay, *sword* and associated parts. The concept is, however, very useful (providing the nature of the simplification is fully realized). A complex component such as the lay assembly can be represented by the theoretical model shown in Fig. 14.3. To be *dynamically equivalent*, the following criteria have to be satisfied.

(a) The total mass of each must be the same.
(b) The first moment about a given external point must be the same for each.
(c) The second moment about a given external point must be the same for each.

In symbols, $M_1 + M_2 = M_t$, $M_1a = M_2b$,

and $$M_1a^2 + M_2b^2 = M_tk^2$$

(where k is known as the *radius of gyration* and I is known as the *moment of inertia).* The latter is a measure of the difficulty of imposing an angular acceleration to the assembly; it is roughly comparable to mass in the case of straight line movement. If the axis of swing is changed, so is the moment of inertia; therfore, the value of I only has meaning when the axis is defined; in this case, I is referred to its *centroid.*

The above conditions can only be met when $k^2 = ab$. For our purposes, we require only one mass in operation and this can be achieved by putting the other one at the pivot point. In this way the effective mass M_1 is situated at distance $(a + b)$ from the pivot and the centroid at distance b. Under these circumstances,

$$M_1 = \frac{b}{(a + b)} M_t \qquad (14.3)$$

If the centroid of the assembly is near the lay, M_1 will be little different from M_t (which is the actual mass of the assembly).

On the other hand, if the mass is concentrated nearer the pivot, it has much less effect. Thus there is every incentive to reduce the mass of those parts which are remote from the pivot axis (*rocking shaft* axis). Consequently, care must be taken to keep the masses of the lay, *shuttleboxes* and other

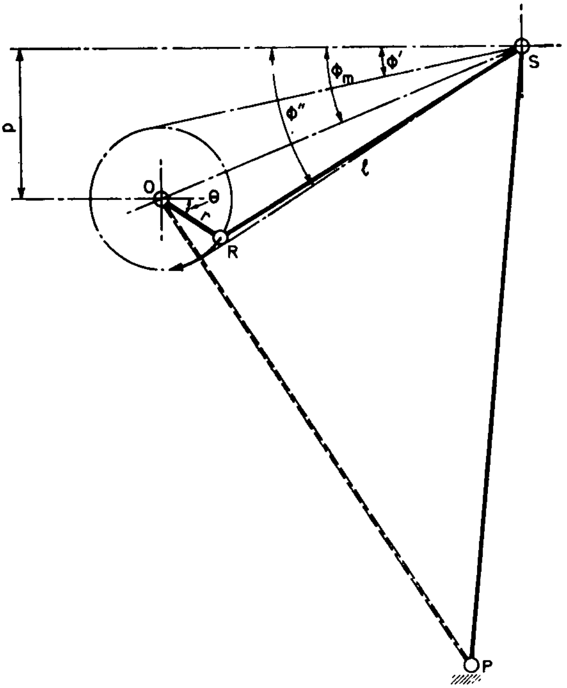


Fig. 14.4. Four bar chain with offset representing a lay mechanism

items at a similar radius, to a minimum. This is one reason why the lay is usually made of wood, which is light and can provide good stiffness without undue weight. It also provides a good running surface for the shuttle. It is apparent that the use of multi-shuttle boxes can be a disadvantage in this respect. With shuttleless looms, it is possible to make the whole mechanism lighter with the result that higher speeds can be used.

In the foregoing analysis, it was assumed for simplicity that the lay moves in a straight line. In actual fact the mechanism is really a *four bar chain*, as shown in Fig. 14.4, but because of the radius of the sword, straight line motion is a very good approximation. Furthermore, the line of movement of the lay does not have to pass through the center of the crank. An *offset* tends to distort the displacement curve and to produce a more pronounced *dwell* and, therefore, it is often used to enable the shuttle to traverse the loom without interference. It can be shown that the following equation holds approximately when p/l is small, i.e. when the offset is small.

$$\text{Acceleration} = d^2x/dt^2 = \omega^2 r\left(\cos\theta + \frac{r\cos 2\theta}{l\cos\phi}\right) \qquad (14.4)$$

The symbols are defined in Fig. 14.4. Equation (14.4) may be compared to eqn. (14.1). It will be seen that the double angle component is still present. Since an increase in offset causes an increase in the mean value of ϕ, then it will further be seen that the offset tends to increase the double angle effect and thereby make the dwell more pronounced.

Power

An electric motor cannot deliver a varying torque without speed variation and a normal relationship is as indicated in Fig. 14.5. A motor is not 100 per cent efficient and some energy is dissipated; this energy appears as heat and is a function of the *electrical slip*. An induction motor, such as is used on a normal loom, works at a speed lower than the *synchronous speed* set by the a.c. electrical supply. The difference between the synchronous and actual speeds expressed as a proportion of the synchronous speed is called electrical slip. As the slip in such a motor is increased, the amount of heat generated in the motor increases; thus,

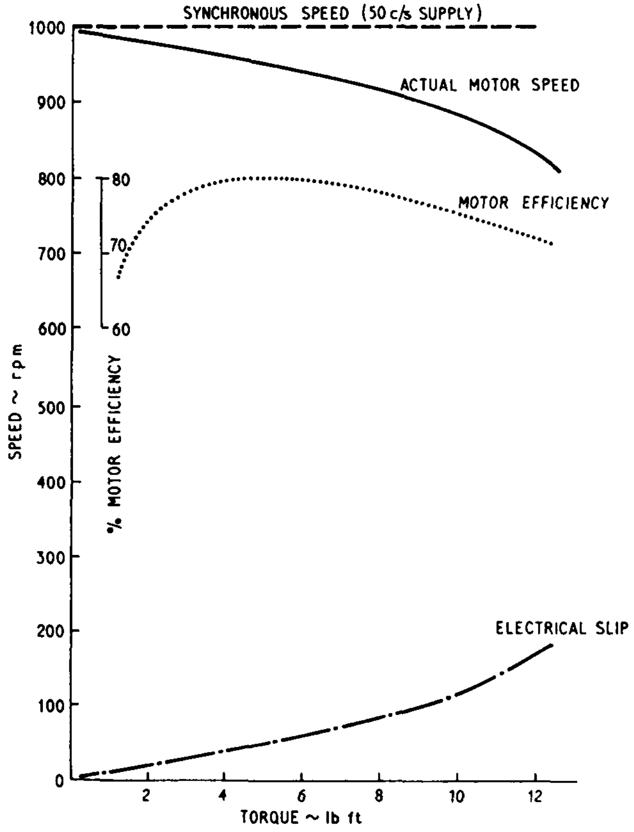


Fig. 14.5. Characteristic curves for a typical loom motor

running at high slip leads to overheating and an inefficiency unless the motor is specially designed. For electrical reasons, it is required that the motor should be kept below synchronous speed; therefore, where there are large swings in speed (as there are in a loom), the average slip has to be rather large. Hence it is necessary to use specially designed motors to drive a loom. Another reason for requiring special motors is that the *lint* from weaving is very easily ignited and the motors should be flameproof to prevent fires.

Since the swings in speed are a function of the inertias involved, a flywheel will lessen them; in extreme cases, however, it is desirable to use a special motor to meet the situation. This might have some advantage in that a smaller slip would be needed and the efficiency of the motor could be increased.

The loom motor works at a higher electrical slip than most other motors and this causes the *power factor* to be poor. The power factor is the ratio of power (in watts) to the mathematical product (volts × amps). It represents a sort of efficiency to the supplier of the electricity and, generally, a cost penalty is imposed for operating at a poor power factor. It is usually worthwhile to apply correction and this is most often done by installing electrical *capacitors* in parallel with sets of motors.

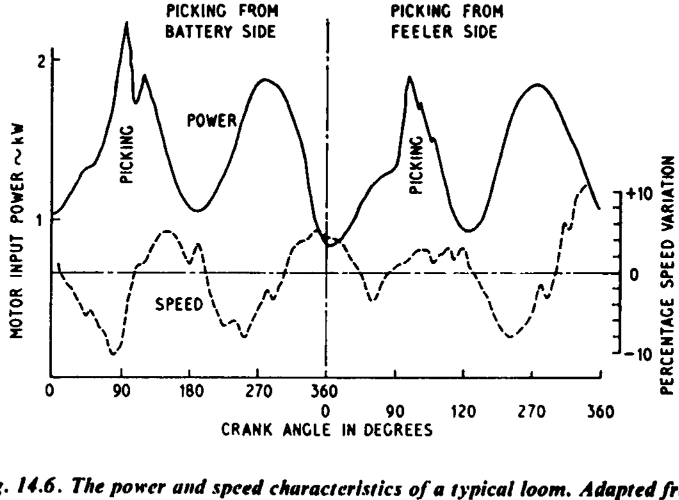


Fig. 14.6. The power and speed characteristics of a typical loom. Adapted from a Ph.D. thesis by M.H.M. Mohamed, University of Manchester, 1965

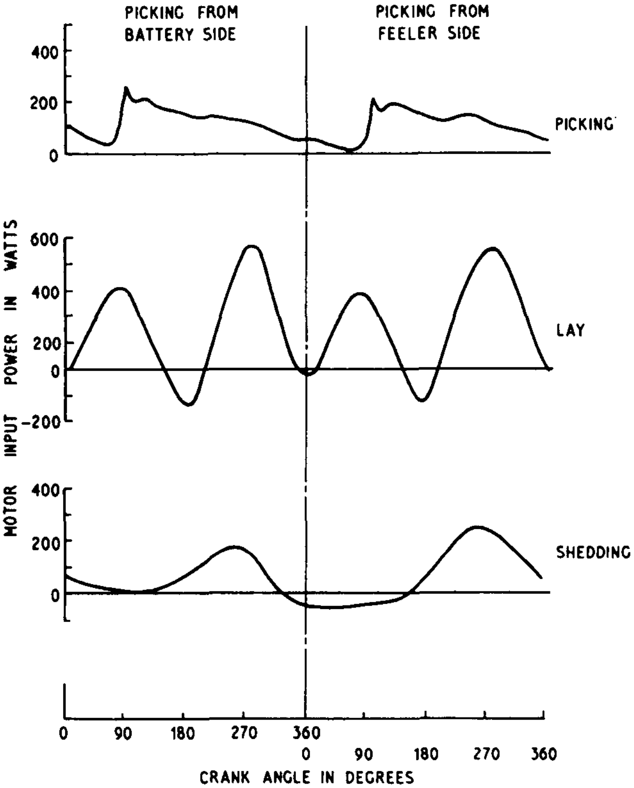


Fig. 14.7. Component power requirements. Adapted from a Ph.D. thesis by M.H.M. Mohamed, University of Manchester, 1965

The demands on the motor vary cyclically, as has been explained, and this results in a variation in power as indicated in Fig. 14.6. The motor, power lines, and switch gear must be able to cope with the peak currents rather than the average; also, a poor power factor yields greater current for a given power and thus all the electrical components have to be oversize by normal standards.

The power needs vary from instant to instant. Power and speed are related, as can be seen from Fig. 14.6. When the speed rises, the power absorbed declines; when the power demand rises, the speed drops. Referring to Fig. 14.2, it will be noticed that there is a strong similarity between the theoretical torque and the actual power demand; the double angle component is particularly noticeable, which indicates the importance of the lay mass.

In the past, attempts have been made to assess the power needed for each of the constituent mechanisms of the loom, but because of the interactions, it is not possible to determine these by progressive disconnection of various components without loss in accuracy. Unfortunately, it is difficult to measure the component behavior in any other way. The results by such disconnections and by difference between components have been used to obtain the curves given in Fig. 14.7. These should only be regarded as approximate; some other data are given in Table 14.1. If the component curves were added together, they would not produce the curve for the loom running with all components in use. This is because the behavior of both the motor and the loom depends upon the speed at the particular moment, as well as the accelerations developed by the other components. As can be seen from Fig. 14.6, picking has an effect on the battery side which is different from that on the other side. This is partly explained by the fact that the speed at the instant of picking is different in the two cases. The results referred to in this section apply to a Picanol President loom of 2.1 m (85 inch) width and are, therefore, particular in nature, but the pattern is somewhat similar to that found in other looms and may be taken as being reasonably typical of most.

Examining the component curves in more detail, it will be observed that the effect of beating and lay movement are the most important as far as power is concerned. The strong double angle effect arising from the sin 2θ term given in eqn. (14.2) is clearly evident. The deformation of the curve arising from beat-up can be detected, but to emphasize the point another set of curves (Fig. 14.8) is also given. It becomes increasingly difficult to beat up as the filling is forced into the fell of the cloth; also, a larger diameter filling (i.e. a coarser count) tends to make beating more difficult. This is also seen in Fig. 14.8; in one case, weaving was fairly normal and in the other a bumping condition existed.

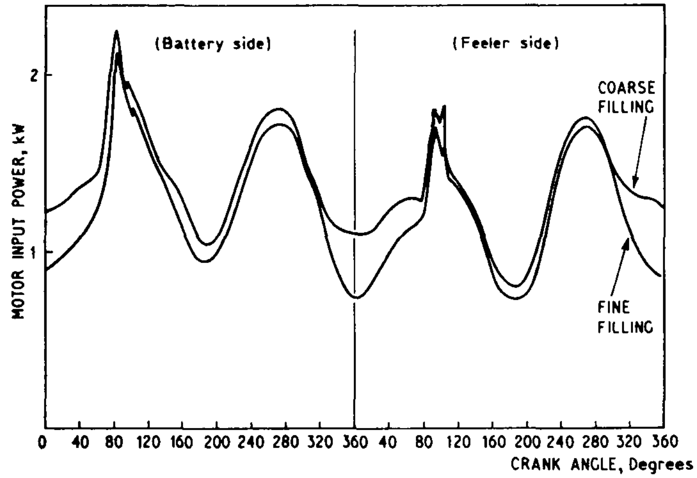


Fig. 14.8. The effect of filling count on power characteristic. Adapted from a Ph.D. thesis by M.H.M. Mohamed, University of Manchester, 1965

The power curve related to shedding is given in Fig. 14.7 and the peaky nature of the curve will be noted. This is because the cam profiles are shaped to give a rapid shed change once the shuttle has passed across the warp shed. The *amplitude* and shape of the power curve relating to this component are a function of the loom speed and the shape of the cam used for shedding.

Figure 14.7 shows the power required for picking. As explained earlier, picking needs only a short pulse of energy which might last only about 25 crankshaft degrees. In fact the sudden and rather large demand for energy causes the loom speed to drop and the character of the loom in combination with the motor determines how long it will take for the system to recover. In the case shown, the recovery takes almost 360°; if it had taken longer there would have been interference between one pick and the next (which could have led to instability). Any attempt to overspeed a loom can lead to this sort of difficulty, as can a large change in inertia.

The power required for picking is proportional to the cube of speed. If the shuttle velocity is taken to be proportional to the loom speed, then the kinetic energy required per pick is proportional to (loom speed)^2. The rate of using energy (i.e. the power) is proportional to (loom speed)^2 × (picks/minute) which in turn is proportional to (loom speed)^3. The bearing friction and windage losses increase as the square of the loom speed; thus the total power requirement of a loom is roughly proportional to (loom speed)^z, where z is between 2 and 3. The heavier the shuttle, and the more massive the loom, the nearer is the index z to 3·0. Conversely, by reducing the masses involved, it is possible to reduce the power required for a given loom speed and this can be translated in terms of cost.

Vibration (A Review of Theory)

Vibration occurs in a variety of ways (see Fig. 14.9). Longitudinal vibration is unimportant as far as this discussion is concerned and will be ignored.

Let the actual mass of the vibrating element be typified by an equivalent mass (M) situated at the points shown in the diagram. Let the stiffness of the system be defined as the force or torque needed to move that point by one unit. These parameters determine the *natural frequency* of the system and the system will tend to vibrate at that frequency if suitably excited.

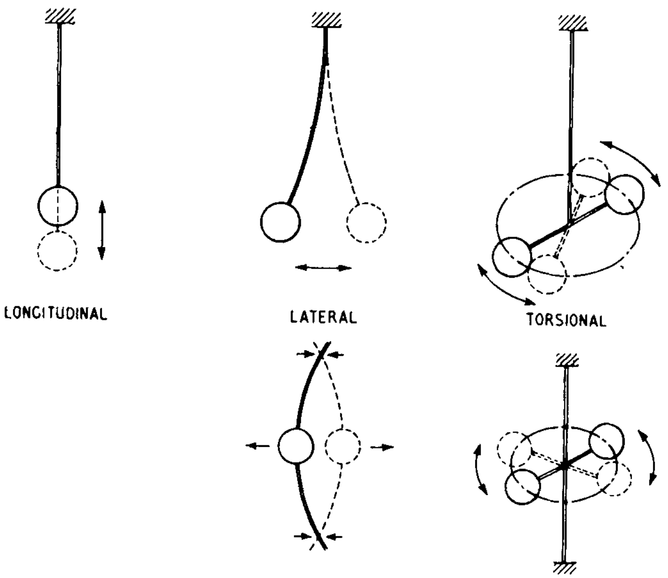


Fig. 14.9. Some forms of vibration

Consider the case of lateral deflection. Let

M = the equivalent mass (not weight),
s = *stiffness* of the vibrating member in the direction of movement,
= force required to produce unit displacement in the direction of movement,
n = natural frequency of vibration in cycle/second (Hertz),
x = displacement of the mass from its equilibrium position,
α = acceleration of the mass.

When the mass M is displaced from its *equilibrium position* by a distance x, the force needed to do this is $s \times x$ and the *elasticity* of the system tends to cause the mass to be returned to its original position. If the member is vibrating, this is still true and at the instant the mass is at distance x from the equilibrium point, there is a force equal to sx acting. This force can also be expressed in terms of the acceleration, i.e. force $= -M\alpha$. Hence

$$\frac{\text{acceleration}}{\text{displacement}} = -\frac{s}{M} = \text{constant}$$

This is *simple harmonic motion* and an exact mathematical solution to this arises when

$$\text{displacement} = x = A \sin \omega t \tag{14.5}$$

where A = *amplitude*,

$\omega = 2\pi n$,

t = time in seconds.

$$\text{acceleration} = \frac{d^2x}{dt^2} = -A\omega^2 \sin \omega t = \alpha$$

therefore $$\frac{\alpha}{x} = -\omega^2$$

and $$\omega^2 = \frac{s}{M}$$

or $$n = \frac{1}{2\pi}\sqrt{\frac{s}{M}} \tag{14.6}$$

In the *torsional* case, a very similar situation exists; if M is replaced by the *mass moment of inertia* (I) and the stiffness by the torsional stiffness (q):

$$\frac{\text{torsional acceleration}}{\text{torsional displacement}} = \frac{-q}{I} = \text{constant}$$

and $$n = \frac{1}{2\pi}\sqrt{\frac{q}{I}} \tag{14.7}$$

In the case of eqn. (14.6), s and M must be expressed in consistent units. For instance, mass M can be expressed as

$$\frac{\text{weight}}{\text{gravitational acceleration}} = \frac{W}{g}$$

if W is in pounds and $g = 32$ ft/sec^2, then s must be expressed in lb/ft to give the natural frequency in Hertz (cycles/sec). In the metric system the mass is expressed in grams or millinewtons (mN), but the stiffness S must be expressed in gf/cm or mN/m (where gf and mN are measurements of force).

Similarly in eqn. (14.7) q and I must be in consistent units. (I is the mass moment of inertia and $I = Mk^2$) The mass moment of inertia (I) is

$$Mk^2 = \frac{W}{g} k^2$$

where k is the radius of gyration measured in meters or ft [Note: in the latter case I has the units lb ft sec^2]. In the *SI* system of measurements (metric), the torsional stiffness may be expressed in mN m/radian but in the Imperial system one would use lb ft/radian and in either case the natural frequency is expressed in Hertz (cycles/sec).

The value of I depends not only upon the mass, but also upon the position of the mass with respect to the axis of rotation. If the mass is concentrated in a rim, we have a very effective flywheel; the greater the radius of the rim, the more effective it is and, with a given torsional stiffness of spring, the lower will be its natural frequency.

In any machine, there are successive disturbances which occur at regular intervals. Each of these disturbances can set up one or more vibrations which continue after succeeding disturbances arrive and pass. The later disturbances might augment the previous ones or not if they do on a regular basis, the vibration might build up to dangerous proportions. In other words, when the *forcing* and natural frequencies coincide, the system *resonates* and the condition is known as *resonance*. The consequences of this are widespread and it is necessary to discuss it in more detail before discussing the part it plays in a loom.

A vibrating mass will not continue to vibrate for ever; the rapidity with which the amplitude declines depends on the nature of the material. Some materials absorb substantial amounts of irrecoverable energy when deformed (which appears as heat) and such materials do not vibrate readily. Other materials absorb little energy in this way and these materials resonate easily. Examples of the two classes are cast iron and spring steel, respectively. This is one good reason why a loom frame is made of cast iron, i.e. because the iron damps the vibrations.

Under conditions of *damping*, the equation of motion is modified to

$$x = Ae^{-t/\tau} \cos mt \tag{14.8}$$

where A = amplitude,
$e = 2{\cdot}718$,
t = time in seconds,
τ = time constant,
$= 2M/\delta$,
δ = damping coefficient,
= damping force/unit velocity,
$m^2 = \omega^2 - \frac{1}{\tau^2}$.

The *time constant* (τ) expresses the decay characteristic of the vibration in much the same way as the half life expresses the decay of a radioactive source. It is a function of the damping coefficient (δ). A further point to note is that the frequency of vibration (m) is a little less than the natural frequency (ω) described earlier; in other words, damping reduces the amplitude of vibration and slightly affects the frequency too. These facts are important in resonant systems because the amount by which the amplitude decays between one pulse and the next determines how much the resonance can build up. With little decay, it can build up to destructive proportions.

If a force of $F \cos \omega_f t$ is applied to the system, this will be balanced by the inertia, damping and elastic forces in the material. In symbols,

$$M \frac{d^2x}{dt^2} + \delta \frac{dx}{dt} + sx = F \cos \omega_f t$$

An approximate solution to this differential equation is

$$x = C \cos (\omega_f t - \beta) \tag{14.9}$$

where β is a phase angle which need not concern us here: suffice it to say that since $\cos (\omega_f t - \beta)$ can never exceed $\pm 1{\cdot}0$, then the maximum value of x is C. It can be shown that

$$\left(\frac{C}{\Delta}\right)^2 = \frac{1}{(1 - (\omega_f/\omega)^2)^2 + ((\delta/M)(\omega_f/\omega))^2} \tag{14.10}$$

where Δ = the deflection the part suffers due to its own weight under static conditions,

C/Δ = the *dynamic magnifier.*

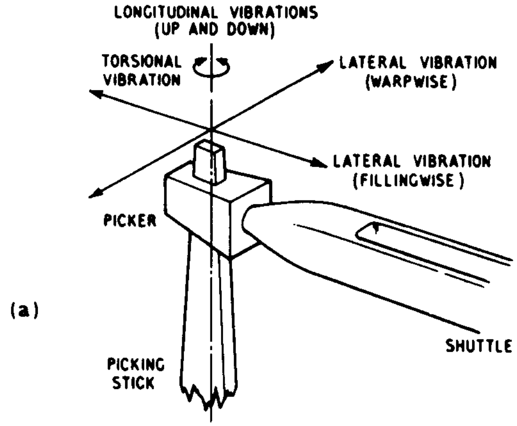
When the forcing frequency (ω_f) is the same as the natural frequency (ω),

$$(C/\Delta)_r = M/\delta \tag{14.11}$$

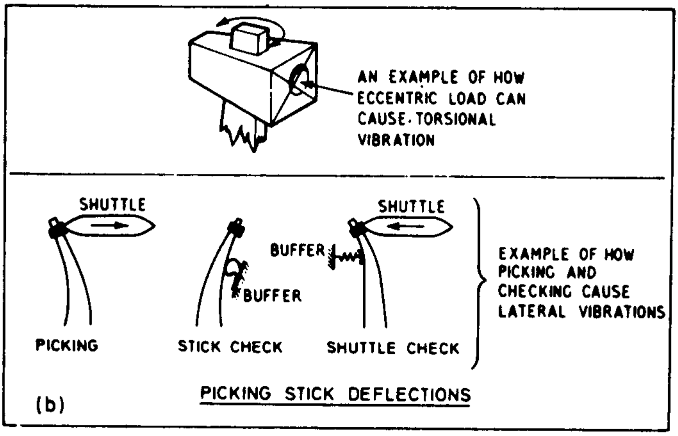
where the suffix r refers to resonance.

Thus if there were no damping, the dynamic magnifier would be infinite, which is clearly impossible. The physical reason for this is that all materials damp to some extent, no matter how small. However, the dynamic magnifier can be very large indeed and, when it is, the structure can vibrate very violently at resonance, even to the extent of self destruction.

In a very complex vibrational system such as a loom, each of the many components possesses a set of natural frequencies. Each of the motions produces a whole series of frequencies and their *harmonics*. Those natural frequencies which correspond with a forcing frequency or their harmonics will be accentuated; this is rather like a panel in a car which vibrates only at a given speed. Therefore, the structure has to be considered as well as the sources of vibration.



MODES OF VIBRATION OF A PICKING STICK



PICKING STICK DEFLECTIONS

Fig. 14.10

Vibration (Practical Aspects)

The picking of the shuttle creates a very sharp pulse which occurs at regular intervals and these trigger a whole spectrum of vibrations throughout the loom. The picking action of a normal shuttle loom depends upon the deflection of the picking stick, and the *alacrity* of the system is very important. This is only another way of saying that the picking system is a vibratory system which can be explained by eqn. (14.9). As was stated in Chapter 11, the natural frequency of the system is extremely important to the proper working of the loom. Looking deeper into the subject as we are now able to do, it will become apparent that the damping character of the material of the system is also important. If the picking stick were to have a very high damping coefficient, it would not work properly; if it were to have too low a damping coefficient it might continue to vibrate during the next pick and cause difficulty. It is necessary to use some material such as wood (preferably laminated) which has good elastic properties and a suitable damping characteristic.

A picking stick can vibrate in a variety of ways (see Fig. 14.10). For example, if the picker is not set correctly, both picking and checking will induce torsional and lateral vibrations which might carry over from one pick to another. The buffer used to check the stick after picking can cause similar effects. An adverse attitude of the picker when it starts to accelerate the shuttle can cause the shuttle to be deflected from its proper path. This can create difficulties as the shuttle enters the shuttle box on the other side. An incorrect entry can impose very high stresses on the shuttle; it can cause vibrations of the quill within the shuttle which can lead to faulty unwinding at a later stage. The entry of the shuttle also affects the way it is checked and this in turn affects the following pick. The irregularity of picking caused by such disturbances tends to be cyclic over several picks and although the mechanisms are complex, it still remains a fact that this is another sort of instability related to resonance.

Not only is the picking stick excited, but so are other elements in the system; for example, the *bottom shaft* can be set into violent torsional and flexural vibrations (Fig. 14.11) each of which have their own set of natural frequencies. To simplify matters, consider only one of these, say the torsional case. The system (which is usually poorly damped) vibrates at its natural frequency because of the blow it received from a given pick, but the frequency of exciting disturbances is related to the loom speed (which varies somewhat from pick to pick) and not to the natural frequency. Consequently, there is a random *beat effect* where the excitation sometimes augments the vibration and sometimes opposes it. This sort of thing seriously affects the stability of the running loom; sometimes there are strong picks and sometimes there are weak ones. Usually the strong picks are late and the

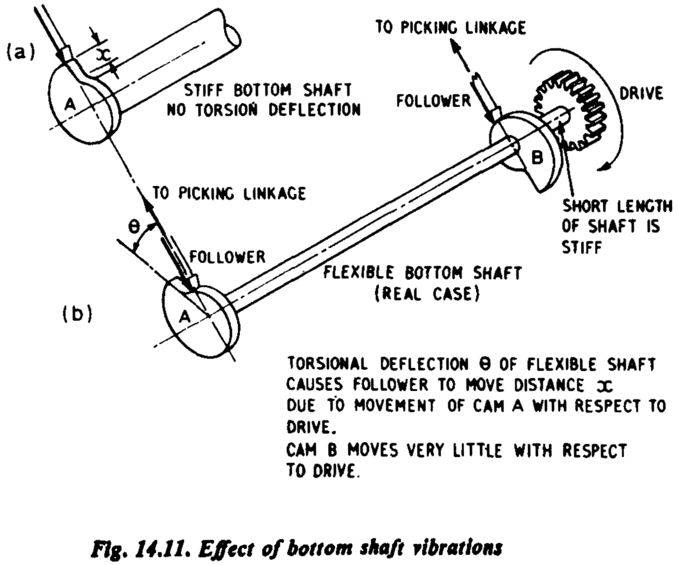


Fig. 14.11. Effect of bottom shaft vibrations

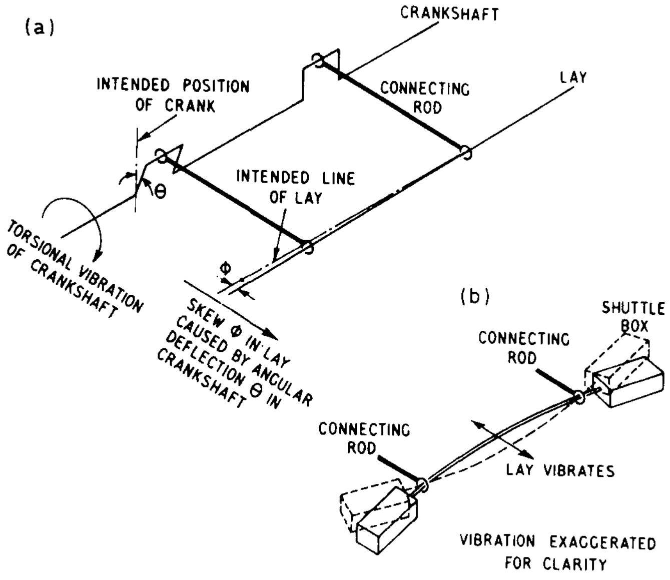


Fig. 14.12. Effects of vibration of crankshaft and lay

weak picks are early; this is because the vibration causes the cam to be displaced from its nominal position and it is this displacement that produces the extra energy (or the lack of it) to give the stronger (or weaker) pick. This leads to a most undesirable variation in speed and performance which tends to depress the acceptable running speed of the loom and thereby reduce its effectiveness.

When there is a strong pick, the motor slows down more than when there is a weak one; the loom also takes longer to recover from the strong pick. Thus these variations also affect the other motions; for example, a strong pick can be followed by a weak beat-up. If this is marked, the effect will show in the fabric and this is of some importance.

The lay beats up the filling and, in so doing, it suffers considerable force. To keep the fell of the cloth straight, the lay has to be rigid so that it does not deflect unduly. There is also another reason. The sort of shocks already discussed could produce a vibration in the lay, as shown in Fig. 14.12, and this would not be related to the loom motion. The vibrating lay could beat one part of a filling strongly and another not so strongly. At the next pick, the position could be reversed or there could be some other more complicated pattern of beating over the area of the cloth. Thus the lay should vibrate little, and one way to ensure this is to make it so stiff that its natural frequency is very high, in which case it is unlikely to vibrate strongly because all materials damp more readily at high frequencies.

In a multi-shuttle loom, the lay has heavy shuttle boxes at each end with considerable overhang in respect to the connecting rod pivots. This could lead to a heavy low-frequency vibration in the lay which would be very difficult to suppress. One solution to this is to use auxiliary cranks and connecting rods to support the extra masses during

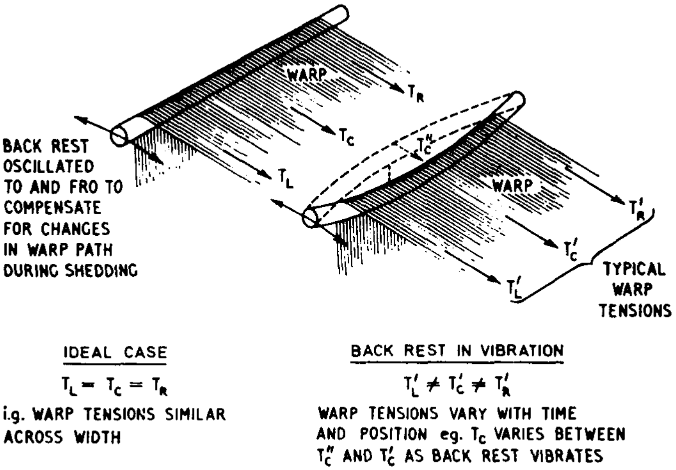


Fig. 14.13. Effect of back rest vibration

beating. If the crankshaft is set into vibration, by whatever means, this too can affect the beating. If one crank is in advance of the other (or others) the reed will be skewed (or bent) as indicated in Fig. 14.12 and this will give the beating irregularities previously described. Also, where a four crank loom is concerned, the vibration of the crankshaft can cause bearing trouble because of maldistribution of load and temporary bearing misalignment. A similar and more serious effect can be met with the bottom shaft; here, the bending and torsion is often quite violent and it has been known for shafts to be broken even though they may be solid steel bars of perhaps 5 cm (2 inch) diameter. Even if the difficulties mentioned do not result in immediate failure, there is always the possibility of an accelerated wear rate of the bearings.

The *back rest* in a loom is often oscillated deliberately to preserve, as nearly as possible, a constant warp tension. This movement not only adjusts the warp length to give the desired tension control but unfortunately it also introduces some disturbing forces. This and other excitations (such as from picking) cause the back rest to vibrate along its length, as shown in Fig. 14.13; this gives unevenness in warp tension across the width of the warp and the pattern is everchanging (because of the nature of the vibration). If large enough, this can produce patterning in the fabric, especially with fine synthetic materials.

A well-designed loom is made in such a way as to overcome most of these difficulties and they have been discussed in order that the design of the loom may be understood. A proper understanding of loom operation also helps in avoiding difficulties that may arise through unwise alterations or additions to the design of the loom.

The loom as a whole can vibrate on a springy floor, and it is often surprisingly difficult to find a suitably rigid floor; even "solid" earth is capable of acting as a spring in this respect. Thus we have a *mass-elastic system* in which the loom (or a set of looms) acts as the mass and the floor and the surrounding structure acts as the spring. (The surrounding structure is very important; *structure borne noise* and vibration from a loom can appear in parts of a building quite remote from the weave room.)

If a loom is mounted on pads to absorb the energy of vibration, it is necessary that there should be movement of the loom to permit the *damping pads* to work. Such movement means that, at best, only part of the vibration can be removed. Furthermore, the damping is a function of the velocity of movement; therefore, the higher frequency components will be damped out quite well but the lower frequency ones will not. The amount by which the loom can be allowed to move on its mountings must be limited, because an undue excursion of the frame whilst the shuttle is in flight could cause all sorts of trouble. Thus pads can do no more than give some relief from the problem; they cannot effect a cure. In general terms, they muffle the noise a little.

If a loom is mounted on flexible mounts, those vibrations arising within the loom which are considerably above the natural frequency of the mounts will be attenuated. This means that the level of vibration in the floor will be reduced for the given frequencies. If the forcing frequency is the same as that for the mounts, the assembly will rock violently because it will be at resonance. Taking into account the mass of the loom, it may be possible to obtain mounts whose natural frequency when installed is (say) 2 cycles/sec. The lowest frequency (in cycles/sec) of any great magnitude generated by a loom is that of the bottom shaft ($\frac{1}{2}$ × picks/min ÷ 60). This means that a normal shuttle loom has a spectrum of frequencies from about 1 cycle/sec upwards. Thus there is a very good chance of getting into disastrous resonance and, even if this is avoided, there will be little attenuation of the low frequency vibrations. However, with a shuttleless loom, the problem is not so severe. In those looms which have a picking mechanism which produces little or no external reaction, the half speed component is negligible and the major component is the double speed one from the lay motion. The frequency in cycles/sec, in this case, is 2 × (picks/min) ÷ 60. Bearing in mind that these looms run faster than conventional ones, the major component might well be at some 10 cycles/sec and such a component could be attenuated by flexible mounts. Even so, the looms would not be rigidly anchored and would tend to flop about; this could lead to operational difficulty. Another factor is the lack of the stiffness which a loom normally acquires by being secured (either by its own weight or by securing devices); this means that the frame of the loom can more easily vibrate. The gains obtained by using pads or flexible mounts or both are reduced by this fact. Extra stiffening without extra mass is needed in such cases.

The foregoing indicates the difficulties which are involved in reducing the vibration levels in a shuttle loom and it is quite clear that the shuttle has much to answer for in this respect. If noise becomes an over-riding factor, there will be a strong incentive to change over to shuttleless looms, which can meet legal specifications for the maximum permitted noise and vibration. This is apart from the other merits that these looms might have.

15

SHUTTLELESS WEAVING SYSTEMS

Key words: *air-jet loom, barré, cutters (weft cutters), effective mass, filling transfer, filling retraction, flexible rapier, fringed, giver, gripper, guides, inertial system, Leno selvage, momentum, rapier, rigid rapier, selvage, selvage motion, shuttleless weaving, slough-off, sonic velocity, staple yarns, taker, toggle, torsion bar, tucked-in selvage, turbulence, water-jet loom.*

Introduction

In a shuttle loom it is necessary to pass a shuttle, which may weigh ½ kg (1 lb), to insert a length of filling which may weigh only a few milligrams. The relatively massive shuttle has to be accelerated rapidly, and it must also be decelerated abruptly; it is difficult to do this without causing shock and noise. The system is intrinsically inefficient from a mechanical point of view, and considerable amounts of energy are dissipated at the binders (swells), picker and checking mechanism generally. The wear life of the picker is strictly limited because of the heavy and repeated impacts that it suffers. In fact, the whole mechanism is subject to great wear and tear, with the consequence that it has to be made rugged and heavy. The shocks arising from picking and checking disrupt the smooth sequence of events in weaving, with the result that there is a certain instability in the loom speed. This affects the maximum permissible running speed of the loom, and it can affect the fabric. Furthermore, the shocks lead to noise and vibration which are extremely difficult to subdue. There is growing concern in many countries regarding the environment in which

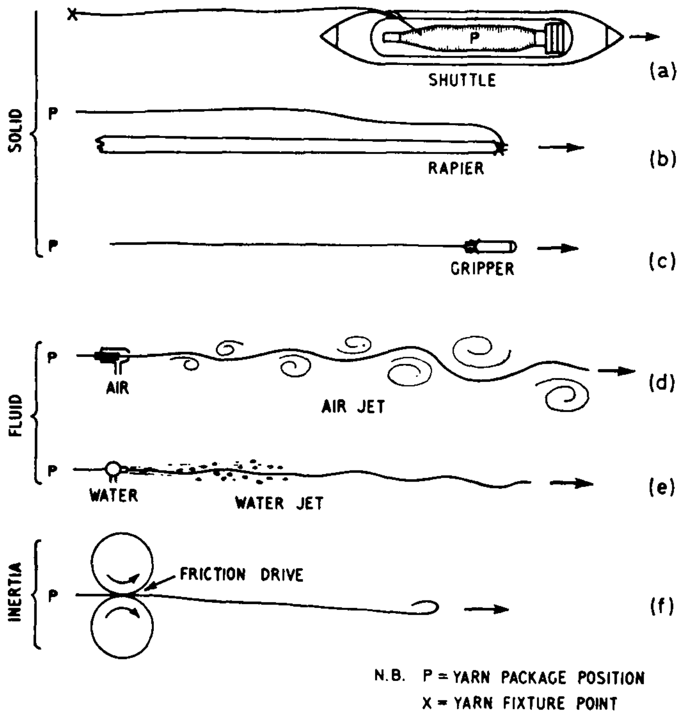


Fig. 15.1. Filling insertion systems

workers are employed, and this is likely to become an increasingly important issue. Little wonder that the shuttleless loom has begun to make its presence felt.

Forms of Shuttleless Weaving

One solution to the problems inherent in the weaving process is to reduce the size of the element used to propel the filling (weft). This element may be a solid or a fluid, and these two categories may be further sub-divided as indicated in Fig. 15.1. In most cases the propulsion element traverses the warp shed in the loom, but it is also possible to apply

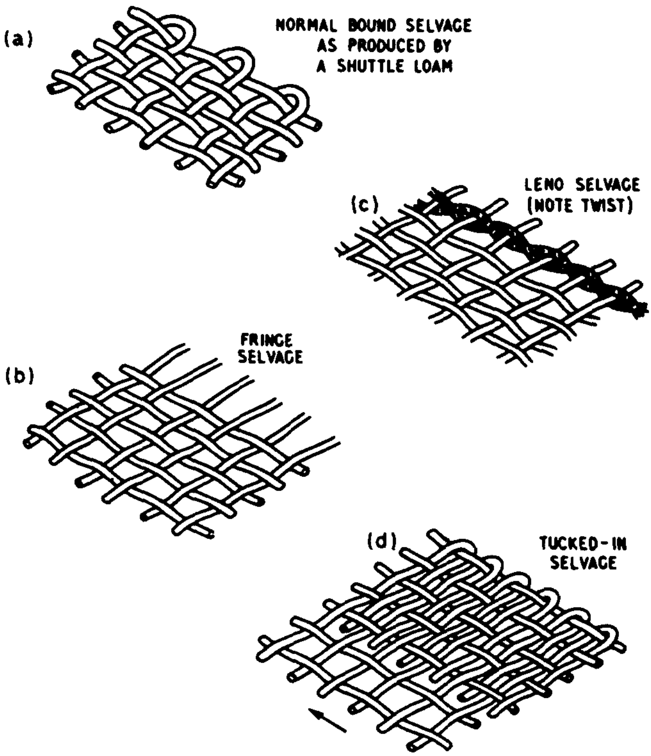


Fig. 15.2. Various forms of selvage

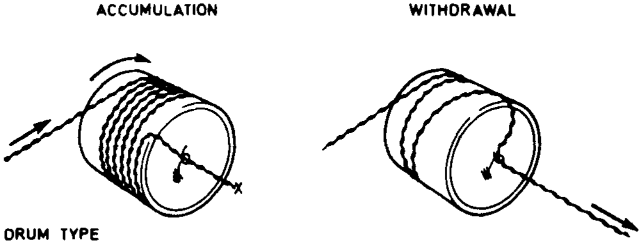
energy to the length of filling before it enters the shed and to allow its inertia to carry it across.

Shuttleless looms of the type which use *projectiles* or *rapiers* now predominate. *Water-jet looms* are also quite widely used, but they are restricted to the weaving of filament yarns because of the effects of water on *staple yarns* which have been sized. However, all the systems have features in common and it is convenient to discuss these common features before considering individual systems.

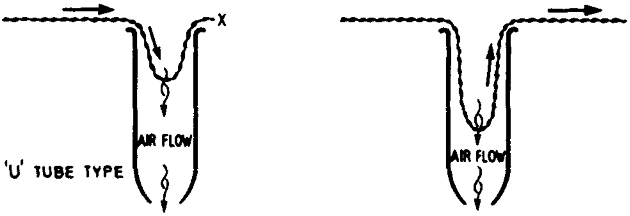
In none of these systems is a quill or pirn carried to and fro to give a normal selvage (see Fig. 15.2(a)). The length of filling is inserted usually from one side, with the result that at least one selvage must be *fringed*, as shown in Fig. 15.2(b). To enable the fabric to withstand subsequent processes, the fringed selvage must be reinforced in some way. It is possible to use adhesives, but the most popular solutions are to use a *Leno selvage* (Fig. 15.2(c)) or a *tucked-in* selvage (Fig. 15.2 (d)). For cut goods, or those to be hemmed, the Leno selvage is usually sufficient, but if a good edge is required on the finished product, as in the case of sheets, the tuck-in motion is preferred. The latter simulates a conventional selvage but there is a concentration of filling ends at the edge and it is usual to alter the fabric structure locally to accommodate the crowding. The tuck-in technique places some restriction on the structures which can be woven but this is rarely an oppressive restriction.

With normal weaving, the quills can arrive at the loom in a different order from that in which they were wound. Bearing in mind that the yarn varies in count as it leaves the spinning machine, there can be a quill to quill variation. If these quills become disordered, there can be sharp changes in count from one to the next, and this shows up in the fabric as barré faults. These stripe-like faults are most noticeable in weaving filament yarns. This difficulty is greatly reduced by weaving from a large package such as used in shuttleless looms; the gradual changes in count within the package are not usually very noticeable and the frequency of change is sharply reduced. With a large package, the amount of fabric produced between changes is measured in meters (yds). (The precise amount depends on loom width, pick density, yarn count and package size). With a normal quill, the amount of fabric is measured in cm. Thus quills may produce narrow barré (which is very noticeable) whereas the large package is only likely to produce one single step change in any normal length of fabric. This also has a repercussion on the level of quality control which must be applied to the filling yarn. Generally, specifications can be relaxed a little with the large packages and this can save money.

Since a quill is no longer used with a shuttleless loom, there is no need to restrict production by using small yarn packages for filling; in fact, a major advantage accrues from using the large package because winding and filling replenishment costs can be reduced. However, unwinding a large package does pose some problems when the withdrawal is intermittent (as it is in most of these looms). At the speeds involved, over-end unwinding is the only practical way of dispensing the yarn and this gives rise to difficulty. Under steady unwinding conditions, a yarn balloon forms which holds the yarn clear of the package as it is withdrawn. Under unsteady conditions, such as apply in the case under discussion, the yarn can be dragged over the surface of the package. This can cause one or more turns of yarn to *slough off* and cause a stoppage; it can also cause the yarn tension to rise suffi-



(a) DRUM TYPE



(b) 'U' TUBE TYPE

Fig. 15.3. Filling yarn storage systems.

ciently to cause a break. Thus it is required to unwind the yarn as steadily as possible and to store excess delivery at certain times against the sudden demand at others. One practical way of achieving this objective is to store sufficient yarn on a smooth cylinder by side winding and then at the point of sudden demand, allow the accumulated yarn to be withdrawn over-end so that it may be removed rapidly without contact against other layers of yarn beneath. The principle is shown in Fig. 15.3(a). Another technique is to use a suction tube to hold a long U-shaped loop of yarn until the sudden demand causes a rise in tension which removes the yarn stored in the U-shaped configuration. The steady supply of yarn to the system allows the U to grow in size until the next demand, and so on (see Fig. 15.3(b)).

In many cases, the filling cannot be located across the width with great accuracy; it is necessary to insert an excess and to cut both ends of each length of filling after insertion to give good register. The *cutters* are usually scissor-like devices but it is possible to use a hot wire cutter when the filling is made of certain fibers. The cut end is tucked in or is left as a fringe. Alternatively, the selvages can be sealed by heat or adhesive, but this tends to give a stiff edge to the fabric.

Some of the methods mentioned lead to the insertion of a filling which has to be straightened prior to beat-up and there are several ways of doing this. Where the contortion of the filling is large, it would be wasteful in material to straighten from the free end and cut off the excess (i.e. to remove the excess yarn at the selvage remote from the filling insertion device). In these cases it is normal to use a *retraction* device which is situated near the insertion device and which pulls out the excess filling and stores it so that it may be used in the next pick. To obtain good straightening, it is necessary to restrain the free end of the newly inserted filling whilst the other end is retracted. It is possible to use an air suction for this purpose or to use a pair of yarns which are twisted so as to entrap the end at the time and place required. In either case the entrapment medium can be used to carry away the ends cut off by the selvage cutters. A third possibility is to use a mechanical clamp which catches the end; this solution is favored where the end is to be tucked in to simulate a normal bound selvage. Sometimes the retraction device is a mechanical finger, which is favored for tuck-in selvages. Suction devices used for retraction are usually combined with the storage system, but care must be taken to prevent the yarn twisting about itself and forming snarls which are likely to cause stoppages and/or fabric faults.

Vincent Inertial System

It is desirable to reduce the linearly moving elements of the filling insertion system to an absolute minimum; ideally, the mass would be reduced to that of the length of filling concerned. The Vincent system aims to do this by causing energy to be imparted to the filling yarn before it enters the warp shed. This is done by introducing the filling to a pair of high-speed rollers which grip the yarn and accelerate it up to speed very rapidly indeed (see Fig. 15.1(f)). The yarn then traverses the warp shed by virtue of its momentum. In its simplest form, the device projects the yarn at constant velocity, but air drag causes the leading end to slow down whilst yarn is still being fed at the higher velocity; this causes the yarn to buckle in an undesirable manner. If, however, the drive rollers are decelerated to match the leading end, this difficulty can be avoided and remarkably straight picks can be generated. The initial acceleration causes a hook to be formed at the leading end because there must be some initial slippage which causes the leading end to be overtaken by following elements of yarn; this is much more difficult to overcome.

Should the length of filling yarn be buckled or have an appreciable hook at the leading end, there is a good chance that the yarn will touch the warp shed. Since the *momentum* of such a light piece of yarn is very low, it needs only the slightest touch to cause it to be stopped or seriously slowed down; if this happens there is nearly always a fault produced in the fabric. Thus a hairy or deformed length of yarn passing through a warp shed (particularly an unclear warp shed) is very likely to cause a fault. This is a defect shared with the ***air-jet loom.***

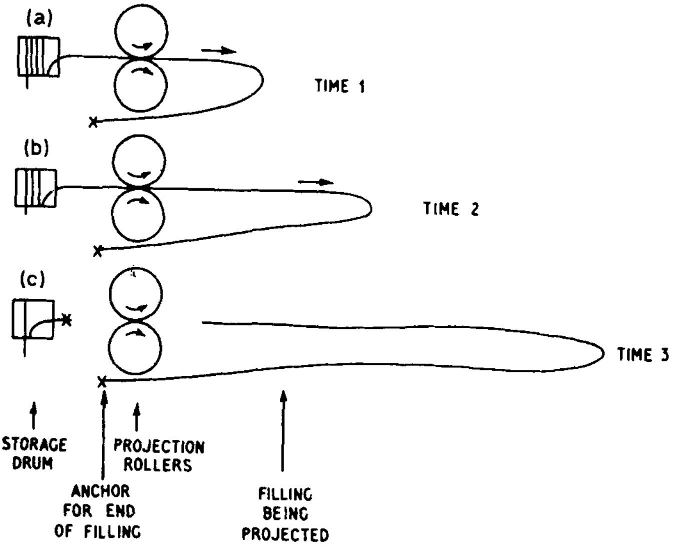


Fig. 15.4. Modified Vincent system

In an interesting development of this technique, the free end is anchored and succeeding elements are projected in the manner shown in Fig. 15.4. The "unrolling" type of motion applied to the yarn tends to straighten it and reduces the potential for faults. At the time of writing, none of these devices has been exploited commercially.

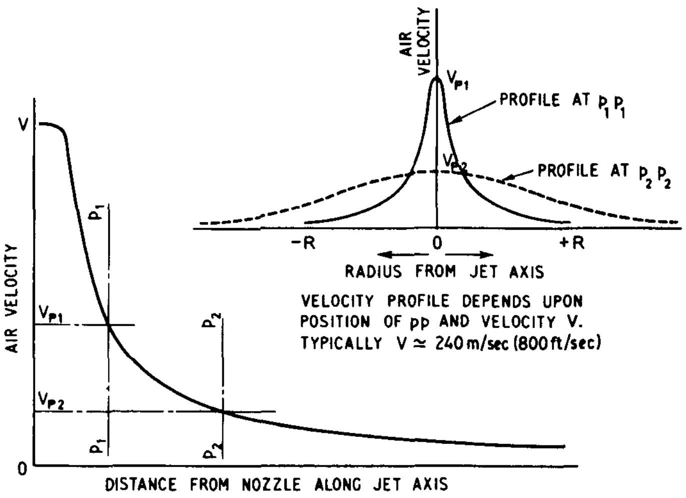


Fig. 15.5. Typical air jet characteristics.

Air-jet Loom

A blast of air would seem to be an effective way of inserting the filling, but to get enough traction on the filling yarn it is necessary to use very high air velocities. These normally exceed *sonic* velocity with the consequence that the looms are noisy and consume considerable amounts of energy. This increases the cost of weaving and tends to make air-jet looms less attractive.

When an air jet is allowed to expand freely, the moving air is contained within an imaginary cone whose axis is coincident with that of the air jet (see Fig. 15.1(d)). The air just emerging from the nozzle is highly energetic and, as it moves away from the nozzle, it entrains some of the surrounding air which tends to slow the mass down. Thus as the moving mass of air moves away, it grows larger and becomes slower. The air velocity component parallel to the jet axis declines sharply with both axial distance and radius, as shown in Fig. 15.5. Friction is low in air, and the original kinetic energy of the air in the nozzle cannot be lost quickly enough. The air stream breaks up into *turbulence*; the excess energy is absorbed by the turbulent eddies and this energy is irrecoverable. This is where the majority of the energy is wasted. Moreover, the eddies cause the filling to become contorted as indicated in Fig. 15.1(d), and it is necessary to have a much larger warp shed than might be supposed, simply because the contorted filling would catch upon the warp. A length of filling traveling on its own has little momentum and can be easily stopped. The problem is increased because the filling moves into a field of declining air velocity and thus behaves as if it is propelled from behind; the front end moves slower than the rear and the yarn buckles. The net result is that usually the warp shed must be larger than that for a shuttle loom. In practice, it is not possible to project a filling more than about 1½ m with a simple air jet of reasonable size and power consumption; therefore, the width of the loom is limited too. Even so, it is possible to run looms of this sort at over 400 p.p.m. which indicates that the bar to increased productivity in a shuttle loom is really the picking and checking system.

One way of improving the performance of an air-jet loom is to use a device to prevent the air-jet from breaking up so quickly. A series of orifices, with slots to permit the removal of the filling at beat-up, can be placed along the filling axis. These act as a sort of porous tube and tend to improve the axial air velocity running over the filling. They also reduce the turbulence so that there is less disturbance to the filling. Such a system permits an increased productivity by allowing a higher loom speed or wider loom or both to be used. The orifices are sometimes called "confusers".

A second way of improving the performance of an air-jet loom is to use a multiplicity of jets across the width of the loom. The auxilliary jets protrude through the warp and yet are arranged in such a way as not to impede the warp shed change or beat-up. The propulsive urge can then be distributed along the width of the loom to maintain the straightness of the filling yarn and to extend the width of the loom. These multi-jet looms can be made in widths that are attractive to the user, and thus the fortunes of the air-jet loom have revived. Unlike the water-jet loom, there is no restriction on the type of yarn that can be woven but, because of the higher speeds used, there is a need for a higher level of quality control of the yarn used. The slashing also has to be carried out with care. Failure to utilise the highest standards of quality control can result in very poor loom efficiencies and loss of production.

Water-jet Loom

A water jet is more coherent than an air jet. It does not break up so easily, and the propulsive zone is elongated, making it much more effective. It is effective in terms of energy requirements, it is quiet and, when the jet does break up, it goes into droplets which create very little turbulence to disturb the filling (see Fig. 15.1(e)).

The droplets spread in such a way as to wet much of the warp; thus a sized warp containing a water soluble adhesive can be adversely affected. Because of this, water jet weaving is usually restricted to filament yarn, but there is some hope that it might become economically feasible to weave staple yarns on these looms.

Two main reasons for the efficiency of the water-jet loom are that there are no varying lateral forces to cause the filling to contort, and the moving element is more massive because it is wet. Thus there is less chance of fault due to contact with the warp.

The range of jet, and thus the width of the loom, depends on the water pressure and the diameter of the jet. Water is virtually incompressible and a simple jerk pump can be used to give adequate pressure without difficulty. A fireman's hose has a tremendous range but the jet is several cm in diameter; large volumes of water and considerable pumping powers have to be used. In weaving, a much more modest jet is used; in fact, it is possible to reduce the diameter of the jet to some 0·1 cm, and the amount of water used per pick is commonly less than 2 c.c. Even with these small jets, it is possible to weave at up to 2 meters in width with small power consumptions. It is also possible to weave at up to 1000 picks/min on narrower looms. Several forms of water-jet loom have now become established. Performance in comparison with other types is shown in Table 15.1.

Projectile Loom (Gripper Shuttle Loom)

A more positive way of inserting the filling without resorting to the heavy shuttle is to use a projectile or gripper shuttle which grips the end of the filling yarn presented to it and, when projected across the warp shed, tows the filling yarn behind it (see Fig. 15.1(c)). This projectile or gripper shuttle will be referred to throughout the rest of this text as a projectile although the alternative names of gripper shuttle and gripper still have some currency. The projectile does not have to carry a yarn package with it and it need only be relatively light in weight; however, it is sufficiently massive to be unaffected by minor obstructions in the warp shed.

Since there is no moving package, there can be no normal selvages and it is usual for the projectile always to travel in the same direction when carrying the yarn rather than to reciprocate as in a normal loom. The projectiles are returned to the starting point by some form of conveyor belt and several projectiles are needed even though only one may be in active use at any one time.

Because the mass of the projectile is much less than that of the conventional shuttle, the forces needed to accelerate it are less and the picking mechanism can be lighter; this in turn reduces the total mass to be accelerated and makes it possible to use new systems. Also, because the mass is low,

Table 15.1

LOOM PERFORMANCE DATA

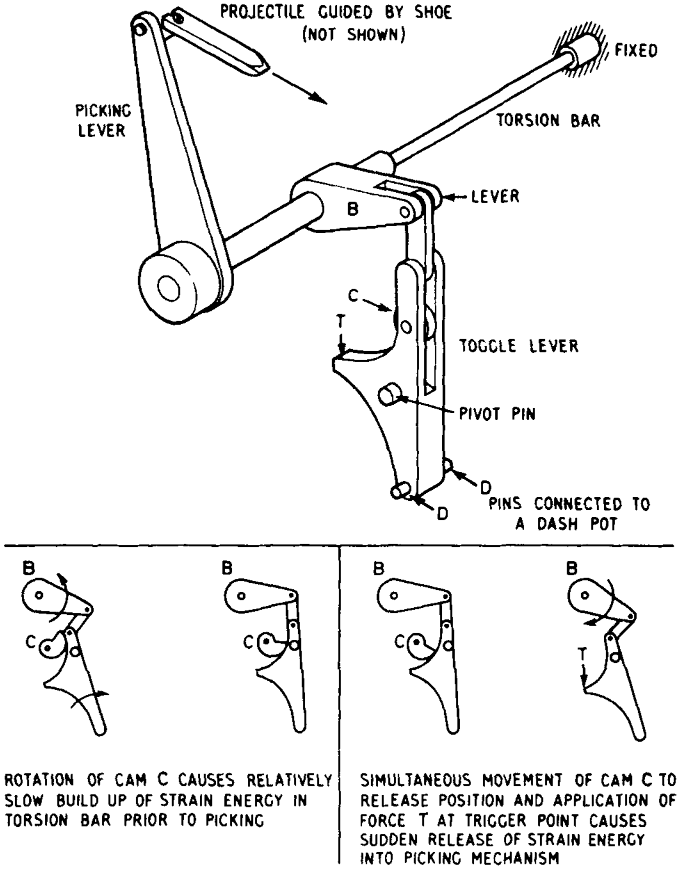
Loom Type	Width Range cm	Speed Range ppm	Maximum Rate of Filling Insertion m/min
Rapier			
Single phase	165 – 360	180 – 325	600
Double phase	2 x 125 – 2 x 205	220 – 300	1100
Projectile	220 – 545	200 – 320	1100
Water-jet			
Single	125 – 210	400 – 700	1100
Double	2 x 165	400 – 600	2000
Air-jet	125 – 330	350 – 600	1300
Multi-phase			
Weft wave	2 x 165 – 4 x 165	280 – 620	2000
Warp wave	2 x 100	3600	3600

the speed can be increased to compensate (at least to the point where shedding and beating give trouble). Thus these looms can be run faster than conventional shuttle looms. Also the acceleration of the projectile can exceed that of a shuttle by a factor of about 7. This affects both the space consumed and the productivity to advantage.

A good picking system needs to store energy which is released as the shuttle is accelerated; the same consideration applies to the propulsion of a projectile. In the most widely used system, a *torsion bar* (instead of the wooden picking stick) is used to store strain energy prior to picking and this energy is released during the acceleration of the projectile by a *toggle* action. The whole unit is very compact and effective (see Fig. 15.6).

Each new projectile is accurately positioned before it is projected across the warp shed and thus the strength of the pick is not dependent on any of the interactions described on p. 224 and 282. The energy expended in picking is roughly one half of that used with a normal shuttle despite the higher velocity of the projectile. In consequence, the picking mechanism is less massive than that used with a conventional shuttle, and it is easier to check the picking lever used with the projectile than it is a normal picking stick. Also it is much easier to check the projectile because of its low mass. Bearing in mind the normal difficulties in checking, it will be realized that this represents a significant advance in design.

The normal projectile is rather short and if it were to meet a substantial obstruction in passing across the loom, it could quite easily be deflected; at worst it could fly out of the loom, which could be very dangerous. Also the collection of the projectile after it has completed its task of carrying the filling is made more difficult if it does not follow an accurate path. For these reasons, a series of *guides* are used to constrain the projectile as it passes across the loom. To make this possible, the guides must protrude through the warp sheets as shown in Fig. 16.1. (p.313).



ROTATION OF CAM C CAUSES RELATIVELY SLOW BUILD UP OF STRAIN ENERGY IN TORSION BAR PRIOR TO PICKING

SIMULTANEOUS MOVEMENT OF CAM C TO RELEASE POSITION AND APPLICATION OF FORCE T AT TRIGGER POINT CAUSES SUDDEN RELEASE OF STRAIN ENERGY INTO PICKING MECHANISM

Fig. 15.6. Toggle torsion bar picking mechanism

At first sight it might seem that a very small warp shed could be used because the projectile is so small. However, it is still necessary that there should be a clear shed, and this means that the angles of the warp must be greater than certain minima. As the travel of the lay cannot be reduced below a certain level, the warp shed has to be rather large

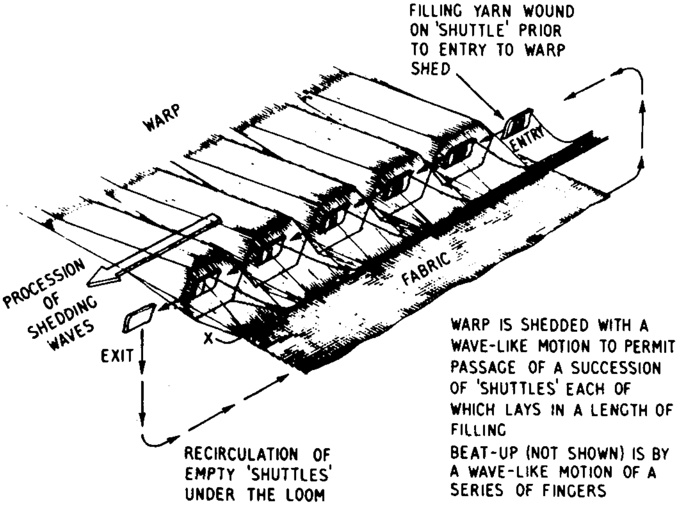


Fig. 15.7. Loom with simultaneous laying of many fillings

considering the size of the projectile. However, there is some gain and, perhaps more important, there is an improvement in the warp breakage rate which has advantageous economic repercussions.

The use of a small projectile tends to reduce the amount of "shuttle" interference (or its equivalent) as shown in Fig. 16.2. This is because the projectile is shorter and the time needed for it to pass a given point is reduced. Also the projectile is slimmer than a shuttle and the warp can more nearly close on the departing projectile than it can on the fatter shuttle. Thus tighter loom timings are possible and the gain can be taken as either an increase in loom speed or in fabric width.

Of the two alternatives cited, an increase in fabric width is usually preferred and looms of up to 6 meters in width are now made. One reason is that the projectile is only usefully employed when it is carrying filling across the warp shed. When the projectile is at rest or is being accelerated, it is not fulfilling its main task. With a narrow loom, the projectile spends a greater proportion of its time in unproductive dwell or acceleration than it does in a wide loom. Since acceleration has to be limited to what the machine elements can bear, it tends to be the same irrespective of the loom width; also in practice the projectile speeds do not vary much with loom width, and therefore there is an advantage in using wider looms. For example, it has been found worthwhile to weave sheets side by side on a wide loom rather than to use several single width looms. This is despite the fact that a pair of *selvage motions* has to be fitted for each fabric width on the loom.

Over the years, loom widths have tended to increase and this seems to confirm the trend noted above. However, there must be limits to the gains which can be achieved. For one thing, the retardation of the projectile in its passage across the loom has to be taken into account. Also, and perhaps more importantly, the wider the loom, the greater is the chance of a warp break. A single end break causes the whole loom to stop and the wider the loom, the more production is lost due to the stoppage.

Wave Shed or Multi-phase Looms

An interesting design utilises multiple *carriers* as shown in Fig. 15.7. By laying in several fillings at the same time, the productivity of the loom is greatly increased if the loom operates at a reasonable speed. To accommodate the several carriers, it is necessary for the beating and shedding to operate in a wave-like manner so that the opening in which a carrier travels also moves with it. This means that the shedding and beating elements have to move independently at the appropriate times, rather than in a block as they do in a normal loom. There are limits to this system; for example, an end break can cause difficulty because of the progressive entrapment of the multiplicity of filling yarns. Winding yarn onto the carriers at a sufficiently rapid rate could also cause problems unless there is a multiplicity of winding heads or the carriers are pre-wound. The system also limits capability of the loom to produce a range of fabric designs.

Another interesting design utilizes a multiplicity of warp shed openings which move in the direction of the warp. Several picks can be in motion at the same time, one to each warp shed opening. The filling carried in the shed opening is beaten into the fell of the cloth as the 'warp wave' approaches the fell. Once again the multiplicity of filling insertions makes possible a very considerable increase in productivity.

Rapier Loom

The shuttle loom is an imperfect machine in that the shuttle is not fully restrained. Mechanical shocks are generated when the shuttle comes under restraint; high *rates* of acceleration are generated and this limits the level of acceleration that may be accepted. Thus if full control of the filling insertion device is achieved, an advantage accrues simply because shocks are almost eliminated; higher levels of acceleration can be accepted and this implies that the speed of the loom can be increased (subject to other limitations).

At first sight it might appear that a rapier system would involve less effective mass than a shuttle system, but this is not necessarily so. In theory, it is possible to replace the actual system by one in which there is an *effective mass* which is driven along the filling path by a massless drive apparatus, the effective mass being that which would cause the input portion of the system to suffer the same torques or forces as the actual one. In a shuttle loom, the effective mass is about twice the shuttle mass, in a rapier loom it is many times the mass of the rapier. The inertia of the rapier drive is thus far more important than that of the rapier itself, and it is the mass of the drive that largely controls the behavior of the whole picking system. Thus it is the improved mass control that is important, rather than the mass advantage.

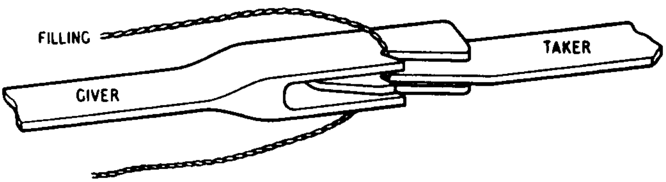


Fig. 15.8. A simplified version of a filling transfer system

One way of controlling the filling insertion device is to use a *rigid rapier* (Fig. 15.1(b)). One end of this carries the filling and the other is connected to a suitable linkage or control mechanism. In some ways it is almost a return to the primitive forms of weaving.

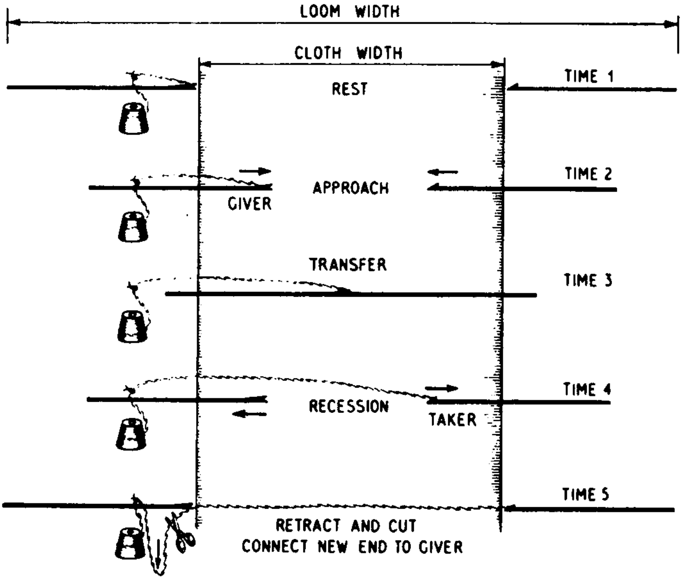


Fig. 15.9. Schematic diagram of a rigid rapier sequence

A disadvantage of this technique lies in the space required for the removal of the rapier to allow the warp shed to be changed. Even if two rapiers are used, one from each side of the fabric, this space requirement remains, and the loom must be at least twice as wide as the fabric being woven. Taking into account the fact that there are always appendages which make any loom wider than the fabric and these are disposed on either side of the loom, it is generally an advantage to use a two rapier system. This requires that the filling be transferred from one to the other in the middle of the warp shed during the filling insertion operation. One rapier (called the *giver*) takes the proffered yarn and carries it to the center of the shed; concurrently, the other rapier (called the *taker*) also travels to the center and the two meet. At this time the yarn is collected by the taker whereupon both rapiers are withdrawn, the giver returning empty and the taker completing the motion of the length of filling yarn. A sketch of a *filling transfer* system is given in Fig. 15.8 and a diagram of a typical system is shown in Fig. 15.9. An alternative system is shown in Fig. 15.10 but in this case it should be noted that the free end of the filling can rotate during the latter part of the filling insertion phase and the yarn can lose twist. This is a problem mainly with twist-lively yarns.

Although it is possible to use some of the excess space needed by rigid rapiers (such as to allow room for large multipackage creels of filling yarn), it is more economical in terms of space to use *flexible rapiers*. The flexible rapier can be coiled as it is withdrawn from the warp shed (Fig. 15.10) and this saves considerable space. However, a long flexible blade tends to buckle when violently accelerated from the rear, and lateral restraints are needed to prevent this. These may take the form of thin guides which can protrude through the warp sheet at intervals along the width of the fabric or of guides attached to the rapier drum (see Fig. 16.1). If the distance apart of the guides is too great, the rapier will buckle; if the distance is too small, the warp will be affected

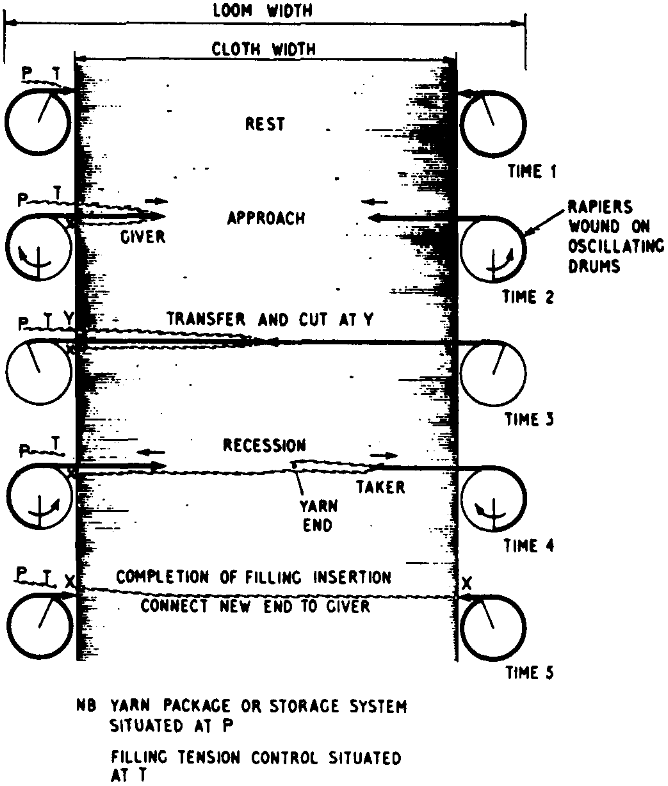


Fig. 15.10. Schematic diagram of a flexible rapier sequence

because of the space taken up by the guides. The rapiers cannot be made too stiff or they could not be coiled properly; on the other hand they cannot be made too flexible or they would buckle easily or need too close a spacing of the guides. It is important to get as good a compromise from the competing factors as possible since this affects the life of the components, and thence the cost of weaving. Of course, it is possible to limit the speed since this will reduce the buckling loads for a given system, but this can only be done at the

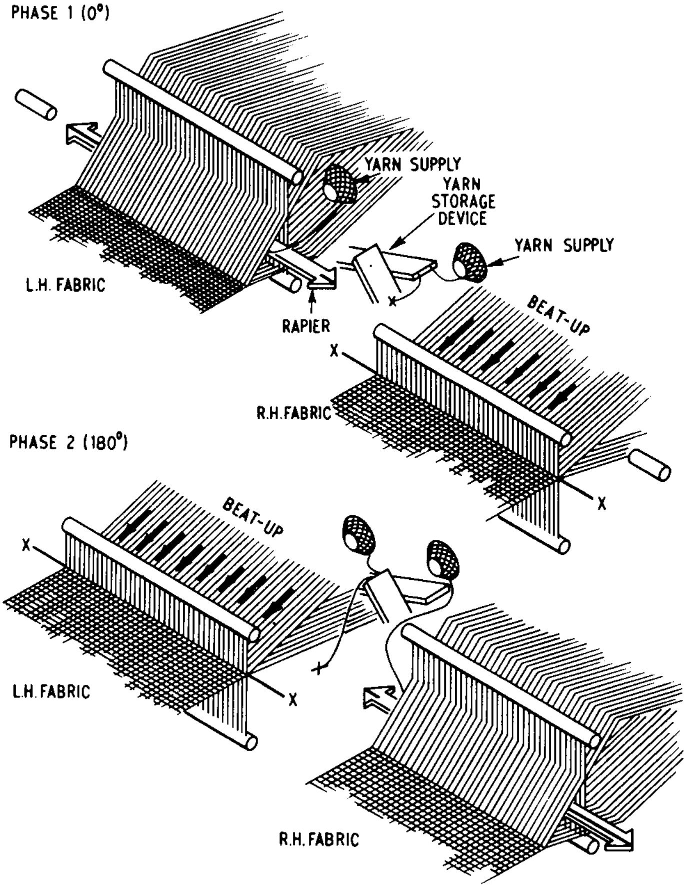


Fig. 15.11. Double-fabric rapier loom.

expense of production. In this context, it is relevant to point out that the use of two rapiers rather than one reduces the accelerations needed (which in turn reduces the buckling forces at a given loom speed). Thus the two rapier system is almost universal in modern looms of this type.

Another development to overcome the space requirement of rigid-rapier looms is the use of telescopic rapiers. This system also eliminates the need for the guides that are necessary with most flexible-rapier looms. In a recent development, a loom was introduced using a single rapier with symmetrical rapier heads at each end. This inserts filling in two warp sheds on either side of the central drive as shown in Fig. 15.11. The two sides of the loom operate with a phase difference of 180°. It is worth noting that rapier looms saw considerable development in the seventies and have reached fairly high levels of width and speed.

An advantage shared by all shuttleless looms is that it is easier to change the filling from one color (or type) to another for the purposes of producing decorative designs than it is in the shuttle loom. Instead of the whole shuttle having to be changed, it is only necessary to proffer a different yarn end to the appropriate rapier. This is quicker and easier; furthermore, it is possible to have a whole array of ends awaiting selection and thus more complex patterns can be woven. Practical limits arise because of creel size and complexity; nevertheless the new systems give the designer a much wider scope and this is important at a time when fashion plays such a large part in determining whether or not the fabric can be sold.

16

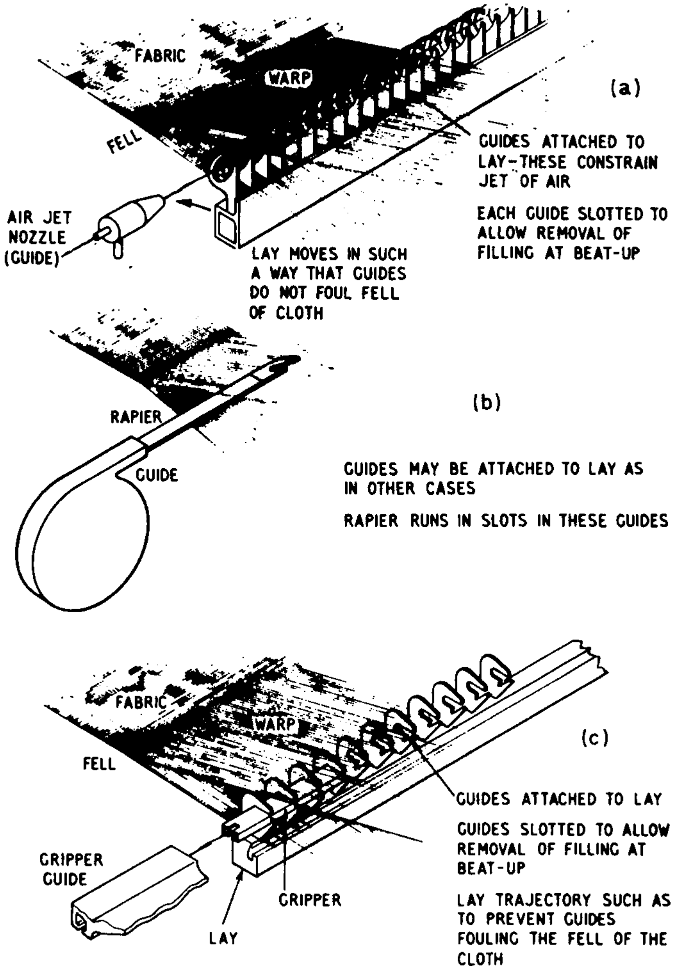
MORE ON SHUTTLELESS LOOMS

Key words: *air-jet loom, beating action, buckling length, buckling load, capital intensive system, coiling drum, down time, effective lay mass, flexible rapier loom, gripper loom, idle time, interest, labor intensive system, lay dwell, negative beat-up, overhead, positive beat-up, productivity, quality control, rigid rapier loom, shedding diagram, speed of filling insertion, transport efficiency, winding pattern.*

Guidance of the Shuttle or Carrier

Apart from the obvious gains which arise from successfully dispensing with the shuttle, there are other potential gains as well.

At first sight, there seems to be little reason why the picking mechanism of a normal loom has to be mounted on the lay. Careful reflexion will reveal that the forward motion of the lay tends to cause the shuttle to be kept in contact with the reed and gravity acts to keep it in contact with the raceboard; the raceboard and reed thus act as constraints which guide the shuttle. Attempts have been made to introduce conventional picking mechanisms which do not oscillate with the reed, but shuttle guidance has created problems. As the shuttle or its equivalent is reduced in size (or is eliminated), so the problems become easier to deal with. It becomes possible to use guides to control the carrier used to insert the filling, and the need to place the picking mechanism on the lay is correspondingly reduced. The carrier used to insert the filling might be air, water, gripper, rapier or shuttle.



GUIDES ATTACHED TO LAY-THESE CONSTRAIN JET OF AIR

EACH GUIDE SLOTTED TO ALLOW REMOVAL OF FILLING AT BEAT-UP

LAY MOVES IN SUCH A WAY THAT GUIDES DO NOT FOUL FELL OF CLOTH

GUIDES MAY BE ATTACHED TO LAY AS IN OTHER CASES

RAPIER RUNS IN SLOTS IN THESE GUIDES

GUIDES ATTACHED TO LAY

GUIDES SLOTTED TO ALLOW REMOVAL OF FILLING AT BEAT-UP

LAY TRAJECTORY SUCH AS TO PREVENT GUIDES FOULING THE FELL OF THE CLOTH

Fig. 16.1. Guidance of filling carriers

It is interesting to observe similarities in a variety of systems. The *air-jet loom* sometimes uses guides as indicated in Fig. 16.1(a), the *rigid rapier loom* is controlled by an appropriate linkage, the *flexible rapier loom* uses guides as indicated in Fig. 16.1(b) and the *gripper loom* uses guides as indicated in Fig. 16.1(c); sometimes, the flexible rapier loom also uses guides similar to those mentioned in the latter reference. In each case, the filling insertion system is not connected to the lay and the object is to control the movement of the carrier. Arrangements have to be made to remove any guides protruding through the warp whilst beat-up takes place and the simplest way of doing this is to arrange the trajectory of the lay to be such that the guides leave the warp without fouling the fell of the cloth as the lay moves forward to the beat-up position.

Lay Motion

Having removed the picking mechanism from the lay and thus considerably reduced the oscillating mass, it is possible to think of increasing the operating speed or increasing the *dwell* of the *lay* to give wider fabrics, or both. The operating speed for a given width is controlled by the *speed of insertion* of the filling and the latter cannot be brought beyond a certain level. Thus, there is every incentive to consider the production of wider fabrics. In the past, air- and water-jet looms have been limited in width and the gains have been taken in terms of speed. Modern developments have permitted some of the gains to be taken in terms of width. Developments in wide shuttleless looms have occurred.

Consider a very wide loom with non-mechanical synchronization. It is possible to contemplate a loom in which the arrival of the shuttle at a shuttle box triggers the beat-up motion and the shedding at appropriate intervals and one of these actions triggers the next pick and so on. In such a case, the *shedding diagram* would be elongated and it would be possible to allow the shuttle to travel for extended times to give very wide fabrics. The filling transport system is only directly useful when it is actually transporting filling through the warp shed. In one sense, the times needed to decelerate the system, replenish it and accelerate it back to speed are waste. Thus, one might think of the efficiency of the system being typified by the ratio t_d/t_s (Fig. 16.2). If a large carrier is used (such as a shuttle), the useful transit time is less than when a small carrier (such as a gripper or rapier) is used with the same shedding. In other words, it is possible to get a wider fabric and a greater *transport efficiency* by using a small carrier. Obviously, to get the best advantage out of this characteristic, it is necessary to redesign the lay drive so that the beat-up motion is completed in time t_b. A simple crank system will no longer suffice and it becomes necessary to seek alternatives. One well-established alternative is to use cams which can be designed to give almost any reasonable dwell period required, and the beat-up motion can be confined to a small angular movement of the crankshaft. It is also possible to arrange for the carrier to be projected across a stationary lay which helps with the guidance problem. The timing diagram of a Sulzer loom illustrates these points well (see Fig. 16.3).

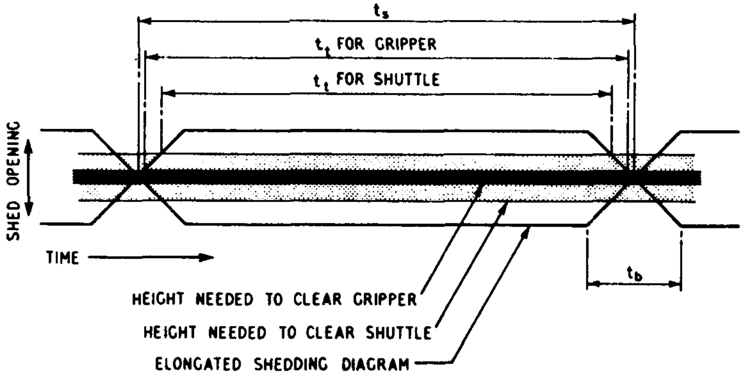


Fig. 16.2. Shedding diagram for a wide loom

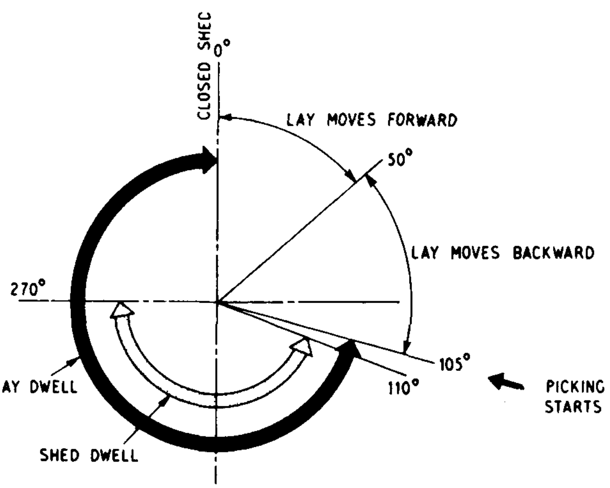
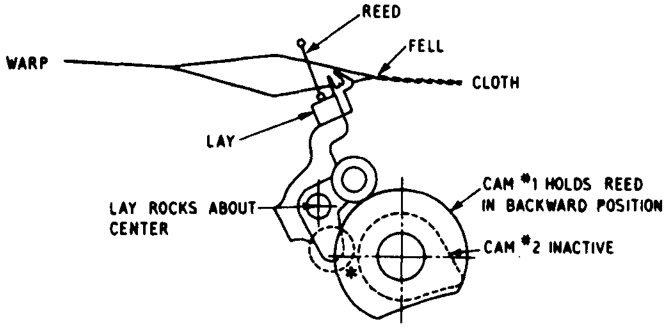


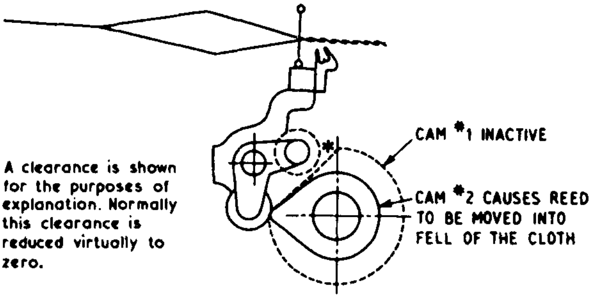
Fig. 16.3 Timing diagram for a 5.5 m (213 inch) Sulzer loom

To minimize forces, the lay motion during the acceleration and deceleration phases should be approximately parabolic in much the same way as is required for picking; also, slight modifications to the cam profiles are needed to reduce shock levels. The similarities between the two cases are so close that further discussion is superfluous for the present purpose. If the lay has an appreciable mass, it would be unwise to allow it to be retarded by the *beating action* itself; normally a *positive* control is needed. One means of doing this is to employ another cam to act to decelerate the lay. A neat way of disposing the opposing cams (conjugate cams) to give the controlled motion required is shown in Fig. 16.4. By dispensing with the shuttle boxes and other impedimenta, the lay mass can be reduced substantially. In one operational design, the *effective lay mass* is less than 30 per cent of an equivalent shuttle loom and consequently the accelerations involved can be increased to compensate without causing mechanical difficulty. The acceleration is a function of the cam design and loom speed; in practice,



SYSTEM IN DWELL

*NB A clearance is shown for the purposes of explanation. Normally this clearance is reduced virtually to zero.



SYSTEM AT BEAT-UP

Fig. 16.4 Lay driven by conjugate cams as in Sulzer looms.

it is possible to take some of the gain in terms of an increase in speed.

If the lay is very light in weight, it is possible to allow the beating action to retard it; this is known as *negative beat-up*. In such a case the beat-up is force controlled rather than position controlled, with the consequence that the pick density might vary from zone to zone in the fabric. This can give difficulties with let-off and take-up mechanisms.

In the case of the cam driven lay, the amplitude and speed of lay movement affect the forces involved. Since the limiting factor is the force involved, the amplitude must be kept as low as possible so as to permit high speeds. Obviously the amplitude has to be large enough to permit a filling insertion device to pass through the shed; it follows, therefore, that the smaller the filling insertion device, the better. Hence by careful design, it is possible to obtain significant gains in speed and width, both of which tend to increase production and reduce cost.

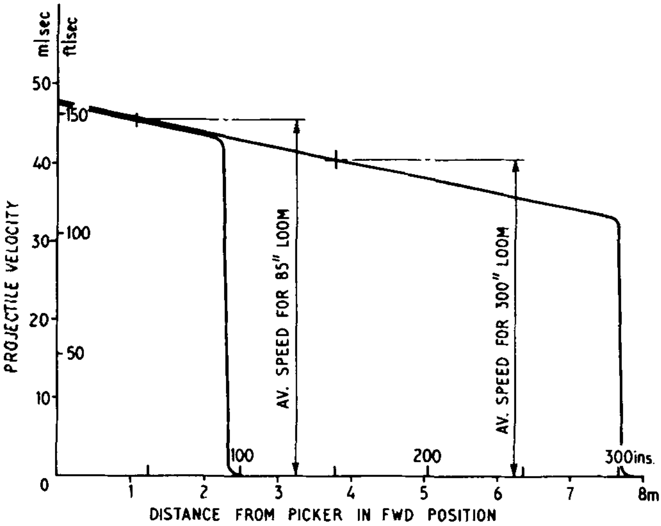


Fig. 16.5. Effect of width on average projectile velocity.

Loom Width

There is a limitation in width for each class of loom. In the case of jet looms, the width is controlled by the jet characteristics. In the case of rapier looms, space and/or rapier characteristics control the width. In all cases end breakage rates limit the widths that can be used in practice.

With projectile or shuttle looms, one controlling factor is the decline in speed of the projectile or shuttle as it passes

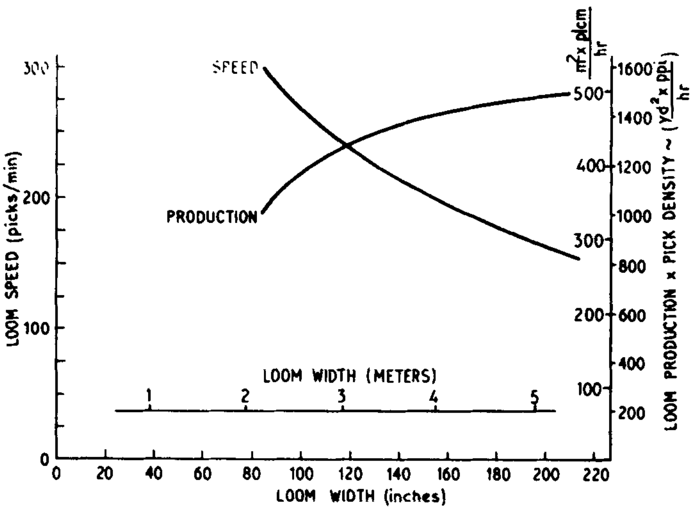


Fig. 16.6. Speed and productivity of a Sulzer loom as a function of width

across the shed. Figure 16.5. shows typical velocity characteristics of a projectile. The accuracy of projecting the shuttle affects this characteristic. If, for example, a projectile were badly projected through a set of guides as shown in Fig. 16.1(c), the projectile would rub heavily against the guide surfaces and would be retarded correspondingly. Hence an accurate picking device is required. Also, even if the picking mechanism is worked to give the maximum initial projectile velocity, the average speed will decline as the loom is made wider and the projectile transit time becomes longer. Thus the loom speed has to be reduced as the width of the loom is increased. The extent of this depends in part upon the design and accuracy of the system. For example, if a single guide is set out of position, it will deflect the projectile and cause an extra retardation which in turn will lower the average speed. This point is illustrated by Fig. 16.6, which shows a graph relating loom speed and width for a Sulzer loom. It is commercially possible to weave some fabrics whose total width exceeds 8 m (300 in); furthermore these fabrics can be woven at speeds higher than with many shuttle looms of a fraction of that width. Figure 16.6 also shows how the productivity of a series of looms increases with width; however, this assumes 100 per cent loom efficiency and, as will be described later, this drops with width if all other factors are kept constant. Nevertheless, the reason for the urge to use ever wider looms can be quite easily seen.

With a rapier loom, the maximum width is set by the rapier characteristics. A very wide loom with a rigid rapier system would require excessive space, and space costs money, but 2 m width models are available. A flexible rapier reduces the need for extra space but it does not eliminate it. The rapier has to be coiled and the diameter of the coils on each side of the loom are extra to the fabric width. Attempts to use more than one wrap on the *coiling drums* have not yet proved to be successful; hence very wide looms normally require rather large diameter coiling drums. Furthermore, the *buckling length* of a rapier depends on the thinness of the blade and upon the unsupported length of blade that has to be accelerated; thus there is a connection between the loom width and the design of the rapier unless intermediate guides are used.

Consider the case of a simple rapier loom without intermediate guides. The *buckling load* of a strut can be stated as $EI\pi^2/\ell^2$ (the so-called Euler equation) and a rapier being accelerated from one end acts as a strut. E is the modulus of elasticity for the material of the blade, I is the second moment of area of the cross section of the rapier blade, and ℓ is the unsupported length of rapier being accelerated. For the purposes of explanation, let the problem be simplified by assuming that the mass of rapier being accelerated does not change as the rapier is extended, and let this mass $= M$.

If the acceleration of the rapier is α, then when

$$M\alpha > \frac{EI\pi^2}{\ell^2} \qquad (16{\cdot}1)$$

the rapier will buckle.

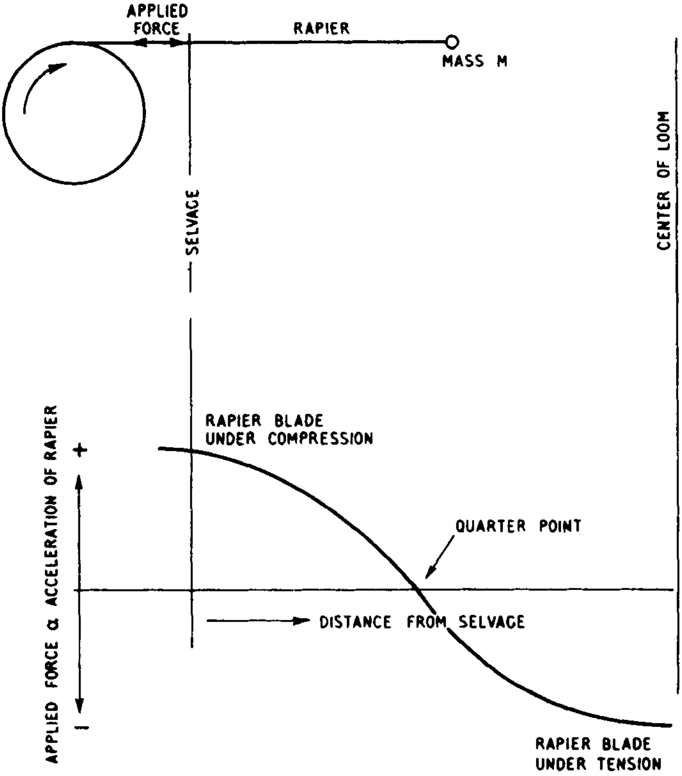


Fig. 16.7. Acceleration characteristic of a rapier

This can be rewritten in the form,

$$\frac{M\alpha}{EI}\left(\frac{\ell}{\pi}\right)^2 > 1 \qquad (16.2)$$

The acceleration characteristic of a normal rapier is similar to that shown in Fig. 16.7, from which it can be seen that as the rapier tip passes the quarter point on its way to the center, the rapier is under tension and will not buckle.

It is during the approach to the quarter position that the rapier is under compression along its length and is likely to buckle. For a given rapier (M/EI) is a constant and therefore $(\alpha\ \ell^2)$ must not exceed some value which is set by the rapier design. This result is based on an approximation, but it still remains true that, for a given rapier operating at a given acceleration, the length has to be limited if buckling is to be avoided; this means that the loom width must be limited, too. Also the acceleration α is proportional to the loom speed; thus, loom width and speed are related.

The above limit only applies if it is assumed that there can be no intermediate guides along the rapier path which can provide lateral support to the rapier blade and prevent buckling at those points. If the guides were packed together to form a continuous tunnel, the rapier would not buckle but it would not then be possible to have a warp capable of shedding. Obviously there has to be a guide spacing that minimises rapier buckling but does not unduly interfere with the warp. The guides have to be somewhat similar to those shown in Fig. 16.1(c) and there has to be sufficient room for the warp, which means that there must be a limit on the number of guides. If the distance apart of the guides is λ, and since $\lambda \ll \ell$, it should become apparent that if the loom with guides as shown in Fig. 16.1(b) can work at speeds in excess of 250 p.p.m. then there should be little trouble with the more elaborate guide system irrespective of width unless it be due to wear of the guides. Thus from a purely mechanical standpoint, it is possible to use rapiers on very wide looms and the ultimate limitations are found elsewhere.

End Breakages

Any wide loom is more prone to warp end breakages and the production lost due to a single end break increases with the width. Hence to make the use of a wide loom economically feasible, the warp and filling breakage rates have to be reduced. The reason for a warp breakage is that the applied force exceeds the strength of the weakest warp end exposed to load. Local weaknesses in the yarn increase the warp breakage rate and it is important, therefore, to have yarn that has a good regularity and which has been slashed properly. This is particularly important with wide looms, and strict *quality control* should be applied to get the best results out of these wide looms. An example may help to illustrate the point. Supposing that serious warp yarn faults occur on average every 2000 meters of yarn and the loom has 1000 ends, then the loom would stop (on average) after weaving only 2 meters.

Looms with a stiff reed (which is often the case with shuttleless looms) and a sharply impulsive beat-up do not allow yarn faults to pass so freely as conventional looms; consequently, efficient clearing of the warp yarn is a necessity. Positioning of the warp can also be more critical; so can the tying-in process.

Another approach is to reduce forces acting on the warp. The majority of these forces are generated during shedding and beating. By reducing the depth of warp shed, the load on the warp can be reduced and the use of a small gripper or rapier permits some relief in this respect; however, these reliefs are offset by the increase in speed with looms of this sort. By having more accurate control of beating, it is possible to reduce the end breakage rate also. This implies that a lightweight, stiff and accurate mechanism should be used. Such precision made components are expensive and this increases the *capital investment* needed; economic considerations have to be weighed very carefully if the new technology is to be used successfully.

The winding of the filling packages in those cases where a storage system is not used can be important. A cone is normally used; the angle and wind are critical and *winding patterns* can increase the end breakage rate to an untenable degree. The breakage rate using a given wind of package varies according to the yarn in use; a smooth yarn tends to allow coil slippage which is a frequent cause of end breakage.

Commercial Considerations

To get a good return on money invested it is necessary to ensure that the machinery installed has a high *productivity* and is kept in operation for as large a percentage of the working time as possible. Thus if the new machinery is more expensive, it must also be more productive and require less *down time* than the machinery it replaces. The new looms should thus work at higher speeds or with wider widths or both, since productivity is measured by the algebraic product (speed × width). Also a more closely controlled technology has to be applied. A further factor is the marketability of the fabrics produced. If the quality is higher than can be produced by the older equipment, then it will either fetch a premium (which increases profits) or will displace poorer products and thus preserve the market (and the jobs that go with it). If the quality is poorer, the reverse will apply; thus care has to be taken in this matter irrespective of productivity.

Yet another factor is the availability of labor. As years pass, labor becomes more expensive and scarce. Fewer people will work in a poor environment and most will seek pleasant and modern working conditions. Many will wish to work at a higher level of skill than today and few will wish to carry out manual labor. The use of sophisticated high-production machinery helps in this respect and makes it possible to recruit labor which otherwise would be unobtainable. The higher cost per man hour has to be offset by the higher productivity so that the cost per unit output of the textile product is kept down to the levels decided by the market. In this respect it is the competition that helps set this price, and the more competitors introduce modern machinery, the more imperative it becomes to follow suit. Thus there is a continuing swing from man to machine, from a *labor intensive* to a *capital intensive system*.

As looms become more expensive, so the cost of keeping them idle rises. *Overheads*, *interest* and other charges still have to be paid on an idle machine and therefore the idle time must be minimized. Even if no interest charges are paid, they should be charged against the machine on the basis that the capital might have been better invested elsewhere. The annual fixed cost contains an appreciable interest component; therefore the cost of *idle time* goes up with the cost of the machine and with the interest rate. The labor cost per unit production goes up with the cost of labor but down as productivity is increased; it goes up with the fault rate. Power and maintenance costs tend to go up with speed but such trends can be offset by good machine design. Hence, to be successful, it is necessary to be able to choose appropriate machinery and then manage it so as to produce the quality of goods required at the minimum cost. This involves technical knowledge and management expertise to keep the looms and other machinery running efficiently over extended periods.

17

WEAVE ROOM MANAGEMENT

Key words: *air-conditioning, helper-weaver system, integrated mill, loom assignment, machine interference, mill, pick counter, pick spacing, relative humidity, smash, smash hand, spinning mill, total cost.*

Introduction

The conversion of yarns to woven fabrics is an integrated system utilizing many types of machinery and skills. Some mills are fully integrated; some are concerned only with weaving and depend on others for the rest of the process. An *integrated mill* will have a different system of weave room management from one which depends on buying the yarn from a *spinning mill.* Since weaving involves the use of all types of yarns—natural, man-made, fine or coarse—this must also have its effect on the weaving system.

Fabric production has become a very competitive industry and the survival of any system depends on the economic production of fabrics suitable for the end use. Fashion and styling play a very important role in fabric production and this has a great effect on the management of weaving mills. Effective management can only be achieved by full knowledge of the mill capabilities, materials used, sales and market situation. Development of new fabrics must be based on this type of knowledge.

Loom Production and Efficiency

The productivity of the loom can be considered to be a function of its speed, width and type, but as was mentioned earlier, the loom speed is function of its width and type. Another very important factor which affects the production of fabric on any loom is the *pick spacing*. Equation 17.1 gives the linear production of the loom in m/h at 100% efficiency.

Theoretical loom production =

$$\frac{\text{loom speed}}{\text{pick density}} \times \frac{60}{100} \text{ m/h} \qquad (17.1)$$

where the loom speed is measured in picks/min and the pick density in picks/cm.

This theoretical production cannot be achieved unless the loom runs continuously without any stoppage; this is not possible in practice, since warps have to be changed and there are bound to be some stoppages because of yarn breakages or mechanical failures. Therefore the loom has an efficiency less than 100 per cent (see eqn. 17.2).

$$\text{Loom Efficiency} = \frac{\text{actual production}}{\text{theoretical production}} \times 100 \text{ per cent} \qquad (17.2)$$

Although the loom speed drops with width, the overall production in m^2/h increases with loom width, as shown in Fig. 16.7. To demonstrate this, consider the following examples. Let the speed of a 1.1 m (45 inch) width loom be 200 ppm and the speed of a 2.1 m (85 inch) loom be 150 ppm. Also assume that the wide loom produces two fabrics side by side, each of 1 m wide and similar to that produced by the narrower loom. Let the fabric have a pick density of 25 picks/cm (63.5 ppi) and let the two looms have efficiencies of 90% for the narrow loom and 80% for the wide loom.

Production of the narrow loom:

$$P = 200\frac{\text{pick}}{\text{min}} \times \frac{1\ \text{cm}}{25\ \text{pick}} \times \frac{60\ \text{min}}{\text{hr}} \times \frac{1\ \ \text{m}}{100\ \text{cm}} \times 1\text{m} \times \frac{90}{100} =$$

$$4.32\ \text{m}^2/\text{h}$$

Production of the wide loom:

$$P = 150\frac{\text{picks}}{\text{min}} \times \frac{1\ \text{cm}}{25\ \text{picks}} \times 60\,\frac{\text{min}}{\text{hr}} \times \frac{1\ \ \text{m}}{100\ \text{cm}} \times 2^{*}\text{m} \times \frac{80}{100} =$$

$$6.48\ \text{m}^2/\text{h}$$

*Note: 2 should be used rather than 2.1 because this gives the *fabric* width.

The *weaving efficiency*, which describes how effectively a batch of looms work in a normal working environment, is affected by many factors including:

(1) Loom type, width and speed.
(2) Yarn type, quality and density.
(3) Fabric structure and style.
(4) The weaver's skill and work load.
(5) The weaving conditions.

The loom speed has a direct effect on the number of warp breaks, filling breaks and mechanical stops. The width also affects the number of breaks because these depend, in part, on the number of ends in the warp.

The quality of the yarn has an obvious effect on loom stoppages and so does the type of yarn. A weak, fuzzy yarn will break very often whereas a strong smooth uniform yarn will withstand the weaving conditions better. The fabric structure also affects the warp breakage rate, since a fabric with a high number of interlacings in the design or a high end density (epi) tends to have a large number of breaks. The style has an effect on the time taken to repair a yarn break. In the case of a one color fabric, the weaver can find and tie the broken end much quicker than in the case of colored stripes; with dark colors it is more difficult to repair broken ends than with light colors. Skilled weavers can repair broken yarns very quickly compared to unskilled weavers. Also the work load of the weaver has a very important effect on the weaving efficiency, since it affects the time a loom is stopped awaiting attendance. Weaving conditions such as humidity, temperature and loom condition are also very important factors affecting the rate of loom stoppages.

The weaving efficiency depends to a very great extent on the number of looms per weaver. This number varies from 4–150 looms per weaver and depends on the number of loom stops and the repair times. Indeed, the maximum loom efficiency can be obtained if the weaver operates only one loom, but this is normally quite uneconomical because the idle labor more than offsets the savings in idle machine costs. Indeed, what is required is a minimum *total cost*. Therefore, there must be a number of looms allocated to a weaver which gives the best compromise between idle labor and idle machine costs. It is the duty of good management to arrive at the best decision for the various different conditions as they arise.

The Weaver's Work Load

Two systems are commonly used for deciding on the type of work the weaver has to perform. In the first, the weaver is allotted a relatively small number of looms and is expected to perform any type of work relating to weaving. This system is only suitable when limited skill or low wages exist. In the second system, the *helper-weaver system*, the weaver is highly skilled and only performs jobs which need these skills; these tasks seldom take more than 1 or 2 min. In this system, the weaver normally has a large complement of looms, and has working with him or her one or more helper weavers. The work of the weaver is to patrol the allotted section inspecting the warp and the fabric to prevent yarn breaks or fabric defects from occurring. Also, the weaver has to repair any broken ends and to start the loom again.

The helper weaver, or *smash hand*, is normally less skilled and his or her work involves those jobs which take more than about two minutes to repair. Such jobs are: repairing a *smash*, changing a warp beam, getting a new warp going, etc. This system uses the weaver to full advantage and is in wide use in large mills.

The work load of the weaver is normally from 45–50 min. every hour, leaving 10–15 min. for relaxation and personal needs. The working time is divided between repairing yarn breaks, walking and inspection. A weaver can walk several miles in an 8-hr. shift and this has to be considered when allotting the weaver his or her load. Table 17.1 lists typical weaving conditions which should give an idea of a weaver's work.

Table 17.1

Loom Stops and Repair Time for a Shuttle Loom

Type of Stoppage	*Typical Occurrence Rate per Loom Hour*	*Typical Repair Time (min.)*
Warp break	1·0	0·9
Filling break	0·3	0·4
Slack ends	0·1	0·5
Other (misdrawn, bang-offs, etc.)	0·1	0·8
Total	1·5	—

From this table it is possible to calculate the time spent by the weaver on repairs per loom hour as follows:

$$\text{Repair time/loom hr} = (1.0 \times 0.9) + (0.3 \times 0.4) + (0{\cdot}1 \times 0{\cdot}5) + (0{\cdot}1 \times 0{\cdot}8)$$

$$= 1{\cdot}15 \text{ min.}$$

If the weaver is allowed 20% of his time for relaxation and subsidiary duties, then the weaver work will amount to 48 min./hr. This time is spent on repairs as well as patrolling. If

30 min'/hr. are considered necessary for repairs, the number of looms per weaver is: $\frac{30}{1 \cdot 15} = 26$ looms.

If on the average the weaver walks from one loom to another in 3 seconds, the time of one patrol is $3 \times 26/60 = 1 \cdot 3$ min. The balance of time available for patrolling is $48 - 30 = 18$ min./hr. and therefore it is possible for the weaver to make $18/1 \cdot 3 \simeq 14$ patrols/hr.

To estimate the distance a weaver has to walk every hour, let the average distance from one loom to the next be assumed to be 3 meters (10 ft).

Patrolling distance/hr = 3 x 26 x 14 = 1092 meters. In English measure this is about 5 miles/shift. This is one of several constraints on the weaver's work load.

Calculation of the Weaving Efficiency

If the weaver works only on one loom, then according to the rate of stoppage and repair times given in the previous example, the efficiency would be $(1 - 1 \cdot 15/60) \times 100 = 98$ per cent. This means that the weaver's work load would be only 1·15 min./hr., which would make the cost of weaving very high. Normally the weaver has to attend to a large complement of looms and there is no guarantee that, when the loom stops, the weaver will be immediately available to repair the break and restart the loom. Thus the loom has to be stopped for a certain period of time waiting for the weaver to attend to it. This results in a loss of machine efficiency due to *machine interference*. As the stops occur at random, prediction of the weaving efficiency is complicated. However, it is not difficult to measure the loom efficiency over a certain weaving time and obtain the average weaving efficiency for any set of looms. This is normally done by counting the actual number of revolutions of the loom crankshaft using a *pick counter*.

Let measured loom efficiency = η

$$\eta = \frac{\text{No. of picks actually inserted}}{\text{loom speed} \times \text{time}} \times 100 \text{ per cent} \quad (17.3)$$

This is actually the number of picks inserted in the fabric expressed as a percentage of the number of picks which should have been inserted.

It is important for the weave room manager to be able to estimate the weaving efficiency before assigning looms to a weaver even though it is usually necessary to adjust it subsequently. It should be remembered that the assignment should vary according to weaving conditions. In other words, the manager should be in a position to calculate the weaving efficiency for any new *assignment* which arises as the yarn, fabric structure, or some other factor is changed. There is no simple formula to give an immediate answer, but there are methods available by which the weaving efficiency can be estimated. One of the methods used in this connection is the one given by Kemp and Mack(30); tables were produced from which the weaving efficiency can be estimated with relatively simple calculations. According to this method, the weaving efficiency for the previous example is calculated as follows:

Let x = Average number of loom stoppages per minute

$$= \frac{1\cdot5}{60} = 0\cdot025$$

C = Average repair time in minutes

$$= \frac{1\cdot15}{1\cdot50} = 0\cdot77$$

N = Number of looms per weaver

$= 26$

k = Walking and inspection time (between two looms) in minutes

$$= \frac{3}{60} = 0\cdot05 \text{ min.}$$

For 20 per cent personal relaxation time the values of C and k are inflated to C' and k'.

$$C' = \frac{C}{1 - (\text{relaxation factor})} = \frac{0{\cdot}77}{0{\cdot}8} = 0{\cdot}96 \text{ min.}$$

$$k' = \frac{0{\cdot}05}{0{\cdot}80} = 0{\cdot}0625 \text{ min.}$$

To find the efficiency in the tables, the following two parameters are used.

$$xC' = 0{\cdot}025 \times 0{\cdot}96 = 0{\cdot}024$$

and

$$xNk' = 0{\cdot}025 \times 26 \times 0{\cdot}0625 = 0{\cdot}041$$

These two parameters relate the idle time of the looms to the total machine and patrol times respectively. In the particular case, the tables show by means of linear interpolation that the weaving efficiency is 91·9 per cent. It should be noted here that the efficiency values obtained from these tables exclude stops outside the control of the weaver, such as mechanical stops. This may reduce the efficiency by as much as 3 per cent and therefore the estimated weaving efficiency might be reduced to some 89 per cent.

The foregoing example shows how the tables can be used to estimate the effects of interference. It does not show what the optimum weaving efficiency should be. Before this can be considered it is necessary to consider some other aspects.

Computers

With computers it is possible to store all the data from the tables and, by using only a simple program, the efficiency can be calculated quickly and expeditiously. The weaving efficiency so calculated can be no more accurate than the estimate of the parameters involved but the use of computers enables the parameters to be continuously assessed so that better accuracy can be obtained. Furthermore the computer can be used to monitor performance and analyze the fault rates in terms of failures of machines, men or materials.

Weaving Costs

The success of any industrial or business enterprise can be measured by the profit per unit capital investment. Since the profits can be considered as the difference between sales income and production expenditures, total profits can be increased by increasing the volume of sales or by reducing expenditures or by increasing the value of the product. Normally, the market is highly competitive and the sales income per unit production is closely defined by supply and demand; rarely can the product dictate the price.

The sum of expenditures assigned to any product represents the cost of the product. Assuming that the price of the product and the productive capacity of the mill are fixed, then any increase in profit must be accounted for by a reduction in the cost of the product. The cost of a meter (yd) of a finished fabric includes a proportion incurred by each department which has a part in the production of the fabric. The elements of production costs can be defined as:

1. (1) Material costs (which in the case of a weaving mill are mainly due to yarn costs).
2. (2) Labor costs.
3. (3) Overheads, such as the cost of building, heat, power, machinery, insurance, tax, etc.

All these costs may be classified as direct or indirect costs.

Again this part deals only with weaving mill costs, but the discussion can only be general because of changing nature of weaving mills as far as the type of machinery, type of yarn, systems of organizations, etc., are concerned. It is intended merely to direct the attention of the reader to some of the important factors. Actual figures vary considerably according to the yarn material, count, fabric structure and so on. However, it is appropriate at this stage to present, in rough figures, the percentage of the different cost elements of a plain cotton woven fabric. In this example the costs are:

Raw material (yarn purchased)	65 per cent
Labor	20 per cent
Other manufacturing costs	15 per cent

The important point arising from these figures is that the weaving management has no control over about 65 per cent of the cost of the fabric they produce and profits can be earned only by very careful control of the remaining 35 per cent or so of the total cost.

The weaving costs (i.e. the cost of conversion of yarn to fabric) may be divided into three main elements:

(1) Labor costs.
(2) Fixed costs.
(3) Other expenses.

The labor cost is a function of the skill and personal efficiency of the operator and the type of work. However, it is not always advantageous in terms of total cost to consider the maximum efficiency in one isolated area. The labor cost is the sum of costs of personnel directly involved in operations from preparation through to inspection of the final fabric. Efficiency in one area may be bought at the price of inefficiency elsewhere. It is therefore necessary to optimize in terms of minimum *total* cost. Of the total conversion cost, labor forms a high proportion (often as much as 50 per cent).

The fixed costs are those which do not depend upon production; examples of these are rent, interest, depreciation on machinery, overheads, etc. These have to be paid irrespective of whether the machinery is earning revenue or not. These costs are of the order of 30 per cent of the total conversion costs, but the proportion is gradually changing.

This is especially true where expensive new weaving machinery is installed. These costs should be expressed in terms of cost/kg (cost/lb) of product and therefore the production rates have to be taken into account; it is entirely possible that the weaving cost/kg when using an expensive modern high-production machine is lower than the traditional cost. However, a new cost balance may be necessary to give the lowest possible total cost.

There is a considerable incentive to increase production rates using advanced machinery, and a corollary to this is that there is usually an increased demand for power. The cost of this power is reflected in the cost of the product; in tropical or semi-tropical areas, the increased power usage leads to a need for air-conditioning which inflates the cost of power and of the installation generally.

With the more expensive machinery and installations, it becomes necessary to spread the cost by shift working and increasing productivity.

Optimization of Costs

Frequently there is an ill advised insistence on high weaving efficiencies, but this does not necessarily lead to minimum weaving costs. To understand this, let the operation be analyzed mathematically after making certain simplifying assumptions.

Assume that the weaver's patrol is always along a fixed path which is in the form of a closed loop. Assume that the looms are equally placed around the loop and that the weaver patrols only in one direction (i.e. she does not turn back to repair a break, even though it occurs just after she has passed the particular loom). Furthermore, assume that the mending time is negligibly small compared to the average running time between breaks.

Let a = number of looms/weaver,

n = actual number of breaks/hr.,

N = number of breaks/hr. if they are repaired immediately,

L = labor and other variable costs/hr
F = fixed cost/loom hr
P = machine productivity (e.g. lb/hr) at 100 per cent efficiency
C = total cost/unit mass added to product during weaving
t = average time to walk from one loom to the next in hours
T = average machine cycle time in hours
= average time between one break and the next on one loom
η = machine efficiency.

Also let

T_O = average running time between breaks on one loom
= 1/N and let this be independent of the loom assignment
T_W = average waiting time for a repair = kat
k = distribution constant

$$T = T_O + T_W$$

$$\eta = \left(1 + \frac{T_W}{T_O}\right)^{-1}$$

Total added cost/unit mass = C

$$= \left(\frac{1}{\eta P}\right)\left(F + \frac{L}{a}\right) \qquad (17.5)$$

$$= \quad U \times V$$

For a minimum value of C with respect to (a):

$$U\frac{dV}{da} = -V\frac{dU}{da}$$

$$-\left(\frac{1}{\eta P}\right)\frac{L}{a^2}=\left(F+\frac{L}{a}\right)\frac{1}{P\eta^2}\frac{d\eta}{da}$$

$$-\frac{L}{a^2}=\left(F+\frac{L}{a}\right)\frac{1}{\eta}\frac{d\eta}{da}$$

$$\text{but } \eta=\left(1+\frac{\text{kat}}{T_O}\right)^{-1} \text{ and } \frac{d\eta}{da}=-\eta^2\frac{kt}{T_O}$$

$$\frac{L}{a^2}=\left(F+\frac{L}{a}\right)\eta\frac{kt}{T_O}$$

$$\frac{L}{a}=\left(F+\frac{L}{a}\right)\eta\frac{kat}{T_O} \quad \text{but } \eta\frac{kat}{T_O}=1-\eta$$

$$\text{and} \quad \frac{L}{Fa}=\frac{kat}{T_O} \qquad (17.6)$$

$$\text{Let} \quad \frac{L}{Fa}=X=\text{cost ratio}$$

$$\text{then} \quad X=\frac{kat}{T_O}$$

$$\text{and} \quad a=\frac{X\,T_O}{kt}$$

$$\text{or} \quad a=\frac{X}{kNt} \qquad (17.7)$$

The constant (k) is a statistical parameter which describes the distribution of breaks actually encountered, and (a) is that assignment which minimizes the cost of conversion of the warp and filling into woven fabric.

The fixed cost (F) includes interest, depreciation, overhead, maintenance, air-conditioning, space and management costs. The variable cost (L) is comprised of the labor cost (i.e. weaver's wages) and any other costs that vary likewise. The quality of the warp shows up in the number of warp end breaks/hr (N) and such quality has a considerable impact on the optimum assignment.

Equation (17.7) implies that the loom assignment also depends on the relative costs of man and machine, as well as the distance apart of the looms. The time of operator traverse (t) depends on the duties assigned to the weaver. If the conversion cost is to be minimized, adjustments in assignments have to be made from style to style, and also when new machinery, working hours, wage rates or altered working conditions are involved.

As wage rates go up in relation to the fixed costs, so the weaver's time has to be conserved by raising her assignment, and this implies that the weaving efficiency will drop. Conversely, any increase in fixed costs (such as that arising from new investment in machinery) requires that the machine efficiency be raised. It is always an advantage to keep the end breakage rate as low as possible as far as weaving is 'concerned. To ensure a good end breakage rate it is usually necessary to spend money on good preparation or good quality yarn or both. Once again, there has to be a compromise to achieve the lowest overall cost.

Often, market pressures can make it necessary to weave cloth narrower than the loom is capable of doing; this means that the production of the loom is correspondingly reduced and the cost of the final article is correspondingly increased. Hence it is desirable to insure that the width capability of the looms be used to the fullest extent. Where the market demands flexibility in this respect, consideration should be given to working in multiple widths on wide looms to get that flexibility or to having as wide a range of widths of loom as is practicable.

A further item is obsolescence due to the inertia caused by the large amount of material in process at one time. Sudden changes in fashion can render the time and money spent on preparing and even weaving these materials into utter waste. Therefore, it is essential to minimize the effects of this as far as possible by reducing the inventory to the lowest level practicable. It is also helpful to use fabric designs which delay the final styling to the latest possible moment so as to keep the options open as long as possible. This is one reason why print materials are so popular, since the final product can be altered to suit the market without having to change the specification of the cloth being woven. Similarly, it is easier to change the filling or the filling pattern than it is the warp.

Weave Room Environment

The atmospheric conditions in a weaving mill are very important not only for the comfort of personnel but also for efficient weaving. The temperature and *relative humidity* of the air can be critical in determining the efficiency of weaving. The required temperature varies between 21° and 25°C (70° to 77°F) and the relative humidity can vary from 50 per cent for some synthetic fibers up to 80 per cent for low grades of cotton depending on the fiber processed. Depending on the location of the weaving mill and the season, this may require heating or cooling and humidity control. Therefore it is necessary to have an adequate *air-conditioning* and control system. This can be of the central station type or it may consist of individual units. The central station system is preferred, especially if the plant is new and the site provides for the necessary space for the duct work, cleaning apparatus and circulation fans. In this case, good maintenance and control is essential since a shut down affects the whole plant; care must be taken, therefore, to ensure that the system consists of readily replaceable units, so that a defective unit can be removed quickly without interrupting operations unduly. All dry textile operations produce *lint* and *fly* (i.e. fiber particles) and the quantity of fly depends upon the yarn being processed; the maintenance schedule for cleaning the filters and plant must be adjusted accordingly.

Good illumination of the weave room is another important factor in maintaining high weaving efficiency. With modern and expensive machinery it is inevitable that the weaving mill will be operated on a shift system. This makes it unnecessary to depend on natural lighting, even where the mill can use the natural light during the day. With the use of modern building materials, such as prestressed concrete, it is possible to have very long unsupported spans in the building. This reduces the number of pillars or vertical obstructions and makes uniform lighting easier to attain. With such large floor areas, windows become unimportant.

It is the responsibility of good management to make sure that the quality of the light and the lighting intensity are such that the weaver can perform his duties without undue strain. Such strain is related to human fatigue and affects the efficiency of the weaver, which in turn affects the efficiency of the mill. Lighting which is considered adequate for certain fabric structures and colors will not necessarily be so for others. The color of walls and ceilings affects the lighting conditions. It has been suggested by many experts that cream and gray are the best colors to be applied.

Vibration and noise are important factors in the environment of the weaving mill; they affect the efficiency and safety of the personnel. Vibrations can affect the running of the loom and reduce its efficiency. Noise is a more comlicated problem because it has an effect on the health of the operators in the weaving room. It can also affect their desire and ability to continue work and may reduce their efficiency. Lack of motivation to work in such environment may well cause recruitment problems in the future. Acoustic treatment of the walls and ceiling has limited value because noise reaches the operators directly from the machines. In many areas the law requires that weavers be provided with ear-protection devices, such as ear-plugs or ear-muffs. Although modern weaving machinery has lower noise levels than hitherto, it is all too often above the allowable limits and thus there is a considerable problem to be solved.

The lay-out of the looms is important, particularly in respect of the width of the alleys through which the weavers walk. The alleys should be wide enough to permit efficient changing of beams and doffing of cloth rolls; also, it should be possible for people to pass each other without difficulty.

Where trucks or portable machinery, such as the warp tying machine, are used, the width of these must be taken into account.

Conclusion

An attempt has been made to provide an understanding of historical, technical, and fundamental concepts relating to weaving, and appreciation of the purpose of the whole operation. The overall object is to produce fabric of suitable quality at a cost which is acceptable. The industry is highly competitive and it is far from easy to satisfy this apparently simple objective. To do so, it is imperative that management of both man and machine should be carefully studied in order that they may give of their best.

APPENDIX I

Glossary and Index

NOTE: There are other definitions for terms marked with an asterisk.

Definition	Index	
	Page	Literature Reference
Abrasion resistance – The degree to which a fabric or yarn is able to withstand surface wear due to rubbing or chafing with another surface.	166, 175	2
Acceleration – The rate of change of velocity, (N.B. Force = mass x acceleration).	200, 211, 219, 230 263, 275, 282, 289 295, 300, 306, 316	
Air-Conditioning – The treatment of air to maintain set levels of temperature, humidity and dust or lint content.	98, 328, 336, 340	3
Air-jet loom – A loom in which the filling is inserted with a blast of air instead of using a shuttle.	30, 290, 296, 313, 318	36
Air permeability – The porosity of a fabric as measured by the ease with which air passes through it.	142	4
Alacrity – A term which expresses the degree of rapidity with which a shuttle responds to the force applied to the picking stick; it is related to natural frequency of the picking mechanism.	223, 282	5
Amplitude – A term which defines the maximum excursion of an oscillating body from its mean position or of a curve from the mean line.	103, 147, 274, 277	
Annual fixed cost – Those costs which remain unaffected by the rate of production, expressed on a per annum basis (e.g. rent, depreciation, interest, overheads, etc.)	71, 325, 334, 336	14
Appearance rating – A visual rating of a fabric when viewed under standard conditions.		21

Definition	Index	
	Page	Literature Reference
*_Aspect ratio_ – A term which expresses the degree of flattening of a yarn when assembled in a fabric.	147	
Automatic loom – A loom in which empty quills are replaced by full ones automatically whilst the loom is running.	24, 253	1, 6, 29
Automatic winder – A winding machine in which an empty package is automatically replaced by a full one when required; it also has an automatic device to detect and repair broken yarn ends.	49, 70, 71, 75	41
Automation – The use of automatic devices to reduce the amount of manual labor required.	223	7
Auxiliary shaft – An additional shaft in a loom which carries cams for operating the shedding motion and which is capable of rotating at submultiples of the normal cam shaft speed.	184	34
*_Back rest_ – A support rod with a curved surface that extends from side to side of a loom (usually at the rear) to support the warp on its way from the warp beam to fabric forming zone. Often the back rest is caused to move to lessen the tension variations in the warp.	240, 286	
*_Balanced_ – (1) The term describes a fabric in which the number of ends/inch is equal to the number of picks/inch and both of the yarns are of the same count (or number). See square construction.		20
(2) A term relating to rotating bodies which specifies that the rotating body should generate no force due solely to its rotation.		31
Balanced twill – A twill weave in which the floats in both warp and filling directions span equal numbers of crosswise yarns.	166	20
*_Balloon_ – A term to describe the solid of revolution produced by a yarn when it is wound on or off a package in a direction essentially parallel to the axis of the package.	51, 56, 70, 82, 96	41
*_Ball warping_ – A process of winding a group of yarns, which are treated like a single end, onto a cross wound package. Normally used to prepare yarns for storage, mercerization or dyeing.	85	9
Band warping – See pattern warping.		

Definition	Index	
	Page	Literature Reference
Barré – A stripe-like effect extending across the width of the cloth caused by variations along the length of the yarn or by a machine fault. It is regarded as a blemish.	244, 255, 292	10, 15, 33, 41
Basis weight – Mass/unit area of fabric, e.g. oz/sq yd.	144, 152	
Basket weave – A weave where groups of adjacent warps are each woven as one and picks are inserted in groups of two or more in each shed. The formation resembles a plaited basket.	162, 163, 175	20
**Battery* – A device for storing quills on an automatic loom in a way which makes them immediately available as the need arises.	254	6
Battery hand – A person who keeps the loom batteries filled with quills.		
**Baulk* – (Jack back) – A lever which is operated by the hooks in a dobby to transmit motion to the jacks.	206	
**Beam* – A cylindrical body with end flanges on which a multitude of warp yarns are wound in such a way to permit the removal of these yarns as a warp sheet.	20, 26, 35, 62, 85, 111, 128, 237	9
Beam creel – A frame on which are mounted a large number of yarn packages from which yarn is taken in the manufacture of a beam.	112, 115	9
Beam-dyeing – A method of dyeing warp yarns on a perforated beam.	38	25
Beam ruffle – A pulley-like appendage on a weaver's beam used to apply a drag force to control the warp let-off.	237	
Beam warping – The manufacture of a warp beam.	35, 62, 85, 111	9
**Beat effect* – The interference between two oscillations whose frequencies are close; the effect appears as another oscillation whose frequency is the difference in the primary ones.	283	31
**Beating* (action) – See beat-up		
**Beat-up* – The process of forcing a filling yarn into position in a fabric.	21, 23, 28, 101, 178, 185, 191, 210, 214, 251, 274, 316, 323	10

Definition	Index	
	Page	Literature Reference
*_Beck_ – A large vessel used for the preparation of size liquor or for dyeing yarns and fabrics.	110	
Biaxial load – A system of two loads (usually mutually perpendicular) acting in a plane coincident with that of the fabric.	156	11
*_Binder_ – A device which forms part of a shuttle box and which is intended to decelerate the incoming shuttle and to restrain the outgoing shuttle.	220, 229, 250, 282, 289	13
*_Blend_ – (1) To mix dissimilar fibers prior to subsequent processing. (2) The mixture of dissimilar fibers in any fibrous assembly such as sliver, yarn or fabric.		
Blended fabric – A fabric which has blended yarns in either the warp or the filling or both.		
Blended yarn – A yarn that contains more than one type of fiber.		
Boardy – An adjective to describe fabrics that are hard, stiff or tough in handling; they are board-like.		18,20,21, 26,37
Bobbin – A small spool-like body on which yarn is wound – used in various forms in spinning, weaving and sewing.	33, 38, 71, 75	
Bobbin loader – A type of loom in which the bobbin in the shuttle is changed when needed (rather than the shuttle).	253	6
*_Body_ – The area of woven fabric between the selvages.		
Bottom shaft – The shaft in a loom which carries the picking cams and which is normally situated below the crankshaft.	183, 204, 272, 283	
Bottom shed – A term given to the warp yarns when they are in the lower sheet during shedding on a loom.	183, 191	
Box chain – A pattern chain which controls the shuttle box selection in a multi-shuttle loom.	259	
Box motion – The mechanism by which the pattern requirements are translated in shuttle box movement.	255	

Definition	Index	
	Page	Literature Reference
******Breaker bar* – A heavy lease rod used for the initial separation of a warp sheet.	120	
Buckling length – The unsupported length below which a given strut under a given load will not buckle.	295, 298, 320	
Buckling load – The load above which a given strut of a given unsupported length will buckle.	320	
**Buffer* – An energy absorbing device designed to reduce shocks: commonly used in picking mechanisms.	224, 227, 281	
**Bumping* – A condition in which the beat-up is so severe that the cloth tension reduces to zero during part of the beating action; the condition produces high warp tension peaks which increases the end breakage rate.	217, 274	
**Bunch* – A small quantity of yarn wound onto a quill or bobbin to provide a reserve in weaving between detection of approaching exhaustion and replenishment.	82, 253	41
Bunter – A protuberance attached to a moving part which can come into contact with a feeler or other mechanism and initiate a sequence of operations.	255	
Bursting strength – The resistance of a material to rupture when subjected to a pressure acting perpendicular to the plane of the fabric. The load is carried by both warp and filling yarns.		11,37
Cam – A device which when moved with respect to a follower, causes that follower to move in a prescribed manner.	26, 184, 195, 219, 225, 274, 303, 316	12
Cam loom – A loom which uses cams to operate the shedding (limited to small repeat weaves).	184, 197	
Camshaft – A shaft which contains one or more cams.	183, 204, 283	
**Can drying* – See cylinder drying.		
Canvas – A plain fabric woven from ply yarn which is similar to duck cloth.		20
Capacitor – An electrical storage device which is frequently used to improve the power factor in factory (it also has many other electrical uses).	271	19

Definition	Index	
	Page	Literature Reference
Capital intensive system – A factory system in which productivity is achieved by investing more money in appropriate machinery than in manual labor.	324	14
Carrier – A device for carrying filling across a loom.	305	
Center filling fork – A device which detects when a filling yarn has broken or when the quill is exhausted.	248	6
Centroid – That point in a body at which the mass may be considered to be concentrated.	266	12
Chain draft – The outline (on design paper) indicating the order of lifting harnesses on successive picks.	157	20
Chain plan – See chain draft		
Change gear – The wheel in a gear train which is changed to give the desired overall gear ratio.	242	
*_Chase_ – A term used in winding to define the traverse length when making a long thin yarn package.	43, 80	41
Chase length – See chase.		
*_Check_ (checking) – The deceleration of a body – usually a shuttle or picking stick.	29, 182, 219, 227, 229 282, 289	13
*_Cheese_ – A cylindrical yarn package whose diameter is usually larger than its length.	40, 54, 62, 293	
*_Clearing_ (clearing operation) – An operation to remove flaws and faults in a yarn.	34, 61, 97, 105, 322	41
Clear shed – A warp shed unobscured by single or multiple yarn ends.	193, 198	34
Closed shed (closed warp shed) – (1) A form of warp sheet.	178, 195	34
(2) A condition when the warp sheets are about to cross.	186, 215	
Cloth roller – A roller onto which cloth is wound.	240	
Cloth take-up – The winding of cloth onto a cloth roller during weaving.	29, 240	28
*_Clutch_ – A device for connecting or disconnecting two concentric shafts whilst they are in motion.	263	12
CMC – Carboxy Methyl Cellulose – A water-soluble cellulose gum which is used as sizing material.	106, 112, 117, 124	9

Definition	Index	
	Page	Literature Reference
Coefficient of restitution – A coefficient which relates the relative velocity of approach of two bodies about to collide with the relative velocity of recession after the collision.	231	12
Coiling drum – A drum on which flexible material (such as rapier) may be wound.	320	
**Comb* – A comb-like device to separate yarns in a warp.	120	
Comber board – A perforated board to separate the drawstrings in a jacquard loom.	208	27
Complete shed – A form of warp shed.	194	34
Compound shed – See semi-open shed.		
Conditioning – The process of changing the moisture regain of a textile material to a standard value.	40	
**Cone* – A yarn package shaped like a frustum of a cone.	30, 29	
**Cone angle* – The angle of the cone defined above.	81	
Cone winding – See Coning		
Confuser – A device to partially confine an air jet.	298	
Coning – The operation of making a cone wound package.	34	41
Coning oil – An oil added in small quantities to yarns to lubricate them – especially valuable in high speed winding and knitting.	110	
Connecting rod – A rod which connects a crankshaft to an oscillating member of a mechanism.	210, 265, 273	12
Contracting vee reed – A device which enables pins to be positioned in such a way as to cause yarns running between them to be spaced as required.	94, 120	9
**Contraction* – The reduction in fabric width or length during weaving or subsequent processes.	144, 189, 245	17,20
Controlled binder – A binder which is controlled by a linkage synchronized with the picking; usually used as an auxiliary binder.	234	13
**Count* – (1) A measure of the end and pick densities in a fabric (see end and pick densities)	158	20
(2) A measure of yarn size in length/unit mass.	146, 158	
(3) A count in numerical sequence.		

Definition	Index	
	Page	Literature Reference
**Counter* – (1) A device for counting. (2) A distance in a fabric design.	97 169	
**Cover* – A term given to woven fabrics to indicate the even appearance of the fabric. See also cover factor.	140	15
Cover factor – A measure of the percentage area covered by one or more threads. May be related to filling, warp or woven fabric.	141, 147	15
**Crank* – A device in which an eccentric pin drives a connecting rod and causes a member to oscillate.	183, 210, 264, 284	12
Crankshaft – A shaft which contains one or more cranks.	183, 284	
Crease resistance – The property of a fabric to resist creasing; molecular cross-linking may be used to improve crease resistance.	176	16
**Creel* – The arrangement of a multiplicity of supply packages to supply sliver, roving or yarn to a textile machine.	86, 112	
Creeling – The operation of filling or refilling a creel.	49, 62, 70, 86, 112	
Creel package – A package used in a creel.	62, 66, 112	
**Crimp* – (1) The sinuous form taken up by a fiber in a bulked yarn. (2) The sinuous form taken up by a yarn in a fabric.	 144, 151, 174	 17
Crimp balance – A state when the crimp in both warp and filling are equal.	145, 148	
Crimp factor – A factor which expresses the length change caused by crimping.	144, 155	
Crimp interchange – The transfer of crimp from warp to filling or vice versa.	148, 189	11,37
Crimp removal – The removal of crimp.	152, 174	37
Crossed shed – A condition in which the warp shed has just passed the closed shed condition.	186, 215	
**Cross section* – The shape or shapes which could be seen if the fibers, yarn or fabric were cut and viewed in or under a microscope.	145, 157	

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Cross wound package – A package in which the yarn is wound in helical fashion in successive layers; the traverse is substantially identical with the package width and there are few coils of yarn wound per traverse.	43, 64	41
**Crowns* – Those points on the surface of a woven fabric which protrude.	152, 174	
**Cutter* – A device for cutting yarns during the various textile processes.	294	
**Cylinder* – (1) A drying cylinder over which wet fabric or yarn is passed. (2) The main component of a carding engine which aligns fibers before they are converted to sliver.	115	
(3) A part of a jacquard loom.	208	
Cylinder drying – See cylinder		
**Dagger* – A stiff lever which is moved to cause contact with another component to operate a control device.	251	
**Damping* – Energy absorption to reduce the amplitude of oscillation.	279	31
Damping coefficient – A coefficient which expresses how a vibration will decay; because the damping force which opposes movement is usually proportional to velocity, the units are quoted in terms of damping force/unit velocity. The velocity is the local vibrational velocity of a given particle in the structure.	279	31
Damping pad – A pad which is introduced into or under a mechanism to reduce the transmission of noise and vibration.	287	31
Decrimping – The removal of crimp.		37
Dent – A term to describe the space between adjacent reed wires.	30, 37, 127, 131	
Denting plan – The plan used to determine how the warp should be threaded through the reed.	128, 131	20
Design – The design of the pattern of interlacing in a woven fabric.	134, 152, 157, 170, 311	20
De-sizing – The removal of size from fabric.	101	
**Direct drive* – A form of drive in which the angular speed of the driven member is the same as the driver – often at constant angular speed.	41	

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Direct sizing – The operation in which a slashing machine is supplied with warp from a single beam which contains all the warp yarns needed for weaving.	85, 115	9
Direct take-up – A form of cloth take-up in any fabric forming machine.	240	28
Dobby – A device which controls the harnesses in a loom to give small geometric patterns in the fabric being produced.	26, 195, 206	
Dobby head – See dobby.		
Dobby loom – A loom fitted with a dobby head.	195, 206	
*_Doffing (doff)_ – The removal of the textile product from a textile machine.	49, 70, 74	
Double ends – Two warp yarns drawn through the same heddle eye and reed dent to weave as a single end.		
Double-lift dobby – A dobby in which two hooks are used to actuate each harness. According to the combination of hook positions used, it is possible to keep the harness in the up position for a number of picks (which is not possible with a single-lift dobby).	206	
Down time – The time during which a machine is unproductive.	36, 71, 90, 101, 189, 322	14,38
*_Drape_ – The quality of a fabric which permits it to mold sufficiently to hang in pleasing folds.	18, 134, 139, 170, 176	18
Drawer-in – One who draws-in.	127	
*_Drawing-in_ – The operation of threading warp yarns through the correct heddles and reed dents.	36, 85, 120, 127, 170	
Drawing-in draft – The plan used to determine how the warp ends should be drawn-in.	128, 170	20
*_Drawstrings_ – Strings used to control single warp ends or groups of them in the shedding process in a jacquard loom.	24, 195, 209	
Drop wire (droppers) – Thin flat perforated plates supported by individual warp ends which fall into a mechanism when the end breaks and cause the loom to stop.	29, 37, 127, 246	

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**Drying section* – A section of a slashing machine where the warp is dried.	117	9
**Dusting off* – The involuntary removal of particulate material (e.g., size) from yarn during processing.	109	40
Duplicated creel – A system of traversing headstock and fixed creels.	87	9
**Dwell* – A phase in the cycle of operation of an oscillating body where the body is stationary.	178, 186, 269, 314	12
Dyeing – A process of coloring fibers, yarns or fabrics.	38, 64, 86, 99	25
Dynamic equivalence – A simple system of masses used in calculations to simulate a more complex system under dynamic conditions.	267	12
Dynamic magnifier – A term which categorizes the propensity of a resonant system to magnify a periodic disturbance when the frequency of that disturbance approaches the natural frequency of the system.	280	31
Effective lay mass – A single mass used in calculation to simulate the lay mechanism in a loom.	316	
Effective mass – A single mass used in calculation to simulate a complex system of masses.	306, 316	
**Elasticity* – The property of material to deform (usually to elongate) in proportion to the load applied and to recover its original shape when the load is released.	223, 276	
Electrical slip – The difference between the synchronous and actual speeds of an electrical motor.	269	19
**End* – A term used to denote a single length of yarn.	20, 33 etc	
End-breakage – The breakage of a yarn during a manufacturing operation.	32, 61, 73, 88, 96, 103, 114, 131, 218, 322, 336	33,38,41
End-density – The number of ends per unit loomwidth. Usually measured in ends/cm or ends/inch.	129, 131, 142, 152, 328	

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Equilibrium position – The position at which a body would come to rest under the influence of a system of steady forces.	276	
*_Evaporation rate_ – The capability of a drying system to remove water in the drying process. Usually measured in Kg/h per sq. meter or in lb/h per sq. ft.	117	
Even-sided twill – See balanced twill.		20
*_Excited_ – The condition of a resonant system when periodic disturbing forces are applied to it.	275	31
Exfoliate – The removal of thin layers of material from a body.	See dusting off	40
Expansion reed – See contracting vee reed.		
*_Fabric_ – An assembly of fibers and/or yarns which is generally in a sheet-like form – also known as cloth.	134, 174	15,16,18,20, 21,37
Fabric construction – The term describes the organization of components and in weaving it describes the weave.	17, 134, 174, 328	20
Fabric count – See count.		20
Fabric design – See design.		20
Fabric extension – The amount by which a fabric extends, usually under load and in the direction of that load.	155, 174	37
Fabric finish – Chemical and other treatments used to modify the fabric to make it more capable of fulfilling its function.	12, 19, 139, 159	
Fabric structure – See fabric construction.		
Fancy rib weave – A rib weave in which the float length is varied to change the width of the ribs to give a patterned effect.	162	20
*_Feeler_ – A light lever-like device used to detect the presence or absence of a component or textile material in a textile machine.	82, 206, 248, 253	
*_Fell_ – The line where the warp shed and the newly woven fabric meet; the filling is beaten into the fell.	29, 181, 192	10
*_Fiber_ – The smallest unit used in a textile structure; a thin flexible element which may be combined with others to make yarn or fabric.		22

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Fiber finish – A chemical compound coating a fiber to improve lubrication and prevent electrification.	98	
Fibering off – The involuntary removal of fiber or lint from yarns during processing.		40
**Filling* (weft) – A yarn which is interlaced with warp threads to make a fabric.	10, 17, 22 etc	
Filling face twill – A twill fabric in which the filling yarns float on the face of the fabric more than the warp yarns.	166	20
Filling insertion – The insertion of filling into fabric during the weaving process.	5, 22, 30 etc	29,32,35,36
Filling insertion rate – The rate at which filling is inserted; may be measured in picks/min or yds/min.	180, 314, 318	29,32,35, 36
Filling preparation — The preparation of filling yarn to make it suitable for weaving.	38	41
Filling retraction – The retraction of one end of the newly inserted filling to straighten it prior to beat-up.	294	36
Filling rib weave – A fabric in which the warp yarns are grouped together to form ribs running in the filling direction.	163	20
Filling satin (sateen) – A satin fabric in which the filling yarns float on the face of the fabric more than the warp yarns.	167	20
Filling transfer – The changing of any empty quill by a full one	253	
or the transfer of filling from one rapier to another.	308	
Filling transfer mechanism – The mechanism for achieving a filling transfer.	253	6
Filling winding – The operation of winding yarn on to quills.	39	
**Finishing* – See fabric finishing.		
Fixed costs – Costs which do not vary with production rate.	335	
Flexible rapier – A flexible long thin blade used to insert filling into the warp shed from the side.	308, 314, 320	36
Flexible rapier loom – A loom using flexible rapiers.	308, 314, 320	36
**Float* – A yarn in a fabric which passes over two or more crosswise yarns.	143, 160, 170, 174, 204	20
**Fly* – See lint.		

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Flying shuttle – A shuttle which flies outside the loom.	182, 226	
Flywheel – A heavy cylindrical body used to conserve angular momentum.	264	12
Forcing frequency – The frequency of a force applied to a resonant system which may or may not coincide with the natural frequency.	278	31
**Fork* – A device used to detect the absence of a filling yarn during the weaving process; a kind of feeler.	248	
**Four bar chain* – A theoretical model of a system such as a normal lay motion; the four bars represent crank, connecting rod, lay sword and loom frame.	269	12
Friction – A mechanism by which energy is lost when surfaces rub together.	32, 56, 68, 81, 101, 137, 175, 190, 216, 231, 238, 253	24
**Fringed* – A term to describe an edge of fabric which has numerous yarns or fibers protruding in a common direction.	292	
Frog – A rugged stop built into the loom frame capable of checking the lay in the case of need.	251	
Gelatinization – The conversion of granular size to a viscous adhesive fluid.	109	9
**Giver* – A term to describe the rapier which first takes filling into a warp shed and carries it to the center where it transfers the filling to a taker which carries it the rest of the way through the warp shed.	308	36
Give-way – A weak link inserted in a mechansim for safety reasons.	262	
**Grate* – A board used to guide and limit the motion of the hooks in a jacquard loom.	208	27
**Gray fabric* – Loom-state fabric which has not undergone chemical finishing.		
Greige fabric – See gray fabric.		
Griffe – An oscillating head which carries the knives in a jacquard loom.	208	

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Gripper – A device which grips one end of a filling yarn and tows it through the warp shed – see Projectile	30, 291, 300, 315	36
Gripper loom – A loom which uses one or more grippers – see Projectile loom		
Gripper shuttle – See projectile.		
******Guides* – Generally devices which constrain moving yarn to a fixed path.	50, 302, 312, 322	
******Hammer* – A device used to force a full quill into a shuttle which in turn forces out the empty one.	249, 253, 255	6
Hammer lever – The lever to which the hammer is fixed.	249	
******Hand* (Handle) – The character of a fabric as determined by handling it.	148	26
Hank sizing – The sizing of yarn in the form of hanks or skeins, normally used for experimental work or short warps.		
******Harmonic* – A term used to describe an oscillatory motion which may be described mathematically as sinusoidal.	266, 280	31
******Harness* – A frame containing a number of heddles which is moved up and down in a loom to help form the warp shed (also harness frame).	26, 129, 170, 191, 200	
Harness chain – See pattern chain.		
Head end – The beginning of a new piece of fabric in the loom.		
******Heading* – The beginning and the end of a piece of woven fabric.		
******Headstock* – A geared head used to drive a warp beam in the beaming, warping or slashing operations.	86, 90	9
Heald – A wire or thin perforated plate through which a warp end is threaded; the heddle is normally fixed in a harness (which is described above).	26, 37, 120, 128, 194	34
Heddle – See heald.		
Helper/weaver system – A system of dividing the weaveroom tasks so as to employ the weaver to best advantage.	329	14

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Hiding power – The ability of a fabric to obscure what lays underneath it.		15
**Hook* – A device which can latch onto another part of a mechanism when required for the purpose of transmitting some desired motion.	206	
Hopsack weave – See basket weave.		
Hot-air drying – A system of drying slashed warp (or other material) by subjecting it to a stream of hot air.	118	9
Idle time – Time during which a man or machine is idle.	325	14
**Immersion roller* – A roller under which yarn or fabric passes in such a way to cause the yarn or fabric to be immersed in a fluid.	116	9
Incomplete shed – A form of warp shed.	194	
Indirect sizing – An operation in which many beams are used to supply the slashing machine and the emerging warps are combined into a single weaver's beam.	115	9
Induction motor – A motor in which the rotor has no electrical connections; the torque is created by currents induced in the rotor by a polyphase system of coils.	269	19
Inertial system – A system which relies on the tendency for any body to persist in its state of motion unless some opposing force is applied.	295	36
Infra-red drying – The drying of (textile) materials by means of infra-red heaters.	118	
Integrated mill – A textile mill which has a complete series of operations to produce fabric from the fibrous raw material.	326	
**Interest* – The periodic payment made to reimburse the owner of money or property for its use.	324	
**Jack* – A lever which transmits movement from dobby head to the harness frames.	206	
Jack back – See baulk.		
Jacquard – An intricate method of weaving which uses punched cards to control the movement of individual groups of warp ends.	5, 26, 196, 208	27

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Jammed fabric (Jammed) – A fabric in which the ends are jammed so closely together that no more could be fitted in; a jammed fabric is usually very stiff.	156, 217	20
Kinetic energy – The energy contained by a moving body by virtue of its motion.	227	12
**Knives* (Knife) – Links held in a griffe (which oscillates) to which the hooks are connected to give the desired pattern motion in a jacquard loom.	208	27
Knock-off device (motion) – A device which stops the machine when a fault or emergency arises.	247	
**Knot* – A joint in a yarn made by tying ends together.	32, 70, 89, 101, 128, 133	38
Labor cost – The cost of employing labor, often expressed in money units per pound of product.	71, 334	14
Labor intensive system – A factory system in which productivity is achieved by investing more money in hiring manual labor than in buying advanced labor saving machinery.	324	14
**Lay* (slay, sley) – A stiff horizontal structural beam which carries the reed and oscillates in such a manner to cause the reed to beat the filling into the fell of the cloth.	30, 183, 192, 210, 264, 273 284, 303, 314, 317	12,29
Lay dwell – The dwell of the lay at back center to give the shuttle or gripper more time to pass. (See dwell).	314	12
Lay sword – The supports which connect the lay to the rocking shaft about which the lay oscillates.	30, 210, 267	
Lease bands – Bands laid across a warp being wound onto a beam to make later handling easier.	94, 120, 127	9
Lease rods – Rods interlaced with a warp to separate the warp ends or to tension them.	94, 120	9
**Leasing* – The operation of applying lease rods.	94, 118, 127	9

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Left hand twill – Any twill weave in which the twill lines on the face of the fabric run from the lower right-hand corner to the top left-hand corner of the fabric.	167	20
Leno-selvage – A selvage in which warp threads are crossed and interwoven into the edges of a fabric to strengthen the edges.	292	
Let-off motion – The controlled release of yarns or fabrics during an unwinding operation.	27, 66, 101, 236	28
Lift – Rectilinear movement generated by a cam system.	191, 195, 198	
Lifting plan – The plan which determines the sequence of lifting the harness	170	20
Linear density – Mass per unit length of yarn.	105, 128 etc	
Lingoes – Weights used to tension drawstrings in a jacquard loom.	208	
**Lint* – Debris from the textile fibers which accumulates in and around the machinery.	98, 104, 271, 340	
**Loom* – A mechanical device which interweaves yarns into a fabric. Usually there are two sets of yarns which are interlaced and these sets are called warp and filling (weft).	2, 21, 32 etc	
Loom assignment – The number of looms assigned to a single weaver.	329, 332, 336	14
Loom efficiency – The percentage running time during normal working hours.	326	
Loom fixer – One who is responsible for the maintenance of the looms in good mechanical condition.		
Loom production – The output of a loom in sq yds/unit time.	326	14
Loom state – The state of a woven fabric when it is just removed from the loom.		
Loom speed – Usually measured in picks/min.	269, 283, 289, 298, 300, 318	14,29
Loom timing – The synchronization of the various loom functions so that they occur in the proper sequence and at the proper relative times.	30, 182, 184, 316	29
Loom width – See also width in reed.	180, 298, 300, 304, 314 318, 339	14

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Loose reed – A protective device which enables the reed to move out of its normal position if it strikes an obstruction.	251	
Lug strap – A strap or other component which is used to accelerate a picking stick on a loom.	226	13,32
Luster – A property describing the brilliance of light reflection from the surface.	141, 170	15
Machine interference – An organizational term which relates to the idle time of a machine arising from the need for it to wait for attention because of the needs of other machines. (Also refers to weaving and machine efficiency.)	71, 331	30
**Magazine* – A device capable of holding many yarn packages.	77, 254	
Magazine creel – A special form of creel in which the tail end of one package is tied to the leading end of the next.	86	9
Magazine creeling – See creeling.		
Magazining – The process of replenishing a magazine.	80	41
**Mails* – Wires which carry warp ends and are similar to heddle wires which are not mounted in a frame.	208	27
**Mass* – The quantity of matter in a body. When a mass is subjected to acceleration, a force is involved; when that acceleration is due to gravity, the force is known as weight.		12
Mass-elastic system – A system in which a mass is restrained by one or more springs and which can be caused to oscillate in simple harmonic motion.	219, 286	12
Mass moment of inertia (I) – A parameter which establishes a relationship between torque and the resulting rotational acceleration. Physically, $I = \sum ma^2$ where m = elemental mass and a = distance from the axis of rotation. ($\sum$ means "the summation of").	264, 267, 275	12
Matt weave – See basket weave.		
Midget feeler – A device which detects whether a quill needs replenishing or not.	253	

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**Mill* – (1) A factory unit such as a weaving mill. (2) To abrade the surface of a fabric to give it a special appearance and hand.	326, 341	
Mixing beck – See beck.		
Momentum (G) – A term which describes the ability of a body to persist in its established state of motion until a force is applied. Quantitatively, G = MV, where M = mass and V = velocity.	295	12
**Motif* – A design, repeat, pattern or figure used to give a certain effect in a fabric.		
**Motion* – (1) Movement. (2) A mechanism.		
Multiple package creel – Creeling systems in which two or more packages per end are warped.	86	
Multiplier chains – Pattern chains used in combination with others to cause a pattern element to be repeated for a desired number of times.	261	
Natural frequency – The frequency at which a body will vibrate if it is given a small impulse.	223, 275, 286	31
**Neck* – The connecting point of the jacquard machine between the hook and the harness.	208	27
**Needle* – A long wire with an eye.	206	
Negative beat-up – An impulsive beat-up system using a light reed and lay which are not positively driven.	317	10
Negative feed back – The feed back of a signal from the output of a system to the input in such a way that it opposes any change.	239	7
Negative let-off – A mechanism for controlling the delivery and tension of the warp during weaving by means of a braking force applied to the warp beam.	66, 116, 237	28
Negative take-up – A take-up system not positively driven, often powered from the beat-up mechanism.	241	28
**Nominal movement* – The movement obtained from a cam assuming the use of an infinitely stiff linkage.	222	32

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**Nose* – Cam tip or the zone of smallest yarn diameter in a conical yarn package.	94	
**Offset* – Non-concentric.	269	
**Open shed* – (1) A warp shed that does not close every cycle and is only closed as indicated by the fabric design.	195	34
(2) A condition where the warp shed is open and ready for filling insertion.	186, 215	
Optimization of cost – Establishment of production conditions to minimize the cost of conversion of yarn into fabric.	100, 336	
Over-end withdrawal – The unwinding of yarn from a package generally along the axis of the package.	49, 56, 68, 80	41
**Overhead* – A cost component which includes items which cannot be assigned to specific production items.	324, 334	
**Overlaps* – Bands of yarn found at the ends of a yarn cone or cheese caused by faulty winding. They are associated with winding patterns (ribbons).	48	
Overpick loom – A loom on which the picking stick is above the level of the shuttle box.	227	
Overwaxing – The operation of waxing a yarn after sizing.	121	
**Package* – A length of yarn wound on a carrier or bobbin. (See also yarn package).	20, 32, 41	41
Package build – The manner in which the yarn coils are arranged on a package.	54, 64, 80	41
Parallel motion – A linkage (or equivalent) that causes one end of a lever to move in rectilinear fashion.	199, 226	
Parallel wound package – A package on which the yarn coils are wound side-by-side roughly perpendicular to the package axis.	35, 43, 80, 85	41
Partial picks – The insertion of an insufficient length of filling.	82	
**Pattern* – (1) The manner in which yarns are arranged in a fabric.	24, 134, 157	20
(2) See winding pattern.	46, 323	41
Pattern chain – A chain used on looms to control the pattern of the fabric.	129, 195, 260	

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Pattern warping – A process for preparing warp beams over two stages; first winding the yarn in narrow tapes on a large drum or reel, and then rewinding the complete warp on to the beam.	35, 85	
Pawl and ratchet – A wedge-like member (pawl) which engages a toothed wheel (ratchet) when it moves in one direction. When the pawl returns it disengages; thus when it oscillates, it causes the wheel to move intermittently and each oscillation moves the ratchet wheel a fixed amount.	240	12
**Peg* – An appendage attached to a pattern chain which causes a change in the pattern mechanism.	208, 260	
Pegging plan – See chain plan.		
**Penetration* (of size) – The extent to which a size solution penetrates into the yarn structure	116, 120	9
**Pick* – A single length of filling yarn, or the process of inserting the filling yarn (see Picking).	80	
Pick and Pick – Same as Pick at will.	259	
Pick at will – A loom on which it is possible to pick more than once from one side or single picks from different sides.	259	
Pick counter – Counter used on looms to record the number of picks inserted in a given time.	331	
Pick density – The number of picks per unit length of fabric (see pick spacing).	129, 142, 152, 243, 292, 327	
**Picker* – The part of the picking mechanism which comes into contact with the shuttle.	183, 224, 229, 281, 289	13,32
**Picking* – The action of filling insertion.	21, 28, 178, 219	13,32
Picking bowl – The follower of the picking cam.	185	
Picking cam – The cam that operates the picking mechanism.	29, 183, 222	32
Picking mechanism – A device for accelerating projectiles or shuttles.	28, 181, 220, 300	
Picking stick – A lever (usually of wood) which is used to propel the shuttle.	29, 183, 220, 227, 281, 289	32
Pick spacing – The distance between two picks in a woven fabric.	142, 152, 155, 243, 285	10

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*_Piece_ – (1) A standard length of fabric usually between 30 and 100 yards. (2) See piecing.		
Piecing – Joining the ends of a broken yarn. – see end breaks	49, 62, 96, 131, 329	
Pilling – The formation of balls of fiber on the surface of a fabric due to wear.	176	21
*_Pinned_ – (1) The placement of drop wires on a warp. (2) A description of a roller containing pins used in various textile processes.	246	
Pirn – See quill.		
Pirn winding – The winding of yarn on pirns or quills – see quill winder.	38, 58, 79	41
*_Pitch_ – (1) The distance between two yarns or other components. (see pick and and spacing)		
(2) The up and down movement of a shuttle during transit across the loom.	283	
Plain weave – A weave in which half the ends pass over one pick and the other half pass under, then the action is reversed on the next pick. The adjacent ends and picks interlace differently.	140, 158, 176	20
*_Plasticise_ – The softening of a synthetic material or polymer usually by the addition of a lubricant.	111	
Pointed draft – The arrangement of warp yarns in the harness frames in sequence and then reversing the order of the next series of warp yarns in the sequence.	131	
Positive beat-up – A beat-up mechanism in which the filling is moved by a positively controlled reed. (See also beat-up).	316	10
Positive let-off – A mechanism for controlling the delivery of the warp during weaving by keeping the delivery rate constant.	239	28
Positive take-up – A take-up system that is directly driven.	241	28
Power factor – The quotient KW ÷ KVA (KW = kilowatts, KV = kilovolts, A = amps).	271	19

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Precision winding – The winding of a yarn package in such a way that consecutive coils are closely spaced irrespective of package diameter.	46	41
Productivity – The rate of production. (See also loom production.)	324	14
Projectile – A device used in place of a shuttle. Instead of carrying a supply of yarn on a bobbin or quill, the projectile grips single ends of filling yarn and carries them through the warp shed at the appropriate times.	291, 300	
Projectile loom – A loom that uses projectiles instead of shuttles	300, 314	
Protector feeler – A light mechanism which detects whether the loom is in a safe or desirable state to continue operation.	225	
Punched card – A card perforated in such a manner to control operations; in weaving to control the pattern in a fabric.		27
PVA – Polyvinylalcohol, used as a size.	107	
Quality control – The testing and inspection of products to ascertain that they meet established quality standards.	299, 322	33
**Quill* – A filling package which is inserted into a shuttle.	23, 38, 58, 61, 80, 229, 253	
**Quiller* – See quill winder.		
**Quill winder* – A machine for winding quills (pirns).	38, 58, 79	
**Quill winding* – See pirn winding.		
Race board – A board over which the shuttle travels and which is attached to the lay.	181, 250	35
Radius of gyration (k) – The radius at which the mass of an object may be considered to be concentrated in calculating the moment of inertia (I) $[I = Mk^2, M = \text{mass}]$.	267	12
**Rapier* – A device for inserting filling from the side of the loom during weaving.	30, 291, 306, 320	36
Rapier loom – A shuttleless loom which utilizes one or more rapiers to insert the filling.	291, 306, 320	36
Reacher-in – The operator who selects the warp yarns and hands them to the drawer-in on a hook.	128	

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Reclining twill – A twill weave which produces a twill line running at an angle less than 45°.	167	20
Reed – A comb-like device used to separate yarns on a loom and to beat-up the filling during weaving.	29, 37, 128, 181, 210, 214	10
Reed number – The number of dents per unit length of the reed.	171	
Reed plan – A plan indicating the arrangement of warp yarns into the reed dents.	128, 170	20
Relative humidity – $\frac{\text{Mass of moisture actually present in a given volume of air}}{\text{Mass of moisture which could be held in the given volume of air}} \times 100\%$	98, 329, 340	3
Repair time – Time to repair a yarn break.	330	
**Repeat* – A pattern which is repeated in the fabric weave.	157	
Resonance – A state in which the forcing and natural frequencies coincide causing the subject body to vibrate strongly at a level dictated by the amount of damping.	278	
Reserve bunch – See bunch.		
Retraction device – See Filling Retraction.		
Ribboning – See winding pattern.		
Rigid rapier – A stiff rod-like rapier used to insert filling.	307, 314	36
Ring tube – The yarn package produced on a ring spinning machine.	74	
**Riser* – (1) A filled-in square on design paper which indicates lifting of an end. (2) A link in a pattern or box chain which activates the lifting of a harness frame or the shuttle boxes.	 260	20
Rocking shaft – The shaft about which the lay assembly oscillates.	30, 267	
**Roll* – (1) A rotatable cylinder. (2) The oscillating rotation of a shuttle during transit across the loom.	233	35
**Sand roll* – Take-up roller.		
Sateen – A filling-faced weave in which the interlacing points are arranged to produce a smooth cloth surface.	167	20

Definition	Index	
	Page	Literature Reference
Satin – A warp-faced weave which is the reverse side of a sateen.	167	20
Section warping – See (1) pattern warping. or (2) beam warping.	92	
Selvage – The longitudinal edges of a fabric that are formed during weaving.	291	
Selvage motion – A shedding motion for operating the movement of the selvage warp only.	161, 189, 210, 291, 305	
Semi-open shed – A form of shed in which the warp yarns that are to remain in the top shed line for the next pick are lowered a short distance and raised again, while those in the bottom shed remain stationary.	195	34
Semi-positive let-off – A driven mechanism which controls the delivery of warp (or fabric or series of yarns or single yarn) in such a way that an adjustment, by slippage, can be made to the delivery rate to maintain tension or path length.	239	
*Shaft - (1) Harness frame. (2) A rotatable long cylindrical rod which usually transmits power.		
Shear strain – Deformation of a material in which a rectangular element becomes lozenge shaped.	19, 138	
Sheath – A device in a semi-positive let-off mechanism which intermittently disengages the pawl and locks the ratchet to adjust the delivery of warp or other material being controlled.	240	
*Shed – The opening formed by the separation of the warp yarns during weaving.	26, 101, 191, 298, 306	34
*Shedding – The operation of forming the shed in weaving. (see warp shed)	21, 178, 187, 191, 195, 206, 208, 263, 306	34
Shedding cam – The cam that operates the movement of the harness frames on a loom to form the shed.	183, 195, 198	34
Shedding diagram – A diagram representing the relationship between the movement of warp yarns during shedding and crank-angle position.	195, 200, 314	

Definition	Index	
	Page	Literature Reference
Shed forms – A term to describe the symmetry or otherwise of the two warp sheets as the warp shed is completely formed in successive picks.	191, 194	
Shed opening – The distance between the warp shed lines.	101, 202	
Shock – The rate of change of acceleration – shock causes noise and vibration.	199, 221, 234, 285, 289, 306	
**Shuttle* – A quill carrier that is projected through the warp shed to insert the filling yarn during weaving.	5, 22, 28, 178, 186, 200, 219, 229, 251, 253, 259, 272, 282, 289	13,29,31,32, 35
Shuttle box – The compartment at each end of the lay for retaining the shuttle during beating-up.	182, 222, 229, 251, 259, 285	
Shuttle box length – The length of the shuttle box which can be used for acceleration or deceleration.	222	
Shuttle interference – The interference between the shuttle and the warp due to faulty timing.	202, 304	
Shuttleless loom – A loom in which an alternative to the shuttle is used.	289, 312	36
Shuttle transit time – The time taken for the shuttle to traverse the loom in one direction.	180, 315	
Shuttleless weaving – Weaving with a shuttleless loom.	289, 312	36
Side filling fork – A device located at the sides of the loom which detects the presence of the filling yarn during weaving.	248	
Side withdrawal – The unwinding of yarn from a package with the yarn roughly perpendicular to the package axis.	49, 55, 66	41
Simple harmonic motion – Reciprocating motion which can be defined with respect to time by a sine wave.	214, 223, 277	12
Single end creel – A package creel which has a single package for every yarn.	86	

Definition	Index	
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Single end slashing – (1) a system of slashing one end at a time (not the usual meaning);	115	
(2) a system in which a series of yarns from a creel are slashed without any intermediate winding.	115	
Single lift dobby – A dobby mechanism in which a single knife is used to effect the lifting of the harness frames. (See also double lift dobby).	206	
**Sinker* – (1) A blank square on design paper.		
(2) A link in a pattern or box chain which activates the lowering of a harness frame or the shuttle boxes.	261	20
**Size* – (1) A solution normally applied to warp yarns to strengthen, smoothen and lubricate them.	99, 107, 120, 138	9
(2) The operation of applying a size (see slashing)	115, 123	
Size add-on – See size take-up.		
Size-box – A container in which the size is applied to the yarn.	116, 123	9
Size liquor – See size		9
Size penetration – The degree to which size penetrates to the core of a yarn.	116, 120	
Size recipe – A list of size ingredients perhaps with cooking instructions.	107	
Size shedding – The removal of size particles from the yarn during processing.	109	9,40
Size take-up – The amount of size material added on the yarn during sizing.	113, 120	9
**Sizing* – See slashing.		9
Skip draft – The passage of the warp ends of a repeat through harnesses by skipping some of them to obtain a certain effect.	131	20
**Slashing* – The application of size solution to yarns by immersion into the solution and squeezing which is followed by drying to make the warp yarn more suitable for weaving.	23, 33, 36, 86 99, 123, 299	9

Definition	**Index**	
	Page	**Literature Reference**
Slay – See lay.		
Slay sword – See lay sword.		
**Sley* – The number of warp ends per inch in a woven fabric.		
Slit film – Yarn produced by slitting extruded film.	143	
Slough-off – The slippage of a number of yarn coils during unwinding which usually causes a tangle.	51, 60, 80, 293, 323	41
Slub – A soft, thick and uneven place in yarn.	40	33
Slub catcher – A device used on winding machines to remove slubs from the yarn.		33
Sluff-off – See slough-off.		
**Smash* – (1) The action of accidentally breaking a large number of warp ends due to the entrapment of the shuttle.	251, 330	
(2) A place in the fabric where a large number of ends have been broken.		
Smash hand – A helper weaver.	330	
**Snarl* – A part of the yarn where it folds and twists around itself.	40, 95	
**Softener* – A chemical which if added to the yarn or fabric improves the feel.	109	
Sonic velocity – The velocity of sound.	297	
Speed of filling insertion – The rate of filling insertion usually in yds/min.	314	29,32,35,36
**Spindle* – (1) A slender rod held in a vertical position on a spinning frame.		
(2) A unit on a winding machine.	70, 71, 75, 79	
(3) A post for mounting packages.	42	
(4) A part of a jacquard loom.	208	
Spindle efficiency – The percentage of the total time that a spindle is in useful operation.	74, 79	14
Spinning mill – A factory producing yarn.	326	
Spool – A double-flanged bobbin.	48	
Square construction – A fabric in which the same yarn number and the same yarn density are used in both directions.	154, 163	20

Definition	Index Page	Literature Reference
Square design paper – Paper used for representing the interlacing of warp and filling in a woven fabric.	157	20
Square weave – A weave in which the number of risers is equal to the number of sinkers in the repeat.	163	20
Squeeze roller – Rollers used to squeeze excess fluids from yarns or fabrics.	116, 121	
Staple yarn – Yarn spun from staple or short fibers.	124, 291, 300	
Static eliminator – A device for ionising the air so that electrical charges on the textile product can be neutralized.	98, 124	
Steep twill – A twill weave in which the angle of the twill line is more than 45°.	167	20
Stick checking – The stopping of the picking stick after picking.	227	13
**Stiffness* – Resistance to deflection or other distortion.	17, 105, 134, 137 224, 275, 282, 320	
Stitched basket weave – A basket weave in which the length of floats is reduced to produce a firm fabric.	163	20
Stop motion – A device which stops the machine whenever a fault or a break occurs.	49, 83, 94, 236, 248, 251	
Stop rod finger – A feeler which detects the boxing of the shuttle and allows the loom to continue if all is correct.	251	
Straight draft – The passage of the warp ends of a repeat in sequence from the first to the last harness.	131	20
**Strain* – Deformation of a material which is usually expressed in dimensionless form.	219	11,37
Stress – Load per unit area – stress causes strain.	218, 223	11,37
Structure borne vibration – Vibrational energy transmitted through the structure of a machine or building (as distinct from air-borne or fluid-borne vibration).	287	31
**Sword* – See lay sword.		
Synchronous speed – A speed dictated by the frequency of the electrical supply.	269	19

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*_Taker_ – See giver.	308	
*_Take-up roller_ – A roller which controls the speed of the fabric leaving the weaving zone.	240	28
Tape selvage – See selvage.		
*_Tappet_ – Another term of shedding cam. (see Cam.)	26, 183	12
Tear strength – The resistance of a fabric to tearing.	166, 175	37
Telescopic rapier – See Rapier	311	
*_Temple_ – A device used on looms to control the fabric width on the loom.	189, 245	
Tensile strain – The extension of a material subject to tension expressed as a proportion of the length of the specimen.		37
Tensile strength – The resistance of a yarn or fabric to tensile loading.	174	37
Tension – The force acting along a yarn or fabric sample tending to elongate it.	64, 66, 80, 95, 101, 148, 182, 187, 194, 236, 245, 293	38
Tension device – (1) A device used to apply tension to yarns.	51, 67, 94	
(2) A device used to control tension.	101	
Tensioner – See tension device.	52	
Thread diagram – A line diagram showing the path of yarn on a machine.	157	
Time constant – A time which typifies the rise (or decline) of a parameter which varies exponentially with time. Frequently the time for the parameter to rise to half its ultimate value is used.	279	12
Tin fillet – A rough surface applied to the take-up roller to enable it to grip the fabric.	242	
*_Toggle_ – A bi-stable device which can rest in either of two possible positions but not in any other.	302	
*_Top shaft_ – Another term for the crankshaft on looms.	183, 285	
Torque (T) – Couple or twisting moment which causes torsion [$T = \sum Fr$; F = force, r = radius and $\sum$ means "the summation of"].	68, 265	12

Definition	Index	
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**Torsion* – The twisting of one end of a body with respect to the other.	224, 277, 283, 302	12
Torsion bar – A bar which is subject to torsion to store energy.	302	12
**Total cost* – The sum of labor, capital and other costs.	329, 335	14
Transfer latch – A part of the filling transfer mechanism of looms.	255	
**Transport efficiency* – The percentage of the time a carrier is usefully employed in carrying yarn (e.g., a shuttle)	315	
Traveling package creel – A creel on which the packages are moved so that the empty ones can be replaced with full ones.	71, 89	41
**Traverse* – (1) The distance moved by the yarn along the package during winding. (2) An adjective to describe a type of mechanism used in winding.	80 43, 77, 83, 92	
Truck creel – A creel which is mounted on wheels to permit movement to the operating position or away for creeling.	87	9
Tucked-in selvage – A selvage in which the filling ends are doubled back and locked into the fabric.	292	
**Turbulence* – A disorderly flow of a fluid.	298	25
Twill weave – A weave which produces diagonal lines in the cloth and repeats over three or more ends and picks.	166	20
Twist – The helical configuration of fibers or filaments in a yarn. See Yarn Twist		
Tying-in – The action of joining the ends on a new warp beam to the corresponding ends in an old warp prior to weaving.	38, 127, 131	
Unclear shed – A warp shed in which the sheets of warp do not form single planes.	192	
Undercam loom – A loom which has the shedding cams under the harness frames.	196	
Underpick loom – A loom in which the picking stick is vertical and under the level of the shuttle box.	185, 226	
Uniaxial load – A load in one direction.	156	11
Unifil – A device attached to the loom which winds the filling quills on the loom.	258	
Variable speed drive	42, 90, 98	

Definition	Index	
	Page	Literature Reference
******Vibration* – Oscillation of a body or part thereof.	221, 228, 263, 275, 282, 341	31
******Viscosity* – A measure of the fluidity of a liquid.	109, 120	
******Warp* – The longitudinal yarns in a woven fabric.	10, 17, 32, 35, 99, 127	9,40
Warp beam – The beam which contains the warp yarns.	20, 33, 37, 84	9
Warp breaks – Breaks in the warp which cause the loom to be stopped. (see end breaks)	32, 247, 322	
Warp end – A warp yarn.	33	9,14,30 38,40
Warper's beam – A warp beam produced by warping.	35, 86	
Warp-face twill – A twill fabric in which the warp appears most on the face of the fabric.	166	20
******Warping* – The winding of warp yarns from packages onto a warp beam.	35, 85	9
Warp let-off – See let-off motion.	27	28
Warp preparation – The preparing of a warp for weaving.	12, 21, 32, 61, 85, 99	9
Warp rib – A weave in which floats are extended in the warp direction to produce ribs in the filling direction.	160	20
Warp shed – The opening through which filling is inserted in a loom.	26, 101, 191	34
Warp shed line – The plane of the warp sheet seen in side elevation.		
Warp sheet – A multitude of warp yarns parallel to each other.	21, 120	
Warp sizing – See slashing.		9
Warp stop motion – A device which stops the loom whenever a warp yarn breaks or becomes slack.	127, 246	
******Warp storage system* – A system of storing a limited amount of warp yarn during the beaming operation so that a broken end may be retrieved before the end is wound on to the beam.	96	
*Warp winding ((*warping) – Winding of warp yarns into large packages or cones.	34, 62, 85	41

Definition	Index	
	Page	Literature Reference
Water-jet loom - A shuttleless loom in which the filling is inserted by a jet of water.	30, 101, 291, 299	36
Wave shed looms – Looms in which it is possible to lay in several fillings simultaneously.	305	
**Weave* – (1) The action of interlacing yarns. (2) The interlacing pattern – see design.	178 134, 160	
Weave room – A room containing active looms.	326	
Weaver's beam – A beam used on a loom usually containing slashed yarns.	33, 86	9
Weaving cycle – The sequence of events between inserting one pick and the next.	178, 316	29
Weaving efficiency – The efficiency with which a batch of looms is kept running.	32, 320, 322, 326, 331	
Weaving out – (1) Weaving until a warp is exhausted; (2) the gradual equalization of warp tension as weaving proceeds.	106	
Weft – Another term for filling.		
Weft cutter – The filling yarn cutter on the loom which operates after a filling transfer to cut the old yarn tail.	30, 294	
Weft insertion – The operation of inserting the filling yarn between the two warp sheets. (See filling insertion).		
**Well* – A slot in the race board which acts as a compartment for the center fork.	250	
Wet finishing – The application of aqueous treatments to impart a certain finish to fabric. (See fabric finish).		
Whip roll – See back rest.		
Winding – The laying of yarn on a yarn package.	34, 39, 41, 58, 61, 65	41
Winding head – Winding unit.	41, 74	
Winding Machines – Machines for winding yarns on to appropriate packages	41, 70	
Winding pattern – The (undesirable) patterns generated by over-lapping helices formed during winding. The patterning is a function of the package diameter.	46, 323	41
Winding speed – The yarn speed in winding.	71, 73, 77	41
Winding tension – The tension developed in yarn during winding.	34, 51, 56, 64	41

Definition	Index	
	Page	Literature Reference
Width in reed – The width of the warp sheet at the reed.	171	
Worm and wheel – A gear with one or more helical teeth (worm) which engages with a toothed wheel to give a large gear ratio.	239, 245	12
**Yarn* – An assembly of fibers or filaments into a long, thin strand.	61, 71, 79, 89, 95, 100, 104, 107, 114, 229, 323	37
Yarn balloon – The solid of revolution created by the rotation of a yarn.	56, 70, 82, 96	41, 37
Yarn conditioning – see Conditioning		
Yarn count – A number indicating the length per unit mass of a yarn.	105, 142, 152, 158, 292	37
Yarn end – See end.		
Yarn faults – Defects in the yarn, usually in the form of local thick or thin spots.	34, 61, 64, 101, 299, 322	33
Yarn guide – Any type of guide used to direct the path of yarn on a textile machine.	50	
Yarn linear density – A number indicating the mass per unit length of a fiber or yarn. See Yarn Count.		
Yarn number – Yarn count or yarn linear density. (See yarn count).		
Yarn preparation – The intermediate series of processes performed on the yarn between spinning and weaving or knitting.	12, 19, 23, 32, 61, 85, 99, 127, 335	
Yarn speed – The linear velocity of a running yarn.	70, 77, 90, 117, 301	
Yarn twist – The number of turns of twist per unit length of yarn.	18, 68, 138, 147, 159 174	
Yaw – (1) Sideways oscillation of a shuttle during transit across the loom. (2) A thin place in a fabric which is detrimental to the cloth.	233	35

APPENDIX II

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Key to References

BP	British Patent
IME Conf	Institution of Mechanical Engineers, London, Conference on Noise
J. Photo. Sci.	Journal of Photographic Science, London.
JTI	Journal of the Textile Institute, London
J. Tex. Mach. S.J.	Journal of the Textile Machinery Society of Japan.
Man Made Tex	Man Made Textiles
Proc. I. Mech. E.	Proceedings of the Institution of Mechanical Engineers, London.
Tex Age	Textile Age
Tex Manuf	Textile Manufacturer, Manchester, England
Tex Merc	Textile Mercury, Manchester, England
TM	Textile Month, Manchester, England
TRJ	Textile Research Journal, Princeton, U.S.A.
Tex Rec	Textile Recorder, Manchester, England
Tex Wk	Textile Weekly, Manchester, England
USP	U.S. Patent

APPENDIX III

DETERMINATION OF YARN LENGTH IN A CRIMPED STATE

Assume that the yarn is formed into a sinusoidal shape:-

$$h = A \sin \frac{2\pi x}{\lambda}$$

where the symbols are defined in Fig. 8.7. Consider a small element of yarn $\delta \ell$ in length and associated with this is a difference in height δh and a difference in width δx.

By Pythagoras $\quad \delta\ell^2 = \delta h^2 + \delta x^2$

$$\delta\ell = [1 + (\frac{\delta h}{\delta x})^2]^{1/2}\, \delta x$$

In the limit $\quad \ell = \int_0^\lambda [1 + (\frac{dh}{dx})^2]^{1/2}\, dx$

Let $k = \frac{2\pi A}{\lambda}$ and $\phi = \frac{2\pi x}{\lambda}$, then $\frac{dh}{dx} = k\cos\phi$

$$\ell = \int_0^\lambda [1 + (k\cos\phi)^2]^{1/2}\, dx$$

$[1 + (k \cos \phi)^2]^{1/2}$ may be expanded binomially and since k^4 and higher powers are negligibly small

$$[1 + (k\cos\phi)^2]^{1/2} \simeq 1 + \frac{1}{2}k^2 \cos^2\phi \text{ --- etc.}$$

$$\therefore \ell \simeq \int_{x=o}^{x=\lambda} [1 + ½k^2 \cos^2 \phi]\, dx$$

but kdx = Adϕ
and equation (1) can be rewritten with different variables and limits

$$\frac{k\ell}{A} \simeq \int_{\phi=0}^{\phi=2\pi} [1 + ½k^2 \cos^2 \phi]\, d\phi$$

$$= 2\pi + ½k^2 \int_0^{2\pi} \cos^2 \phi d\phi$$

$$= 2\pi + ¼k^2 \int_0^{2\pi} [1 + \cos 2\phi]\, d\phi$$

$$= 2\pi + \frac{\pi}{2}k^2 + ¼k^2 \int_0^{2\pi} \cos 2\phi\, d\phi$$

$$\text{but} \int_0^{2\pi} \cos 2\phi d\phi = 0$$

$$\therefore \frac{k\ell}{A} \simeq 2\pi + \frac{\pi}{2}k^2$$

Substituting $k = \frac{2\pi A}{\lambda}$ in equation (2) and simplifying

$$\frac{\ell}{\lambda} \simeq 1 + [\frac{\pi A}{\lambda}]^2$$

$$\ell \simeq \lambda\, [1 + (\frac{\pi A}{\lambda})^2]$$

APPENDIX IV

UNITS AND CONVERSION FACTORS

	S.I.	Imperial or other unit	Conversion factor (see note below)
	A	B	C
Length	mm	inch	0.0394
	cm	inch	0.394
	m	yd	1.094
	micron (μm)	mil (0.001")	0.0394
Linear density	tex	denier	9
	tex	cotton count (N_e)	*
	tex	worsted count (N_w)	*
Pick density	pick/cm	pick/inch (ppi)	2.54
end density	end/cm	end/inch (epi)	2.54
Cover factor	(pick/cm)$\sqrt{\text{tex}}$	$\frac{(\text{ppi})}{\sqrt{N_e}}$ or $\frac{(\text{epi})}{\sqrt{N_e}}$	0.1045
OR	(end/cm) $\sqrt{\text{tex}}$		
Basis weight	g/m^2	oz/yd^2	0.0295
Twist	turn/m	turn/inch (tpi)	0.0254
	turn/cm	tpi	2.54
Twist factor (multiplier)	(turn/cm)$\sqrt{\text{tex}}$	$\frac{(\text{tpi})}{\sqrt{N_e}}$	0.1045
	(turn/cm)$\sqrt{\text{tex}}$	$\frac{(\text{tpi})}{\sqrt{N_w}}$	0.085
Breaking load or	millinewton (mN)	lbf	0.000225
Tear Strength	or		
	newton (N)	lbf	0.225
Force	kilonewton (kN)	kgf	0.102
Tenacity		gf/tex	0.102
or	mN/tex	or	
Specific stress		gf/den	0.0113
Bursting pressure	kN/m^2	lbf/in^2	0.145

Note: To convert from SI to Imperial or other units cited, multiply the value given in the units quoted in column A by the factor C to get the units quoted in column B.

* These are inverse relationships: $\frac{590.5}{\text{tex}} = N_e$ and $\frac{885.8}{\text{tex}} = N_w$