TEXTILE SPINNING WEAVING AND DESIGNING

M G Mahadevan

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Basic Aspects of Textile Fibres

The word fibre creates a mental picture of a long, thin, hair-like objects and indeed textile fibres are like that in general physical shape.Not all fibres though are suitable for textile purposes because a textile fibre must possess sufficient length, fineness, strength and flexibility to be suitable for manufacture into fabrics. It will be seen later on now they vary in these respects and how the variations are responsible for the differing character of materials. It will be seen also that this definition can apply both to natural and to man-made fibres.

Filament and staple

'Filament' and 'staple' are two terms represent the two basic forms of textile fibres. Filament is the name given to a fibre of continuous length, that is to say it is long enough to be used in a fabric without increasing its length by adding other fibres on to it. An example of a natural filament is silk; the cocoon of a silk-worm can contain about two miles of continuous twin filaments. Man-made filaments produced by spinning machines can be many miles long. Staple is the name given to fibres of limited length. To make a continuous length of yarn, staple fibres have to be twisted together.

Staple fibres can range from about one-quarter of an inch to many inches in length, but in no case do they ever become long enough to be classed as filament, so the two terms are quite separate except for the fact that man-made filaments can be converted into staple fibres by deliberately cutting them into short lengths. This is a very common way of processing man-made fibres, but the reverse process is never carried out. An example of a natural staple fibre is cotton.

Yarn

A yarn can consist of either staple fibres, or of filaments put together. Filaments merely need grouping in order to produce the thickness of yarn required, the length is already there in the individual filaments. Grouping of filaments is achieved by twisting them together. The twist, usually quite a small amount, merely serves to keep to filaments reasonably together. Staple fibres have to be twisted to make them cohere into a continuous length of yarn.

The action of twisting forces the fibre surfaces into contact with each other setting up friction between them which enables a lengthwise tension of the yarn to be resisted. In this way a continuous length of yarn can be made even from very short fibres.

The type of yarn exerts a strong influence on the texture and appearance of the fabric. In general, filament yarns are thin, smooth and lustrous and staple fibre yarns are thicker, fibrous and non-lustrous. An excellent example of these different characteristics can be seen by comparing the fibrous nature of the outer wool fabric of a coat or suit jacket with the smooth lustrous surface of the lining of the garment.

Fabrics

Most fabrics are made from yarns.

Woven fabrics

In their simple form these consist of two series of threads, warp and weft, interlaced at right angles to each other. The warp threads run the length of the fabric and the weft threads run across the width of the fabric. The edge at each long side of a woven fabric is called the selvedge and it is commonly of a different construction or appearance, to the rest of the rest of the fabric because its function is not only to provide a firm neat edge finish to the fabric for the sake of appearance, but also to provide a secure grip for finishing machinery. For this latter reason, small regular groups of pin-holes can often be seen in a fabric selvedge showing where it was held by the machine pine. Other types of machine use clips which do not mark the selvedges. The section drawings at the side and the bottom of the plan show that warp and waft interlace with each other in a similar manner.

If the threads are closely spaced it can be seen that this form of interlacing gives a very tight structure because the alternate interlacings give no room for sideways movement of the threads. The draping properties of such a structure would depend entirely on the flexibility of the fibres and yarns. For example, a square of wire gauze, as used in a laboratory, is formed by interlacing steel wire in plain weave. As a result a fairly rigid piece of fabric is produced which is the intention. This fabric is too rigid to be used for any normal fabric purpose because steel wire is far less flexible than any textile fibre or yarn.

A fine cotton calico can be made by interlacing cotton yarns in plain weave much more closely than the wire gauze, but because of the softness and flexibility of the cotton, the resulting fabric is quite supple and is flexible enough for many fabric purposes. The toile used by dressmakers for making preliminary models of dresses is often calico of this type.

Woven structures can vary in density and in interlacing, and this can make them differ in appearance and handle, but in their simple forms they represent a very stable material. By this it is meant that unless a woven fabric is deliberately made otherwise (such as in a 'stretch' fabric) it does not extend a great deal in warp and weft directions because of the interlacings—which resist an attempt to pull warp or weft straight.

The natural elasticity of the material will produce a reasonable amount of 'give' in warp or weft directions. This will very according to the tightness of the structure and the amount of elasticity in fibre and yarn. The amount of movement is usually small enough to ensure that a piece of woven fabric cut to shape, as part of a garment is not too easily distorted, but yet in wear it will 'give' enough to be comfortable if the garment is cut and styled properly. If tension is exerted diagonally much more movement is obtained because the force is not now directly along a yarn direction but is pulling across both series of threads causing a 'scissor' action. This diagonal direction is known as bias.

True bias is an angle of 45°, i.e. exactly between warp and weft, and smaller angles of bias can be used if necessary, but the greatest amount of movement is along the true bias line. In using a woven fabric for clothing, due regard must be paid to the grain of the fabric. The grain is represented by warp and weft. If the fabric is true, the warp runs straight lengthways and the weft runs across the fabric at 90° to the warp. Garments are usually made up so that the warp runs vertically down the garment as it is worn and the weft horizontally across it.

Knitted fabrics

Knitted fabrics consist of a structure formed by interlocking loops of yarn. This term is used because the yarn is fed horizontally to form rows of loops which are individually locked vertically with the corresponding loop in the next horizontal row. This is the type if knitting which can be produced by hand using two knitting 'needles' and one ball of yarn. Knitting machines can produce either a flat fabric or a tubular fabric according to type. It will be seen that the interlocked loops form vertical rows which are called wales and horizontal rows which are called courses. If the fabric is correctly on grain, wales and courses intersect at 90° and are thus the directional equivalent of warp and weft, as far as grain is concerned.

Stability of a simple knitted fabric is much less than that of an ordinary woven fabric because any tension exerted on it will never be along the line of a yarn, but will distort the loop structure so that the fabric can be stretched in any direction. This simple structure can also be unravelled very easily from the top down—wards, and if the yarn forming a loop is broken it immediately releases loops so that a 'ladder' quickly forms which will widen and lengthen under tension. The instability of simple types knitted fabric was a limiting factor in their use for garments.

At one time hosiery and underwear formed the main bulk of garments. At one time hosiery and underwear formed the main bulk of garments made from this type of fabric because shapes could be kept simple and the stretch of the knitted structure enabled a close fit to be obtained without complicated cutting or styling. Knitted fabrics are now strenuously competing with woven fabrics in many clothing uses due to the fact that improved machines and techniques have produced knitted fabrics in complex structures which in some cases are equal to woven fabrics in stability and in addition makers-up and consumers are more accustomed to handling and using stretchable materials so that prejudice against knitted fabrics no longer exists to the extent to which it once did. Techniques of fabric lamination and bonding, also serve to make knitted fabrics easier to handle by the maker-up and to give them more stability for garment use when required.

Lace and net fabrics

Manufacture of Lace and net fabrics formerly was a hand technique but they are now mostly machine made. In this respect these fabrics behave similarly to simple knitted fabrics, but whereas compound knitted structures can be made close, compact; and stable, lace structures must remain relatively open to preserve their character. For this reason lace is mostly used for decoration in the form of edgings and inserts.

It can be sued as the main fabric of a garment but the easily distorted and open structure produces cutting and lining problems. Bonding techniques can be used to stabilise the fabric and simplify the making-up difficulties. Lace-type fabrics are frequently made on a special type of knitting machine called a Raschel where the lace formation is produced by a loop structure instead of by twisting threads around each other.

Braided fabrics

Braided fabrics produced by interlacing yarns diagonally in a form of 'plaiting'. This type of structure is confined to narrow flat fabrics or to relatively small tubular structures because the machine must keep all the constituent threads in motion simultaneously, and separately, so that a very large or wide structure would need an extremely complicated and uneconomic machine. A common example of braid use is the normal shoe lace which can be either a flattened; or a rounded tube according to type. The rounded effect is sometimes enhanced by filling the tube with packing yarns which lie perfectly straight.

Apart from use as shoe laces and various forms of cord, such as sash cord and blind cord, braid is used for decorations in either flat, rounded or in more elaborate ruched or zigzag forms. The diagonal course of the yarns normally makes braid easily extended in the length direction with a corresponding contraction in width but setting in finishing processes can produce stability to lengthways stretch if necessary. The term braid is also used in general to describe narrow fabrics which have actually been woven, or even knitted. Woven 'braid' is of course quite compact and stable in dimensions and is often used for edge bindings and for stabilising edges of knitted garments.

Knitted 'braids' are usually used for girdles and other minor uses where length instability is not important. The manufacture of braids, ribbons and tapes, known as small-wares is carried out by a specialised section of the textile industry. All the fabric types so for dealt with are those in which the textile fibres have been converted into yarns first and then the yarns used in various ways to form the fabrics. On sheer common sense grounds the idea of converting fibres directly into fabrics, by-passing the yarn stage, seems economically attractive providing some means of consolidation the fibres is available.

Felt fabrics

Felt has been used by man for centuries and its manufacture is made possible by the fact that wool, and some other animal fibres, possess a natural tendency to felt or mat together under the influence of heat, moisture and mechanical pressure. In this way, webs of wool fibres can be consolidated into a fabric. A fabric produced in this way is entirely without grain because the flat webs of fibres are non-directional, i.e the fibres point in all direction. Felt can be cut in any direction without fraying or unravelling because of the compact fibre arrangement. Unfortunately this convenience is marred by distinct deficiencies in drape, stability and durability so that felt is of very little use for normal garment making.

If felt is to be strong and stable the fibres must be so consolidated that the material is staff and heavy with very little draping property. If felt is made soft and supple its properties of tensile strength, resistance to abrasion and distortion are too low to be of practical value for normal garment use. The main apparel use of felt is in the manufacture of hats where its capacity to be shaped by heat and moisture can be exploited. Its lack of grain makes it suitable for handicraft and applique work where cutting of intricate shapes is possible and certain types of soft bulky felts are used as padding in garment interlinings. Certain types of woven or knitted wool fabrics are given a felted finish which gives them the appearance of felt in that no yarn structure is apparent and the fabric appears to be composed entirely of fibres.

Bonded fibre fabrics

The development of bonded fibre fabrics is comparatively recent and is based on the use of fibres other; than wool, in fact man-made fibres are the principle fibres used for these fabrics. As they do not possess an inherent felting property some form of chemical bonding is necessary, hence the name.

Although the method of fibre consolidation is different the initial formation of fibre webs is similar in general principle to felt making with the exception the certain bonded fibre fabrics can be made with the majority of fibres laid in one direction. This gives them considerable tensile strength in the direction of the fibre majority but very little lateral strength. For general fabric use bonded fibre fabrics still suffer from the same disadvantages as felt with the result that they are not suitable for 'top' fabrics in clothing.

However, they have found considerable use as interlinings and this method of manufacture can produce a wider range of materials at a much lower price than is possible with felt. The possibility of a material possessing sufficient conventional fabric properties, or of a disposable textile garment material being able to be made by this technique must not be discounted. Every textile fabric is the result of a combination of materials and processes so that any understanding of fabrics must include some knowledge of materials and processes involved in fabric production since no single stage of production is entirely responsible for; the appearance and performance of a fabric.

Each stage of processing has its variables so that in the complete sequence of manufacture the number of possible combination is enormous. This is a very simple explanation of the wide variety of fabrics available. Once the principle of the common variations in the separate stages of manufacture are understood, the effects of the usual combinations of them in fabrics soon form a pattern of fabric appreciation. These are the basic fabrics referred and knowledge of; these makes the uncommon fabric easier to comprehend because it can be compared with the usual pattern and with some experience, the points of difference will be perceived so that the probable behaviour of the fabric can be assessed.

Textile mills

Many textile mills are comparatively small organisations. Other mills are large concerns employing thousands of people. However, there are no giant corporations, such as DuPont or General motors, in the textile field. The Department of Labour separates the textile mills in several groups for statistical purposes.

There are four major types of mills:

1) broad-woven fabrics mills, which employ about 530,000 persons all of whom are not weavers, however, since many of the weaving mills have their own spinning or finishing departments, or both;
2) yarn and thread mills, which employ about 160,000 persons;
3) knitting mills, which employ about 250,000 persons; and
4) dyeing and finishing plants, which employ about 100,000 persons.

Besides the major groups, there are smaller groups specialising in certain fields. The carpet mills employ about 50,000 persons; narrow-fabric mills, 35,000; wool scouring and combing plants, 6000; hat factories, 19,000; and miscellaneous other mills, about 75,000. It often happens that textile mills grow larger, or that several mills are combined under one top management. Such groups of mills are called integrated, and the integrations may be vertical or horizontal. In an ideal vertical integration, the same management would own the spinning mills, the weaving mills, the finishing plants, and the retail outlets. There are very few such plants, because it is quite a job to keep track of textiles from the raw material to the finished products.

Unless the various mills in such a concern are run more or less independently; the organisation may become too unwieldy to follow the rapid changes in fashion. In a horizontal integration, the management own several mills on the same level. For instance, one management may own a mill that weaves corduroys, a mill that weaves rayon fabrics, a mill that weaves gabardines, and so on. This type of integration, perhaps combining a group of spinning and weaving mills, is very common in the textile industries.

There are small mills and large integrations that are successful-and there are others that are not. To succeed, a mill or group of mills need good management, an alert sales organisation, and well trained, cooperative technical personnel. Experience has shown that many medium-sized plants out in the country, where living conditions are good and the climate is pleasant, are better than large plants in an industrialised area. A modern textile mill should not only be efficient but also be a pleasant place to working. Of particular interest is the system used to merchandise textile fabrics. In the United States practically all merchandising activities are carried out in New York. At first glance it seems absurd that the sale of broadcloth from a mill in North Carolina to a garment factory in Los Angeles should be handled in New York. But look at it from the viewpoint of the clothier.

A mill management is in similar fix. No mill wants to produce goods that can't be sold. The merchandising organisation must be in touch with the market in order to tell the mill what types of cloth are in demand. Since it is impossible for the sakes staff to visit prospective customers all over the world, there must be a central point where the merchandising can be done. In large textile concerns, the sales organisation is often controlled by the mill. The situation may be reversed, however, and the sales organisation may own the mills. In either case there is usually a central office in New York which styles, promotes, and sells the production of the whole concern. Such a sales organisation may employ a hundred persons to carry out its various functions. Besides the organisations just mentioned, there are independent sales agents. These may represent a number of different mills whose products do not compete with each other. The sales agents, or brokers, work on a commission basis and fulfill the same functions as the company-owned sales organisation.

A mill may have produced more goods of a certain type than the customers need and is therefore willing to sell the goods at cost to get rid of them. The jobber buys these goods and accumulates a great variety of fabrics. Clothiers, stores, and others who need textiles buy from the jobbers when they need material for immediate delivery. Of particular importance to the cotton and rayon mills are the converters. These buy large amounts of cloth as it comes off the loom. Cloth at this stage of production is called gray goods. When a certain fashion comes into style, they send the gray goods to a finishing plan. There the gray goods are dyed, bleached, or printed. They are given a dull or a lustrous surface. They are made soft or slick.

Woven textile fabrics

The quality of the fibres influences the quality of the fabric. The construction and finish, however, are as important as the fibres. You will make a separate study of the fibres later. Here we'll only deal briefly with some of the major types.

Cotton

Cotton is strong and reasonably low in price. The fibre is short and fine, usually about 1 in. (inch) long. Cotton is called a dead fibre because it has little luster, wrinkle resistance, and elasticity. Cotton is by far the most commonly used textile fibre.

Wool

Wool is warm, wrinkle-resistant, and fairly strong and elastic a live fibre. Depending on the spinning method and cloth construction, wool fabrics can be made in many different types; wool is perhaps the most versatile of all fibres. The small scales on top of the fibre open under pressure in warm soapy water, causing the fibres to move in the fabric and felt together. New wools is fairly long, usually from 2 to 5 in. Re-used wool varies in quality, the fibres are usually short, and the scales may be loosened or broken. Finishing is very important. It can bring out all the desirable qualities in wool, or it can ruin a fabric. Wool prices fluctuate, but in general wool is about 4 to 5 times as expensive as cotton, rayon, or acetate. That is perhaps the main reason why today more rayon and acetate is used than wool.

Silk

Silk is a beautiful luxury fibre. It is strong, elastic, and lustrous. Silk is expensive, and the price fluctuates widely. Each silk fibre is hundreds of feet long. It is technically defined as a filament. Several filaments are thrown, or twisted together, to form silk yarn. Or else the filaments may be cut into short pieces and spun, just about like cotton.

Rayon

Rayon is a beautiful fibre, too, and it is priced competitively with cotton. Cupra-ammonium rayon, or Bemberg, would look more like nylon under the microscope. Rayon is normally lustrous, but it can be made dull. It can be had in long filaments or as short fibre, or staple. Regular rayon is weaker than cotton, and still weaker when wet. However, a special type called high-tenacity rayon is extremely strong. Rayon stretches easily, and has little wrinkle resistance unless specially treated. It is the most commonly used of all man-made fibres.

Acetate

Acetate resembles rayon in appearance and price. It is a little weaker than rayon, but wrinkles less. Acetate holds pleats that are heat-set, that is, it is thermoplastic. It will melt when touched with an iron that is too hot. Acetate is usually lustrous, but can be made dull. It can be had in filament or staple form. It is not very absorbent, and so it is easy to wash and dry. Acetate is not pure cellulose like rayon and cotton. It requires special methods in dyeing. Acetate ranks with rayon in popularity.

Nylon

Nylon is extremely strong and elastic. It is about twice as expensive as rayon or acetate. Nylon can be had lustrous or dull, in filament or staple form. It resembles silk more than any other man-made fibre, and has replaced silk for most purposes. Nylon is thermoplastic and keeps its shape even after washing, but melts when touched by a very hot iron. It is used wherever strength and elasticity are needed, and has gained great popularity.

Vinyon

Vinyon is a filament. An improved staple form is called dynel. Vinyon and dynel are fairly strong. Dynel is often used in blends with other fibres to improve wrinkle resistance, and to hold heat-set creases. Like nylon and most other synthetics, it absorbs very little water. The price of the fibre is below that of nylon.

Mohair

Mohair is stronger and more elastic than wool. The scales on this fibre are larger and tightly closed. It does not felt like wool. It is blended with other fibres to add strength and wrinkle resistance to fabrics.

Linen

Linen is a beautiful and very strong fibre. It is a dead fibre and wrinkles easily, but it wears like iron. Like silk, linen is imported in the United States and is quite expensive.

Glass fibres

Glass fibres for textile purposes are usually in filament form. They are extremely strong, but should not be bent too sharply or they may break. Glass fibres don't absorb water, and they can't burn. The fabrics are mainly used for curtains and other decorative purposes.

Dacron

Dacron is mostly made in staple form. It is quite strong and extremely wrinkle-resistant. Dacron fabrics retain their shape after careful washing. However, they accumulate static electricity, and a hot iron will melt them. The fibre is often blended with other fibres to get the benefit of its good properties and to counteract the bad. The price is a little above nylon.

Orlon

Orlon is available in staple and in filament form. It is almost as strong as nylon, and it is more resistant against weakening by sunlight or salt water, or both. The thermoplastic properties of the fibre make the staple popular in blends with other fibres. The price is somewhat higher than that of nylon.

Vicara

Vicara resembles nylon under the microscope. It is rather weak, and is used in staple form for blending with stronger fibres. Vicara is soft and pleasing to touch. It improves the feel, or hand, of fabrics. The price is between the prices of rayon and nylon.

Yarns for weaving

The cotton is taken from the field to a gin, where the fibre, or lint, is removed from the seed. The cotton from several bales is mixed to get an even quality. At the same time, some of the dust and dirt is removed, and the clumps of fibres are somewhat opened up. The machines used for this purpose are called openers and pickers. The cotton comes out as a thick sheet of cotton batting, or picker lap. The picker lap is put on a cotton card. This machine has thousands of little wire points that separate the fibres and spread them into a thin, even web.

The web is condensed into a thick strand of loose fibres called a card sliver. If you intend to make very fine, even yarns, the sliver is then combed. Combing removes short fibres and push the remaining fibres parallel. The resulting yarns are called combed yarns. Ordinary yarns are called carded yarns. The silver from the card or comb is then drawn out, or drafted, on a drawing frame. That is, several slivers are put between rolls that draw them out and combine them into one sliver. The drafted sliver looks just about like the card sliver, but it is much more even.

After drafting the sliver is put on a fly frame that converts it into roving and winds it on bobbins. This frame has attachments called flyers to control the roving, hence the name fly frame or roving frame. This process can be done in several stages and the fly frames may be called slubber, speeder, and so on, to differentiate between them. In any event the roving will be a thin, loose of fibres. The roving is taken to a spinning frame, where it is drafted further and has twist inserted in it. This changes the roving into yarn.

On the spinning frame the yarn is controlled by little wire clips, or travelers, that move in a ring. The frames are therefore often called ring frames. The ring frame winds the yarn on bobbins in a single strand, and the yarn is then called single yarn. At this point you have covered the major spinning processes from raw material to yarn. For greater strength it is often desirable to ply, or twist, two or more strands of single yarn together. This is done on a ring twister. The resulting yarn is called ply yarn; or, more specifically, 2-ply, 3-ply, and so on, depending on the number of single yarns in the twisted yarn. There are other systems of spinning which differ more or less from the system just described. However, most yarns spun from rayon and other synthetic staple are spun just about like cotton.

Systems used for wool differ somewhat from the cotton spinning system. Wool is full of dirt and grease when it comes from the sheep. It must be washed and cleaned before any further processing. After that it is handled in different ways, depending on whether you want worsted or woollen yarns. Worsted is more common, so let's first look at the worsted spinning systems. In general, the processes are more or less the same as those for combed cotton yarns. Because wool fibres are longer and more difficult to handle, there may be several machines, and more complex machines, than in cotton processing.

There are systems called the Bradford system, the French system, and the American system which differ from each other in detail. But in any system the wool is carded, combed, drafted, and finally spun into worsted yarn. The system for spinning woolen yarn is different from those used for cotton and worsted yarns. The card web is not condensed into sliver and drafted. The web is separated into strands of roving and taken right to the spinning machine. This machine may be either a ring frame or a special machine called a mule.

Since the fibres have been neither combed nor drafted, they are arranged crisscross in the yarn. Woolen yarn is, consequently, rather thick and loose, or lofty. The woollen system is ideal for very short fibres, whether they are wool or some other material. However, fabrics made from woollen yarns are not as popular as they once were.

Silk and man-made fibres can be had in the form of long filaments. These filaments are not spun like other yarns, but simply twisted together in an operation known as throwing. The machine commonly used for this purpose is called an up-twister, because the yarn travels upward in it, not downward as in an ordinary ring twister. Many throwsters call the machine an up-spinner, which is very confusing to the layman, because it is definitely a twister and not a spinning machine.

Two

Structure and Properties of Textile Fibres

If any study of textile fabrics is to be made, the meaning of the word textile must be made quite clear. The dictionary states that the word is derived from the Latin word texere to weave; but a wider meaning than simply that of weaving must be accepted since that is only one of various ways of making textile fabrics. It is now generally accepted that a textile is a fabric made from fibres but, the fibres may either be converted into yarn first and then the yarns put together in one of a variety of ways to make fabrics, or the fibres can be converted directly into a fabric. This definition excludes clothing materials such as fur, leather, suede and unsupported plastic sheeting.

The first three are natural materials and are not made from fibres although the fibres of fur can be detached from the skin and used as textile fibres. Leather and suede are fibrous in structure but the fibres have no separate identity in a textile sense, and plastic sheeting has no fibre content at all. Fur, leather and suede can be simulated in textile structures and in combinations of textile and plastic materials. Textile fibres have at least a few of the several properties referred to below and which enable it to be converted into yarns and fabrics by means of machinery now commonly used in the textile industry.

Fibre structure

Fibres are made up of long chain molecules running more or less in the direction of the length axis. Just as a durable flexible thread must be built up of tine tenuous fibres arranged there or less parallel to each other and aligned in the direction of the thread length, so does it seem necessary that each textile fibre shall be built up in a similar way with long chain molecules. The ultimate units of a fibre are the molecules, but in a textile fibre these are never found singly or isolated; they are always present joined end-to-end in the form of long chains, and it is these which must be considered as the real building units. It appears essential that these chain molecules shall be long and preferably straight.

In some fibres, notably wool, the adjacent long chain molecules are also held together by lateral forces and these play an important there are few, if any, cross-linkages of this kind on cotton, linen, silk, viscose, cuprammonium, acetate and the synthetic fibres. But cross-linkages (mainly produced by formaldehyde treatment) are purposely introduced into some fibres to give them increased stability and resistance to swelling during dyeing and other wet processing. When a fibre is placed in water it usually swells about 30 to 40 per cent in thickness but extends only about 3 per cent on length. This indicates that the forces by which the molecules are held together, end to end, are considerably stronger than those responsible for the lateral linkages.

When a textile fibre undergoes deterioration it is often that the lateral linkages are broken first and then the fibre swells more easily and to a greater degree in water. It is thus easy to understand how such textile materials has decreased wear especially in laundering. A fibre is usually stronger and more durable in proportion to the length of its long chain molecules.

When a strong fibre is overbleached, exposed to sunlight or damaged by chemical treatment its long chain molecules will be broken into shorter ones. There are various methods at the disposal of the textile chemist for determining the degree to which the long chain molecules are shortened and it is invariably also found that the fibres are weakened more or less in proportion to this shortening. From these considerations it is easy to see that in modern developments concerning the manufacture of man-made fibres more progress will be made in the production of stronger and more durable fibres as it becomes possible to use for their manufacture substances which consist of very long molecules and which resist strongly all influence to break them down into shorter ones.

There is just one further point about this structure of a textile which is of interest. The fibres are stronger in proportion to the degree to which the long chain molecules are aligned parallel to each other and to the fibre length. In the case of natural fibres long chain molecules are mainly disposed in this way. But in the manufacture of man-made fibres it is sometimes difficult to ensure this in the freshly formed fibres.

By subsequently stretching these, much better alignment can be obtained and so the strength of the fibres can be increased. Today some very tenacious tough rayon fibres are being made by application of stretching processes to the first-formed weaker fibres. With this special alignment of the long chain molecules the fibres become less extensible and sometimes even brittle, so generally a compromise has to be reached. The stretching is carried out to a point at which a good increase of strength is secured and the extensibility of the fibre is not so lowered as to prevent the fibres passing satisfactorily through the manufacturing processes by which they are later made into yarn and fabric and during which they are often subject to considerable and varying stresses.

Properties of synthetic fibres

Synthetic fibres are very different in many respects from the older natural and rayon fibres. It thus seems appropriate to make some further observations which apply particularly to the synthetic fibres such as nylon, Orlon and Terylene. Diagrammatic sketch of the increased alignment of the molecular chains within a textile fibre which is produced by stretching. Such stretching gives the fibres increased tenacity, but less extensibility The chemical compositions of the synthetic fibres vary considerably but they all resemble each other in respect of three very important properties:

1) a tendency to soften at elevated temperatures and become thermoplastic;
2) a lack of internal stability so that the fibres tend to contract in length when exposed to high temperatures in either the wet or dry state or when exposed at ordinary temperatures to substances capable of swelling them;
3) a very low affinity for moisture which is correlated with a correspondingly small affinity for most of the dyes which are in common use for dyeing other textile fibres.

It will be useful to discuss these important properties somewhat more fully.

From the nature of the polymeric substances used in the manufacture of synthetic fibres and the way in which several of them are converted into fibres by extrusion of the molten polymer through spinnerets, it is easy to understand that these fibres must be liable to melt or a least soften when sufficiently heated. It may be recalled that acetate fibres are also liable to soften during not ironing but the public is now so well aware of this that it is natural to take care and avoid the use of dangerous temperatures.

During the past few years examined to test their suitability for different polymers have been examined to test their suitability for conversion into synthetic fibres, and a very high proportion of these have been rejected almost solely on account of their low melting point.

The first type of Vinyon was actually manufactured in a large scale but it is now being replaced by Vinyon N. The very low softening temperature of 65°C. has proved too large an obstacle to the wide use of Vinyon H as a textile fibre. It is likely that for some years to come synthetic fibres will be liable to soften on heating, but it is anticipated that in due course research will allow fibre- forming polymers of low melting point to be replaced by others of higher melting point. A fairly low softening temperature is not altogether a defect in a synthetic fibre; the softening can be utilised by a textile finisher to produce permanent embossed patterns on fabrics made from synthetic fibres.

Synthetic fibres are liable to become sticky or tacky when softened and this property can be employed in the manufacture of non-woven fabrics. But, in general, it is better for the synthetics fibre to have a high softening temperature, for when the fibres are heated to their softening point and then cooled they can become stiffer and more brittle so that the fabric or other article thereby loses some of its wear value.

The internal instability of synthetic fibres is of considerable importance and has been the subject of much research on the part of synthetic fibre manufactures. It has been noted that the freshly extruded filaments, whether they be melt spun, are usually relatively weak and capable of being stretched to many times their original length. Generally these freshly made filaments are valueless for textile purposes on this account. So the filaments have to be original unstretched state when they are relaxed, and synthetic fibres are not exception to this rule.

However, the manufacturers take steps to set the extended fibres in their stretched state. This is usually accomplished by holding them under tension in the form of yarn while exposed, in either a wet or dry state, to a temperature which is higher than that to which the fibres will subsequently be exposed. The setting temperature will always be above the boiling point of water if the fibre is not to soften at such a temperature.

When the synthetic fibres are set they can be handled without fear of shrinkage provided that the setting temperature is not approached too closely. Thus the stability of synthetic fibre materials is limited and if they are hot ironed or treated in liquors near to the setting temperature they will commence to shrink and lose their shape.

In all synthetic fibres there are latent forces which are awaiting the opportunity of including the fibres to attempt to return, at least partially, to their unstretched state and all users of synthetic fibre materials must fully appreciate the significance of this fact. While dry and wet heat can free these latent contractive forces, it is possible for the synthetic fibres to shrink in another way.

Many organic substances have the power to dissolve or swell synthetic fibres given suitable conditions. During the swelling the internal structure of the fibres is loosened, contraction is facilitated and the latent contractive forces are given the opportunity to exert their power. This type of shrinkage is of particular importance to dyers of synthetic fibre materials for the reason that such organic swelling substances are sometimes required to be used in dye liquors to assist dye absorption. This internal instability of synthetic fibres has to be taken into account in various ways. It has to be counteracted in those instances where it can cause trouble in dyeing and finishing, and it can be utilised with advantage where it is desired to modify the form or shape of a synthetic fibre material.

In dealing with nylon some mention was made of the fact that before nylon hose can be processed in hot liquors, say in scouring and dyeing, it is necessary to set them on shapes at a temperature which is somewhat below the softening point of nylon and yet appreciably above the highest temperature at which the hose will be processed. If this heat setting or pre-boarding is not carried out, the hose shrink and become distorted permanently during their treatment in the hot scouring or dyeing liquors and are thus made useless.

However, the heat-set hose retain their shape and smooth texture perfectly, so long as the wet treatment is not allowed to reach the heat-setting temperature, which is usually about 122°C. Heat setting is also required for nylon fabrics and garments and, in this pre-treatment, all that is required is to hold the nylon material to the size and shape desired while it is exposed to a dry or moist heat for a few minutes. With garments, as with hose, it is usually most convenient to have them stretched over suitable shapes.

In the case of fabric there are two alternative methods of treatment. The fabric can be held out in open width to the desired dimensions and exposed to hot air whilst travelling along a stenter frame such as is much used in finishing operations. The alternative is to wind the fabric evenly on a perforated central tube, place into a closed chamber and blow steam through the fabric from inside to outside and then in the reverse direction.

In all such setting operations it is necessary to percent shrinkage during exposure to the high temperature. The setting of permanent pleats in nylon fabrics and garments is an instance of how the stability of a synthetic fibre can be modified beneficially.

It is necessary to heat set them whenever they are to be processed at a high temperature, so that they may have no tendency to shrink or distort. The temperature conditions of such heat setting will vary from fibre to fibre and be governed by the softening point of the particular synthetic fibre being dealt with.

All these last-named fibres readily pick up moisture from a damp atmosphere and imbibe much water when they are completely wetted. This is not the case with the synthetic fibres. In their air-dry state they may absorb less than 0.1 per cent of moisture from the surrounding air as compared with, say, 12 per cent for viscose rayon.

In the normal way synthetic fibre fabrics and garments with their hydrophobic or non-absorbent properties have been considered unsuitable for many types of garments, particularly underwear. However, now that these fibres have been put to use in their cut-up or staple form, it has been found that these restrictions on their use need not be observed so much as was anticipated. It is found that the porous nature of staple fibre materials counteracts the poor moisture-absorbent properties of the fibres themselves.

In the case of synthetic fibres a small affinity for moisture is important in many directions but especially in their manipulation during weaving the knitting, and in dyeing and finishing operations. During the manipulation of synthetic fibre yarns in the subject to a considerable amount of friction as they rub against themselves and various parts of the machinery employed. This friction generates static electricity which is technically termed static.

In the case of cotton, wool and other fibres, which normally retain 6 to 18 percent of moisture in their air-dry state, the static leaks away to earth, just as fast as it is formed, via the metal parts of the machinery used and so causes no trouble.

On the other hand, owing to their extreme dryness, synthetic fibres are poor conductors of electricity, and this allows the static to accumulate on them. This static eventually causes the individual filaments and yarns to repel each other so that yarn and fabric manipulation can become very difficult.

So considerable may be the difficulties caused by this static that, in the early days, much defective nylon fabric was produced and the elimination of static became quite problem. Since then, methods, for overcoming static have been devised but it still remains a disadvantage of synthetic fibres that they are so ready to accumulate static electricity. Synthetic fibre materials charged with electrostatic electricity readily attract dust, dirt particles, etc. to become soiled.

Three methods for overcoming static difficulties are now in use.

In the first, the synthetic fibre yarns are sized with substances which make them much better conductors of electricity.

The second method involves ionising the air around the machine where the synthetic fibre material is being wound, woven or otherwise processed, so that the static electricity formed on the fibres leaks away to earth via the ionised air.

In the third method it is arranged that the synthetic fibre material touches one or more earthed conductors which carry away the static electricity.

When a textile fibre has a poor affinity for moisture, this is usually a sure indication that it will be difficult to dye. In dyeing cotton, linen, wool and similar materials it is usual to apply the dyes from an aqueous dyebath, not only because water is the cheapest of all solvents for dyes but also because it is rapidly absorbed by the fibres.

The imbibed water swells the fibres, loosens or opens out their internal structure, and so facilitates the entry of the dye particles into the fibre interior. Some dye particles are so large that they could not enter into, say, a cotton fibre unless this was first wetted so as to increase its porosity and thus make possible the entry of these large dye particles.

Now, the synthetic fibres absorb so little water that their internal structure remains contracted and compact during dyeing, and a large proportion of the dyes commonly used for dyeing other fibres are unable to enter the synthetic fibres or only enter to such a limited degree that it is impossible to dye really deep shades. Thus with the large-scale production of synthetic fibres dyers have met a major problem, that of devising methods for dyeing these fibres in deep shades as easily as the older fibres.

With the introduction of acetate fibres some thirty years ago a somewhat similar difficulty was encountered, for, as regards its affinity for moisture, acetate fibres lie about half-way between a hydrophilic fibre such as nylon. This difficulty was solved by the manufacture of entirely new types of dyes, generally known as acetate dyes, which differ from the usual dyes in being insoluble in water but soluble in organic solvents.

It was fortunate for the early dyers of nylon that many of these acetate dyes were found to be applicable to the synthetic fibre, and it may be noted that all nylon hose are coloured with these dyes. Even with these acetate dyes, however, it has been found difficult to produce deep shades of very good fastness to washing. So new dyes, somewhat similar in type, have had to be discovered to supply this deficiency.

Generally, the dyes which are applicable to acetate are useful for colouring all the synthetic fibres. Such dyes are now more usually referred to as disperse dyes. In recent years, new methods have been devised for applying ordinary cotton and wool dyes to synthetic fibres. They are based on the expedient of adding to the dye-bath a comparatively small proportion of an organic substance which is generally referred to as a dye carrier or fibre-swelling agent.

This substance splits the large dye particles into smaller ones and also opens out the internal structure of the synthetic fibres so that the dye particles can enter more freely. There is the alternative dyeing at temperatures above the boiling point of water, say at 250°F. for such high-temperature conditions also have the effect of loosening the fibre structure.

Three
Spinning Diagnosis

In the beginning of the history of spinning, progress in spinning technique was mainly made by accumulating empirical facts; that is to say, by repeating a set of procedures such as setting a spinning, condition and measuring the resultant properties and structures of the spun fibres. When ring spinning ruled in mills, one spindle produced roughly 15 metres of yarn per minute. Today, 300 metres per minute of yarn are produced by one spindle in air jet spinning, and in laboratories astronomical figures go round; in the near 1000 metres per minute will be achieved and even much more, for some technologies.

Quality and productivity requirements inevitably cause the production systems to adapt. This adaptation is based on two factors that cannot be separated; first the use of on-line sensors with information centralization, and second the automatic processing of this information. If the number of sensors and consequently, the amount of information increases, the automation of their processing becomes necessary.

Weight regularity

The weight regularity of a yarn is the variation of its count. It is a factor which conditions the aspect regularity of the fabrics and consequently is a very important commercial quality criterion. In this field, an HF (high frequency) sensor is used, which makes it possible for the yarn count variations to be measured around a nominal value. So, the number of defects. as well as the count variation coefficient and the spectrogram can be determined. This basic sensor which was well designed by Zellweger Uster is the most popular one in the textile world. It is a relative sensor without any contact which makes it very sensitive to various pollutions and to thermal drifts.

For example, much is known about the sensitivity of those sensors to hydrometric variations from climatic origin or possibly due to the water content of the material. If this sensitivity is real, the weight sensor without any contact is capacitive and the presence of polar molecules like the water molecules will have an influence. However, it can be noticed that if the frequency of the electrical voltage of the sensor can be made to vary there are frequencies where water does not matter so much. These are evidently the working areas. Yet, such a sensor remains sensitive and in on-line controls, simplified versions are used.

The biggest drawback of this sensor is that it somehow lacks credibility when a fibres blend has to be measured because, in this case, the dielectric within the sensor can vary independently of the captive weight and hence the response of the sensor is not meaningful. This type of sensor prevailed, for it has the advantage of performing an overall sampling for a constant length of measure, whatever the structure and the shape of the yarn.

Diamter

Diameter sensor is appropriate for performing a measurement that is independent of the fibres nature. The diameter is a direct measurement of a parameter which effectively conditions the fabric aspect. This measurement is suitable for monofilaments but less suitable for staple fibres yarns because these structures are rarely cylindrical, and there are fibres around the compact core where sensing becomes difficult. The different techniques that can be used to measure the diameter are presently discussed.

— *Shadow measurement*: The shadow of a yarn should be proportional to its diameter. This method gives good results for metallic threads or organic monofilaments dyed in dark colours. In these conditions, the accuracy reaches some micrometers, but for a texturized yarn, for example, differences of over 50 percent of the value obtained by microscope are frequent.

— *Measurement through a beam scanning:* An element sets the beam to vibrate so that the bulk of the yarn can be scanned. According to how the sensitivity of this device is adjusted, important differences unfortunately appear. This solution is often used for metallic threads, glass, etc.

— *Measurement through a picture scanning*: A big source illuminates the object to be measured, but it is the receptor that scans the obtained image. When compared to shadow measurement, the latter two techniques bring about a much better analysis in the evolution of the limit of the object to be measured; however, for our structures, the estimation is not always satisfactory since it depends on the threshold value of the adjustment.

— *Measurement of the bulk of the yarn through a diffraction process with picture reconstitution*: The estimation of the limits can be performed by using the phenomenon of diffraction. Using filters in Fourier's plane makes it possible to split the information which is actually responsible for the phenomenon of diffraction. So, the compact core of the fibres gravitating around can be split, based on the differences in their spatial frequencies (HF filter and LF filter). The so-treated picture can be reconstituted and analysed.

— *Measurement of the yarn bulk through a diffraction process at Fourier's plane*: Another way to obtain the dimensional information consists in examining the picture of interference obtained in the focal plane of the lens. The distance between two rays depends on the inverse of the yarn diameter.

Among all these techniques, the most sophisticated solutions are those requiring information treatment in Fourier's plane. Such techniques are particularly simple to implement with laser sources. Yet, two remarks are to be made.

The first is that measuring the diameter does not really provide any information on the shape and bulk of the fibres. The second is that according to the bulk, the sensitivity and precision of the measurements are likely to be quite different based on the techniques that have been used for reading the luminous data. Recent research has shown an easy way for measuring interference fringes. This principle combines two identical sensors which have a fixed distance between them, in two perpendicular directions.

Each sensor comprises a variable slit. The yarn is shown centred in the middle of that slit. The whole yarn inserted in the slit generates two slits on either side of the yarn, hence producing a system of interferences. Based on the geometrical quality of the yarn, bands, alternatively bright and dark, are more or less well-defined but their frequency is a function of the inverse of the distance between those slits and hence from the diameter of the yarn. These slits, which are adjustable, make it possible to work in satisfactory conditions for reading the optical data.

Analysis of the fringes can be carried out directly through a scanning process of the interference picture or according to an optical process. The presence of fibres in the loose structure does not really affect the information being sought. Moreover, both sensors which are in two perpendicular di rections enable the processing of the shape of the yarn by means of inter-correlation functions, In such an arrangement of the sensor, the shape of the section is assimilated to an ellipse.

Twist

If the yarns were monofilament assemblies, the problem of analyzing linear structures would not be so critical. But, the fibres being entities of a few microns in diameter, have to be effectively combined so that the whole assembly can resist the different transformations and wear; this can be accomplished by introducing cohesion into the fibrous assembly. This cohesion determines the way the fibres are linked and indirectly their structure.

Two approaches can be envisaged for measuring the twist:

— A mechanical method which requires the destruction of the initial sample and is incompatible with on-line measurement. The other method, an optical one, lies on the hypothesis which states that, what generates the cohesion is maximum at the surface of the compact core and quantified by the angle of inclination of the fibres in relation to the axis of the linear textile. The sample size of the mechanical method can only be reduced below a certain threshold of one centimetre and a real twist is achieved.

— The method of diffraction at low angles is not ideal and does not provide the real twist but it is very significant because of its measuring principle without any contact.

Low angle diffraction

Paramonov proposes a fast technique to determine a the helix angle of the fibres. Based on the slow angle diffraction of a laser beam, it orientates a narrow beam at right angles to the yarn. The diffracted light is collected on a device set behind the yarn. The diffraction diagram can be seen in the form of a cross with,three branches. One component is due to the yarn, the other two are due to fibres orientations behind and in front of the yarn.

According to observations by Paramonov, it seems impossible to attribute the observed phenomenon to the diffraction of the fibres of the compact core. Conversely, the phenomenon helps if one is interested in the fibres which are peripheral to the compact core and these fibres represent only a small proportion of superficial fibres; moreover as they are marginal, it is doubtful that orientations represent compacted fibres.

This method does not aim at the light going through the fibres arrangement of the yarn but on the contrary to use it as a rough screen. The beam, which is very much focused, falls on the fibres of the superficial arrangement of the compact core. The beam is narrow enough to light only one or two fibres [diameter of the beam between 15 to 100 pm]. The lit fibres diffract the light which forms a reflection of a spot perpendicularly oriented to the lit fibres on the nearby fibres. Increasing the angle of inclination of this spot also means increasing the angle between the fibres in relation to the axis of the arrangement.

The analysis can also be carried out through a circular scanning of the spot, to determine the direction which actually shows a maximum intensity. Measurements performed in visible light on fibres that have been guided in black, show that even in extreme conditions the slightly reflected light still enables the angle of inclination of the fibres to be read. However, it is better to work in infrared light, for most dyes used in the textile industry are transparent in this field of the electromagnetic spectrum.

The previously defined method makes it possible to read the angle of inclination of the fibres in the yarn but does not make it possible to analyse the assembly which is resulting from several types of operations on yarns, such as simple winding. It is also important to know this microstructure that notably influences the estimation of the microstructure and which in itself is a major indicator.

This measurement is carried out by the same assembly as before, but, there is only the direct reflection component that is taken into account. The macrostructure generates a reflection which is more or less intense, as a function of the position of the reflection plane. The variations of intensity are analysed in frequency owing to the speed of displacement of the yarn and the intensity; the uniformity of the phenomenon can be calculated.

Hairiness

Measurement of hairiness is not new and has not yet been implemented on-line. However, the technique designed by Durand and marketed by Uster is a reliable means of measuring hairiness that can be reproduced.

Up until 1950, yarn hairiness was considered to be an insignificant characteristic, it was only in 1952 that the notion of hairiness coefficient appeared; this characteristic will become more significant as newer production technologies appear.

By observing a fabric made of spun yarn under low angle light, it can be noticed that certain numbers of these fibres escape the twisting process and populate the surface of the yarn, and hence the woven surface. If one has to identify these fibres, it can be noticed made of long ends of fibres greater than 1.2 millimeters and others that some of them and others yet which form loops. The shadow of the hairs on the surface of the fabric brings about an impression of darker nuance according to the lighting system that has been set.

The hairiness irregularity often results in an optical impression of irregular dyeing. This is why different means to evaluate the hairiness of the spun yarn have been sought after through electrostatic, gravimetric and optical methods.

The ideal sensor would make a distinction between the core of the yarn and the hairiness of the yarn. Now, physically, the function providing the cohesion can be seen through a compact fibres arrangement and the perturbation function by a loose fibres arrangement, the fibres being practically in contact with the air only. Placed in a luminous flow, the core of the yarn i.e., the compact arrangement, will stop the luminous rays proportional to the projection in that direction of the core of the yarn.

Conversely all the fibres belonging to the perturbation function will diffract quite a high proportion of light, while they will only stop a small amount of it. This is why we have opted for placing the yarn in front of a lens in a widened laser beam. The edges of each emergence behave like secondary light sources while the body of the yarn absorbs all the received luminous flow. By stopping (in the focal plane) the rays that have not been subjected to any interference with the yarn system, it is possible, by only considering the diffracted light, to reconstruct a picture in which only the fibres of the perturbation function will appear. So, the perturbation function and the cohesion function are simply split.

In the picture plane in which only the diffracting elements appear, the limit of length of the yarn samples can be extremely reduced or on the contrary very much widened. Practical conditions, however, limit the length of the yarn in the measuring field which is a function of the increase of the width of the sensor window. These constraints are connected to the spatial differences of energetic distribution of the laser beam, so that the reading can be performed with a good regularity, which implies a reduced reading space that is still sufficiently energetic.

In the measuring field, a given fibres produces a signal whose intensity is proportional to the tightness of the fibres in the assembly. At this stage, the luminous data are transformed into an electrical signal which spatially averages (in x,y) the information.

The use of the diffraction phenomenon enables the arrangement of superficial fibres to be well separated from the arrangements of the compact core fibres. This discrimination between the structures finally gives rise to results that are unquestionable and that can be reproduced. This principle resulted in a patent that has been taken up by a textile metrology equipment manufacturer and which has been sold throughout the world. The reliability of the measurement technique made this quantity credible so that the analysis of the hairiness phenomenon could be made clearer.

However, this credibility must not mask that the perception is only global and that many properties may be due to the shape of the fibres arches. Although an in-depth analysis of the structure may be of paramount interest, it is currently out of reach because, except for the global characterisation of structure, the distribution of the fibres length cannot be established. For this, it is therefore necessary to locate the beginning and the end of the fibres arches. Trials are currently being carried out in this direction by studying the angular distribution of the fibres ends.

Strength

As for the yarn strength, it isn't estimated. We can only know a threshold. Any fragility of the yarn which has a strength lower than the imposed stress brings about breaking, so the weak points must be eliminated.

Speed

Speed measurement is classical, but the techniques involve contact with yarns. The measurement is generally performed by a wheel carried by the yarn itself. Speed is limited by problems of breaking, inertia and contacts. New techniques are being developed.

Speed measurement by intercorrelation method

The principle that we have used requires two sensors which can evaluate the transit time by inter-correlating the random signals stemming from sensors. Generally the sensors can't be specified, a phenomenon with random fluctuations and carried by the yarn is only needed.

Two appropriate sensors detect the phenomenon in two distinct places. In these conditions, the random phenomenon fluctuations are supposed to be seen by the first sensor, and then by the second but with a delay that is a function of the transit time. The measurement problem is to estimate the delay between the two signals x(t) and y(t), that is to say $y(t) = x(t - \tau_m)$. The estimation τ_m of this delay can be achieved with the intercorrelation function that measures the similarity between two temporal signals.

Noncontact speed measurement on running thread using spatial filter

The basic concept of spatial filtering is to observe the natural irregularity of a moving object through an optical system and a set of parallel slits. This works as a kind of narrow-band-pass spatial filter that selects a particular spatial frequency component of the irregularity.

When the object moves, a narrow-band random signal with a central frequency is proportional to the running speed of the object. The speed of the object is then determined from the central frequency of the output signal. The error in estimating the central frequency, which is proportional to the speed, is about 2.0 percent for threads which exhibit an optical irregularity; the spatial filtering method is also applicable to the speed measurement of textile materials whose optical irregularity cannot be observed when the materials are sprayed with a substance like water, which do not change the quality of the material.

Tension

Measurement of tension seems to be perfectly controlled; however all measures are taken with contact between the sensor and the yarn and in limited spaces. The principles are always the same, a bending strain is imposed on the yarn and the stress is measured. The sampling lengths on the yarns cannot be controlled, and the high speeds, of the order of 1,000 m/min, require very high rotations of the sensor wheels; this gives rise to limits in sensor utilisation.

Fourier's analysis

This analysis consists in achieving a Fast Fourier's Transformation (FFT) of the signal. The principle of FFT is as follows: any g function can be analysed through a family of sinusoids making a convolution between g and each sinusoid with a specific frequency.

$$G = \int g(X)\, e^{-2i\pi rfx}\, dx$$

G(f) is a complex whose modulus has the dimension of energy. The G(f) spectrogram is defined as: $S(f) = 2\,|G(f)|$, pour $0 \leq f + \infty$. When the g function presents a periodic phenomenon of an f_0 frequency, the value of Fourier's transformation $G(f_0)$ has a significant energy, that is to say presents a maximum in f_0. Let us recall that in the textile field, spectrograms are not expressed in frequency waves but in wavelengths. The obtained spectrograrn in this way shows a peak for the wavelength of the defect and possibly on the harmonics. Five major categories of defect can be distinguished, to analyse weight regularity:

C1— periodic defects with sinusoidal variation

C2— periodic defects with a non-sinusoidal but symmetrical variation

C3— periodic defects with non-symmetrical and non-sinusoidal variation

C4— periodic defects shaped as an impulse with positive and negative components

C5— periodic defects shaped as an impulse with solely positive or solely negative components.

The FFT can only detect periodic defects; moreover it cannot locate in time the defect because of the use of infinite sinusoid in its calculation. So for example, if two distinct defects of the same frequency exist with a Fourier's Transformation, one single peak will be obtained with a corresponding frequency, and we cannot say if there are two defects.

If one is interested in using these parameters in spinning process, one should also have a detailed knowledge of the machines of the different spinning processes. Such a knowledge should also involve the different parts of each machine and even the influence between these parts in terms of defects. If one is interested in using these parameters in the weaving or knitting fields, one should perfectly master all the characteristics of the manufacturing process so as to be able to foresee the final aspect of one's item from the data of the yarn that one is going to use.

On the other hand, it would be desirable that one should be able to consult the statistics and the standards which can actually evaluate the quality of a yarn in relation to the world production of that category of yarn. These statistics enable the relative quality to be only roughly grasped but one therefore may know if the yarn can be located within the most regular yarns of that category.

At present, this kind of control makes it possible to monitor quality but not to control it. Because an actual quality control system must not only enable the quality to be evaluated but also to correct, if not in real time, at least relatively quickly, the causes of the off-quality; in our case, this means locating the different parts which have given rise to the variations of a parameter measured on the yarn so as to be able to intervene or foresee the behaviour of the yarn in the subsequent operations.

We can develop an equipment which provides interesting data on a theoretical level and it is quite possible for these data to be interpreted, but only after extensive work that cannot be carried out only within the frame of daily control.

In addition, owing to the multiplicity of the sensors, of the methods of analysis, and of the manufacturing processes and the increase of production speeds and to the increasing interest of controls in real time, the analysis and interpretation of all the parameters to be taken into account as well as the diagnosis of a manufacturing process should be effected with greater speed so that the expected quality can be achieved.

Classical computing programme (CCP)

Classical computing programme (CCP) propose the same solution as the individual for the same spectrogram. Yet, there isn't one single type of defect nor one single cause for the defect. So one is capable of giving another interpretation or questioning the previous interpretation for another spectrogram. From a data processing point of view, this results in a programme for each interpretation or a programme that takes all possible interpretations into account. In the latter case, the increase of the programme is in 2^n being the number of independent tests which are necessary to model all cases. In this CCP, knowledge being the body of the programme is frozen, i.e., any modification of such a knowledge requires the source code of the programme to be modified, then compiled again.

Expert system

An expert system is a software meant to replace or assist anybody in fields where there is a significant human expertise, subject to be revised or complemented according to the accumulated experience. Such a system allows:

i) to capture easily the know-how units, i.e., to facilitate most directly the expression of the rules in relation to the way they appear in the expert's mind.

ii) to exploit all the units of know-how, i.e., to combine and/or to chain the groups of rules to infer different types of knowledge such as evaluations, plans, proofs, decisions, predictions, new rules, etc. and often to report how the new types of knowledge have been inferred.

iii) to enable the whole set of units of know-how to be very easily revised, i.e., to offer facilities for rules to be added or suppressed.

An expert system can be split into three parts:

i) a knowledge base which groups the knowledge pertaining to a field of application, and which splits up into two parts: a base of facts, which are the actual system data, and a base of rules which comprises the operational knowledge of the considered field;

ii) an inference engine, which is roughly a didactive computing mechanism whereby the order of execution of the rules which are contained in a base of knowledge can be arranged at will;

iii) a dialogue interface with the user.

We shall now study the evolution costs of both solutions that have been presented to replace our individual. We shall envisage four possible extensions and compare the advantages and disadvantages of CCP or ES in each case.

— *Modification of an already programmed knowledge solution CCP*: The body of the programme has to be modified. For example, if a solution is added (one independent test) to n others, 2^n tests will no longer be adequate but 2^{n+1} tests will be needed. It can be seen that this modification is costly not only in time but also in money because the evolution of the programme is exponential.

  Solution ES: Rules are added or substracted in the existing base of rules without modifying the body of the programme.

— *Interpretation of a new sensor: Solution CCP*: A new programme modelising the interpretation of this new sensor must be conceived as well as a third programme allowing to take this new sensor and the already existing sensor into account. In this case, a problem of memory may arise, for the resulting programme involves $2^n + 2^m$ cases. Some cases which are useless when the modification occurs, can be cut off. But the latter unfortunately may prove indispensable during a further modification which, then, will be more difficult to effect.

  Solution ES: The body of the programme remains the same. A new base of rules modelling this new sensor can be created, and so we have two islands of knowledge in the resulting base of rules, one for each sensor. Both islands need not be loaded simultaneously in memory because they can be successively loaded, which doesn't pose any memory problem.

— *Intercorrelated interpretation of several sensors: Solution CCP*: If the interpretation of two sensors are to be intercorrelated, as the modeleine of each sensor respectively comprises 2^n and 2^m tests, 2^{n+m} cases must be considered. This number may become considerable, and in this case the limits of a CCP begin to appear.

  Solution ES: For the interpretation of two sensors to be intercorrelated, an island of knowledge is created which takes the results provided by these islands of knowledge for each sensor into account. Here again the simultaneous presence of three islands is not compulsory, therefore no memory problem arises.

— *Discovery of an algorithmic model*: Currently, the interpretation of a sensor is empirical. But a significant progress of the modelling of a textile yarn might lead to an algorithm in the classical sense of the word to interpret a sensor.

  Solution CCP: In this case, the knowledge becomes an algorithm and so it is very easy to programme it.

  Solution ES: Programming such an algorithm with an expert system is not very interesting because of the complexity of the programming operation and because of the time of execution. Yet, an expert system can use a classically programmed algorithm: the island of knowledge is replaced by a single rule which triggers off the algorithm. In this case, if the expert system is considered to be useful, it is often necessary to adjust some parameters for the algorithm to work at its best.

The ES solution is extremely flexible without being too expensive. So it is not difficult to imagine that the company which sells this type of system will be able to provide updated copies of the system every year, which in fact are an enrichment of the knowledge base of the ES. Moreover, such a solution makes any sort of knowledge to be modelled: algorithmic, deductive, intuitive, heuristic, quantitative or qualitative. Finally, an ES can also use the data from other fields of artificial intelligence like neural networks or fuzzy logic. For example, it may be possible to grasp the shape of the spectrograrn thanks to a neural network and then to transfer this elementary knowledge into an ES. To conclude, the ES solution seems to be best adapted to carry out a diagnosis of the yarn, from data obtained from the sensors.

Knowledge based system

An overview of the working of the software is as follows: first, a signal stemming from the weight regularity sensor is received by the software; second, the user must define the yarn manufacturing process, and if necessary, the test conditions; then, the software detects the defects on the weight regularity signal and suggests their possible causes. At present the defect detection on the yarn is based on Fourier's analysis, but other kinds of analysis can be used. The signal treatment module receives the weight regularity signal and, using Fourier's transformation, one class is allocated to each defect. The defect, and some information about the testing yarn and its manufacturing process are passed on to the interpretation module which then proposes possible causes for each defect.

The storage in memory of the signal, the defects and their real causes, is planned for the manufacture. This software needs to assist humans. This implies two things: the software must contain the present knowledge which permits the evaluation of yarn quality and defects and it must be able to pick up new sets of knowledge. Human knowledge is varied, it can be intuitive, and it is based on quantitative, qualitative and heuristic notions. Then the software will have to be able to accept all types of knowledge.

Macintosh Pascal Lisa Object has been used to develop this software to take as much advantage of the graphical resources of the Macintosh environment. In addition, such a language can be well interfaced with the C language which is the programming language of Nexpert's libraries. Nexpert is the expert system generator used for our prototype. We have chosen to use Nexpert only to process the part devoted to analyzing the defects and using a classical programme for whatever may be introduction or display of the data: There may be an analyzing signal, a process to be defined, results to be displayed. This has numerous advantages.

It is the CCP that controls the coherence of the data used by Nexpert, which considerably alleviates the base of rules. Moreover this solution enables our interfaces to be created so as to use a friendly environment. Our software is therefore a CCP with Nexpert only as a sub-progamme. Object-oriented programming offers several advantages, so that different parts will be functionally well split. Each object has a well-defined functionality and the links between the different objects constitute the framework of the programme.

Furthermore, the programme tolerates a lot of signal-type documents, process-type documents, screen result documents if the memory contains enough space to store everything. So, for the same process several signals can be analyzed, or for one single signal several processes can be proposed, and the results of each analysis can be seen in a different resulting document. Later on, a data base has been planned for addition to the system, so that the history of the defect, signals, statistical data, the characteristics of the machines, and the badly identified defects can be stored.

The main difficulty which came up during the implementation of this module has been looking for the fundamental wavelength and the harmonies. First of all a criterion meant to locate the energy peaks associated with a fundamental wavelength had to be defined. Then an algorithm had to be designed with a parameter of degree of tolerance in frequency and energy to detect the harmonies associated with the fundamental wavelength. However, all the ambiguities have not been removed and when the system hesitates between two types of defects for a detected defect, it creates two defects with the same fundamental wavelength but of a different type. It is up to the expert system to remove the ambiguity.

The weight regularity signal is noisy. This noise can be decomposed into two noises of different origins: a measure noise, and a noise due to the random distribution of the fibres within the yarn. Currently, the two noises cannot be separated.

Models for the theoretical distribution of the fibres in the yarn exist, but it is essential to know which case actually comes up for each test. In this field, statistical studies are to be done. It is possible, when such studies are conducted, to create an island of knowledge which, according to the qualitative and quantitative criteria, will choose the noise model to be applied; the purpose of the system being either to filter this noise by computer, or to evaluate its power in relation to the power of the pure signal of weight regularity. Because of the noise, the detection of defects is semiautomatic because it is necessary to pre-adjust the various filter to try to eliminate this noise without eliminating too much significant information contained in the signal.

Interpretation module

Interpretation module consists of an expert system generated with the help of Nexpert Object software and interfaces. We will first see the data in the knowledge base and then the different options which make it possible to achieve this knowledge base for weight regularity. To propose a set of possible causes, that are at the same time coherent and limited, human experts go through successive filtrations to eliminate infeasible solutions. Using the classes of defects that can be identified from the spectrogram as the basis, it is possible to find the possible causes for a class of defects; then the possible sources in the manufacturing process can be identified based on the existing machines and the wavelength of the defect.

These machines constitute a M set which in fact is the intersection of the two following sets:

i) the set of all the machines which can contain the component which actually generated the defect,

ii) the set of the existing machines in the manu-facturing process of the tested yarn.

At this stage, causes associated with machines can therefore be proposed for a defect. But the wavelength of the defect has not yet been taken into account. Now this can reduce M set to a M' set of machines whose wavelength intervals of the defect they generate are compatible with the wavelength of the considered defect. To achieve this new filtering operation, one has to know: the intervals of the wavelength of the defect that can be generated for all the spinning machines and for each machine, the draft between the input and the output of the machine so as to successively correct the wavelength of the defect by different drawing operations of the machines that are not concerned.

Nexpert object: Nexpert object is an expert system generator, i.e., it supplies the inference engine, the user's interface and a set of controls, whereby a knowledge base can be created. In addition, the created knowledge base and the supplied inference engine can be integrated is an independent application.

Knowledge base: Knowledge base is a model of the specific knowledge of the application field. It comprises a base of facts and a base of rules.

Base of facts: Base of facts are a set of assertional knowledge used to describe the considered situation either as established, i.e., true, or to be established, i.e., facts that are looked for which there are hypotheses. So, the rules to be exploited can be conditioned and achieved.

In Nexpert, the structure which groups the set of facts is composed of objects and classes, each object or class having properties. A fact can then be defined as a specific property of an object or of a class. All the objects and classes together are called the world of objects.

Nexpert proposes two structures as far as the world of objects is concerned:

i) either a flat world in which all the objects are independent, This world enables a simple reasoning to be performed but we will see later that the performance is poor.

ii) or a hierarchical or genealogical world in which each object or class can be the child or the father of one or several other objects or classes. This world has an oriented graph structure.

Various types of inheritances are possible between the elements which constitute the base of facts:

i) property inheritance: an object can inherit properties of the class or of the object it is the son of,

ii) value inheritance: an object can inherit the value of a property of the class or of the object it is the child of;

iii) method inheritance: for each property of a class or of an object, actions can be defined to be triggered off in relation to the value of this property, these actions can be inherited.

Base of rules: Base of rules are a set of operational knowledge which represents the knowhow of the considered application field. They indicate which consequences are to be triggered off and/or which actions to be carried out when a situation is established or is to be established. The rules are interconnected by their hypotheses and the whole set of rules builds up a graph which can be displayed.

The base of rules has a tree structure. This structure highlights the backward chaining in relation to the forward chaining, but the latter remains possible. So, suggesting hypotheses and validating values can be proposed for some properties and this makes it possible to operate the inference engine by changing at will the initial state of the base of knowledge and of the pile of hypotheses to suggest.

Inference engines. It is a deductive computer system which exploits the knowledge of the previous base by considering them as data and therefore as different types of knowledge which are likely to be changed. There are three types of actions on the knowledge base;

i) checking and/or questioning the validity of the knowledge; (ii) reaching the knowledge;

iii) triggering off specific actions according to the state of the knowledge; in general this entails modifications of the knowledge base, particularly in its 'facts' part, but sometimes in its 'rules' part.

Nexpert inference engine functions in mixed chaining. It can be noted that the latter also comprises two sorts of forward chaining systems:

i) A forward chaining which is due to the modifications of the value of the data. When the value of data changes, Nexpert looks for all the rules; this fact is a condition to evaluate them.

ii) A forward chaining which is pertinent to the hypothesis; when the value of H1 hypothesis has been determined, H2 hypothesis can be evaluated if it belongs to the H1 context even if H1 is not a condition of a rule that leads to H2.

Processing modes of the rules, through backward chaining, forward chaining or mixed chaining, have only a partial influence on determining the chaining process of the rules. In fact, one or the other classical strategies to develop the search can be superimposed on the releasing mode of the rules: in depth-first strategy, in breadth-first strategy, in ordered search strategy. Nexpert offers different strategies:

i) according to the case, one can opt to use only the forward chaining or only the backward chaining during the evaluation mechanism sequence of the hypothesis;

ii) to establish the value of an hypothesis, all the rules leading to it can be evaluated, or the rules leading to this hypothesis can be evaluated until a true one can be found;

iii) in forward chaining pertaining to the hypothesis, the value of truth of the hypothesis enables its context to be taken into account.

Developed expert system typically functions as a backward chaining system. This has many advantages: several causes can be proposed for the same defect; and it is not necessary to ask the user the same question twice.

Four

Theoretical Basis of Spinning

In technological analysis of spinning, there are three fundamental equations are derived from the conversion of energy, the conversion of momentum and the conversion of matter, respectively. Here, for simplification, the two differential operators are defined as follows:

$$\nabla \cdot = i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z} \tag{1}$$

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + V_x\frac{\partial}{\partial x} + V_y\frac{\partial}{\partial y} + V_x\frac{\partial}{\partial z} \tag{2}$$

where t is the time, (x,y,z) the spatial co-ordinates, V(Vx,Vy,Vz) the velocity of polymer, and *i, j* and *k* are the unit vectors in the *x, y,* and *z* directions, respectively.

Consider an arbitrary small-volume element d*v* fixed in space along the spinning path and an enthalpy change in the element. The fundamental equation for conservation of energy can then be derived.

We assume that the thermal conductivity of the polymer K_c is independent of temperature *T*. The net inflow of heat in unit time conducted through the *xy*-plane into the element, the centre of which is located at (x,y,z), is expressed as

$$\left(K_c \frac{\partial T}{\partial z}\bigg|_{z+dz/2} - K_c \frac{\partial T}{\partial z}\bigg|_{z-dz/2} \right) dxdy = K_c \frac{\partial^2 T}{\partial x^2} dxdydz \tag{3}$$

Accordingly, by summing such quantities for all the three directions, heat transferred into the element in unit time is

$$Kc\nabla^2 T d\nu \quad (\nabla^2\text{: Laplacian}) \tag{4}$$

For the polymer, the specific heat at constant pressure, the heat of crystallisation, the crystallinity and the density are expressed as C_p, ΔH, X and ρ respectively. We assume that C_p, and ΔH are independent of T and that the enthalpy per unit mass (H) is a function of T and X.

Accordingly, by summation of such quantities for all the three directions,

$$-\nabla.(\rho \; HV)d\nu \tag{5}$$

Using the equation of continuity $\partial R/\partial t = -\nabla.(\rho V)$.

$$-\nabla \cdot (\rho \; HV)d\nu = H\frac{\partial \rho}{\partial t} - \rho V \cdot \nabla H \tag{6}$$

While considering conservation of enthalpy within $d\nu$

$$\frac{\partial(\rho H)}{\partial t} = K_c \nabla^2 T + H\frac{\partial \rho}{\partial t} - \rho V \cdot \nabla H \tag{7}$$

Since $\partial H/\partial T = C_p$and $\partial H/\partial X = -\nabla H$,

$$\nabla H = C_p \nabla T\text{-}\nabla H.\nabla X \tag{8}$$

Substitution of this relation into equation 7 gives

$$\rho\frac{\partial H}{\partial t} = K_c \nabla^2 T - C_p \rho V \cdot \nabla T - \rho \Delta H V \cdot \nabla X \tag{9}$$

For the steady state, equation 10 becomes

$$\frac{D\rho}{Dt} = -\rho \nabla \cdot V \tag{10}$$

where $k = K_c/(\rho\ C_p)$ is the thermal diffusivity Generally speaking D/D*t* can be regarded as V.∇.

$$\Delta . V = 0 \tag{11}$$

The following equation is derived on the basis of the balance of the matter which flows into the volume element.

$$\rho \frac{DV}{Dt} = -\nabla P - [\nabla \cdot p] + \rho g \tag{12}$$

Assuming that the polymer is not a compressible material,

$$[\nabla \cdot p]_x = \frac{\partial p_{xx}}{\partial x} + \frac{\partial p_{xy}}{\partial y} + \frac{\partial p_{xz}}{\partial z} \tag{13}$$

Conservation of momentum

Based on the balance of the momentum which flows into the volume element the following equation is obtained

$$X = 1 - \exp\{-\textstyle\int_0^t K(T, \Delta n)dt')^n\} \tag{14}$$

where P is the pressure, in a normal sense, of isotropic fluid, p the excess stress tensor and g the acceleration of gravity. [∇.p] is a vector, and, for example, one of its components is expressed as

$$D\Delta n/Dt = (\Delta n_{st} - \Delta n)/\tau \tag{15}$$

Under the assumption of non-compressibility, P has no physical meaning, but will be determined by the boundary condition. When the spinning direction is chosen as the z-axis, the quantity, $P_{zz} - P_{XX}$, corresponds to the tensile stress.

We must take account of constitutive equations (rheological equations), equations of crystallisation kinetics, the equation concerning molecular orientation (birefringence Dn) and the thermodynamic equation of state. Before turning to the discussion of each of these equations, we shall direct our attention to the number of unknown variables and of equations. The important equations governing the boundary conditions are the equation of thermal conduction on the surface of filament and that of air resistance. Various complicated formulae have been proposed so far as constitutive equations which relate the excess stress tensor p to the thermal and deformation history. The simplest example is Newton's equation of viscosity.

The nucleation rate of polymers at a constant temperature is greatly accelerated by molecular orientation. For the present, however, there is no general formula expressing the quantitative relation between the crystallisation rate and molecular orientation.

Furthermore, the crystallisation under molecular orientation may be different from ordinary unoriented crystallisation, which is expressed in terms of the nucleation rate, the growth rate of the nucleus and the mode of geometrical growth. At any rate, the process of structural change in oriented crystallisation has never been clarified.

If crystallisation kinetics are described in the form of the Avrami equation, $X= 1— \exp(—K,At^n)$, with increasing molecular orientation the rate constant K_A increases rapidly and the Avrami index *n* decreases to unity or even below. In reality, the Avrami equation applies only in the early stages of crystallisation.

In addition, it should be noted that secondary crystallisation becomes prominent in the advanced stages of crystallisation. Adopting the birefringence Δn (or the tensile stress σ) as a parameter relating to molecular orientation, we can tentatively express the rate constant of crystallisation K_A at a constant temperature as a function of T and Δn.

Nevertheless, there still remains a question of how to utilize the corresponding data for describing non-isothermal crystallisation. Though we have no approved answers to this question, the following expression for the crystallinity X can be adopted without any gross errors.

$$X = 1—\exp\{-\int_0^t K(T, \Delta n)dt')^n\}$$

where the equation for kinetics of isothermal crystallisation is expanded into the case of non-isothermal crystallisation and the relation, $K(T, \Delta n) = \{K_A(T, \Delta n)\}^{1/n}$ is assumed. Equation 16 is an integral equation which describes X using the history of T and Δ n (namely, σ).

An experimental linear relation between the birefringence A n and the tensile stress a during spinning has been reported for small $\sigma(\sigma<3\times10^7$ dyne/cm^2 for polyethylene terephthalate [PET]). This is easily understood because the theory of rubber elasticity has definitely proved that σ/KT (K is Boltzmann's constant) is directly proportional to Δn for small a (Gaussian chain approximation). In the case of high speed spinning, however, we must take account of the relation between Δn and σ for large a because a readily reaches up to 10^8 -10^9 dyne/cm^2.

While a can approach infinity, Δn has its maximum value defined by the intrinsic birefringence Δn_{in}. Hence, with increasing σ, the rate of increase of Δn decreases and Δn itself approaches a constant value. Ziabicki and Jarecki obtained a numerical relation between the value of Δn in the steady state (Δn_{st}) and σ/KT for Langevin chains. The above applies to steady-state flow but the spinning process is in the non-steady state in terms of molecular orientation. Thus, Δn is always smaller than Δn_{st}.

Assuming a single delay time τ,

$$D\Delta n/Dt = (\Delta n_{st} - \Delta n)/\tau \qquad (16)$$

then through σ/KT, Δn_{st} is a function (and through T, τ is a function) of position and time.

Solution spinning

In dry spinning, fibre structure is formed by forcing the polymer solution out through a fine nozzle and then evaporating the solvent. Accordingly, dry spinning can be treated as a problem of structure formation in a two-component system of the polymer and its solvent.

Technological analysis of the dry spinning is, therefore, much more difficult than that of melt spinning which is treated as a problem of structural formation in a one-component system. An equation of diffusion for a two-component system is needed to describe structure formation within the filament, and an equation of evaporation rate of the solvent at the boundary between two phases is also needed on the surface of the filament.

Moreover, some equations used in the mathematical treatment of melt spinning should be modified to apply them to dry spinning.

Wet spinning

In wet spinning, where a solution of the polymer is forced out through a nozzle into a non-solvent for the polymer, mass transfer for both the solvent and non-solvent must be considered. Technological analysis of wet spinning is, accordingly, much more complicated than that of dry spinning. In a spinning process accompanied by chemical reactions, quantitative analysis is almost impossible. As for the spinning process without any chemical reactions, the phase diagram using triangular co-ordinates for a three-component system of polymer (P), solvent (S) and non-solvent (N) can be drawn.

In this case, it is the ratio F_N/F_S of the flux of solvent from the filament into a spinning bath (F_S) to that of non-solvent from the bath into a filament (F_N) that determines which path is followed on the phase diagram in the process of fibre formation.

Structural formation

Structural changes in the spinning process, crystallisation, gelation, and phase separation, are discussed here. Crystallisation arising from the state of molecular orientation in a polymer solution, melt or amorphous solid is termed 'oriented crystallisation'.

Crystallisation during spinning is a typical example of oriented crystallisation. Structure formation in oriented crystallisation is of great interest because it is a phenomenon reflecting the nature of the macromolecule. Since the 1960s, studies on oriented crystallisation have been carried out extensively and the publications so far are too many to mention. Of all these studies, that of flow-induced crystallisation of polyethylene in particular attracted researchers' attention.When polyethylene is crystallised from solution by stirring the solution, what is called the shish-kebab structure is formed.

The following are general features of oriented crystallisation:

— The morphology of the crystallized materials changes according to the degree of molecular orientation.

— With increasing degree of molecular orientation, the temperature which gives the maximum rate of crystallisation goes up and, in some cases, the maximum rate itself also increases by several orders of magnitude.

— The mechanism of oriented crystallisation may be very different from that of non-oriented crystallisation.

The knowledge that we have so far acquired of structure formation from oriented melts of flexible polymers is summarized as follows:

— In advance of crystallisation, a spatial non-uniformity of density occurs. A domain with higher density has a rod-like shape elongated along the direction of molecular orientation. The diameter of the domain depends strongly on the degree of molecular orientation and decreases with increasing degree of orientation. The domain, generally speaking, is of a size which can be seen with a light microscope.

— Within such a domain, density fluctuations on a scale of several tens of mn occur within a stacked lamella-like structure in which constituent 'lamallae' are developed perpendicularly to the direction of molecular orientation. The fluctuation can be detected by meridional small-angle X-ray scattering. At this stage of structure formation, wide-angle X-ray diffraction from the crystalline state is still not observed. In conclusion, there exists a mesomorphic state during transformation from the amorphous state to the crystalline.

— In the shish-kebab structure and the row structure (a structure showing an appearance like a Japanese mat, 'tatami'), crystalline lamellae are stacked in the direction of molecular orientation. Such morphology was interpreted by Keller and co-workers as a structure consisting of folded-chain lamellar crystals grown epitaxially on a long and slender nucleus composed of extended chains. Row structure, however, can readily emerge even from very weakly-oriented melts, and in a thin film of the polymer we can observe many nuclei which are aligned in a line in the rod-like domain. It is, therefore, presumed that the concept of a nucleus composed of extended chains would be a product of too extreme modelling. We should rather venture to say that the characteristic of structure formation in oriented crystallisation is that oriented nuclei are apt to align themselves in a line. In thin films crystallized under molecular orientation with a rather high degree of orientation, however, a crystalline domain of about 200 nm in length and about 15 nm in width was identified by high-resolution electron microscopy as a domain in which lattice fringes are observable.

Non-uniformity of density generated in a polymer system which was already deformed or is now being deformed mechanically has been noted recently and termed stress-induced phase separation. In this regard, an interesting result of simulation has been reported.

A state with different strains which depend on the position is given as an initial condition and the process of strain relaxation with time is simulated on the basis of dissipative molecular dynamics. As a result of such simulation, the existence of a metastable state is predicted, in which expanding and contracting phases coexist.

If we regard the polymer melt as a gel in which the points of entanglement appear and disappear temporarily, we can understand the fact that in the relaxation process of a system deformed by elongational flow, there exists a metastable state which has spatial non-uniformity of density.

Gelation

Studies on gelation and phase separation of polymer systems have flourished. According to experiments on a polyvinylalcohol (PVA)-water system by Komatsu *et al.* the solgel transition curve intersects the SD (spinodal decomposition) curve, and the phase diagram is partitioned into four areas:

— Area corresponding to a homogeneous sol state.
— Area in which liquid-liquid separation takes place due to SD but gelation does not occur.
— Area in which gelation takes place due to SD.
— Area in which gelation takes place without any liquid-liquid separation.

The molecular orientation induced by the flow of such a solution, needless to say, shifts these curves. In dry spinning of the system in question, the path which the system follows on the phase diagram changes according to the spinning conditions and consequently the mode of structure formation and the structure itself in the spun filament will vary.

Structure of fibres

The fibre structure in commercial fibres has been investigated by transmission electron microscopy (TEM), scanning electron microscopy (SEM), X-ray diffraction, and so on.

Polyethylene (PE)

The specimen was prepared by stretching a thin film of PE spread on the surface of hot water and thereafter annealing it at 126°C The fibre structure of PE has two faces of lamellar and-fibrillar structure. In ultra-drawn films/fibres of ultra-high molecular weight PE, one face the lamellar structure, is lost and the other face, the fibrillar structure, having a great number of tiecrystallites, is enhanced.

Rigid chain polymers

Rrigid chain polymers are commonly produced by solidifying their liquid crystalline domains, in which extended chains are aligned parallel to each other, with all chains being oriented uniaxially owing to elongational flow working on the domains.

Poly (p-phenytene terephthalamide) (PPTA)

A Kevlar fibre was annealed at 400°C under the condition of constant length, and then fibrillar fragments were obtained by tearing them off from the fibre. The fragments thus prepared were used as specimens for TEM.

High-speed melt spinning

High-speed melt spinning has been proposed and developed as an attempt to produce highly oriented filaments by a single-stage process without any drawing after spinning. Since a commercial winder with a take-up speed of about 6000 m/min became available in the latter half of the 1970s, studies on high-speed spinning have been greatly advanced.

The features of high-speed spinning are as follows:

— Polyethylene terephthalate (PET) does not crystallize appreciably in normal melt spinning, but does at a spinning speed of about 4000 m/min or more.

— An abrupt necking-like change of diameter of the filaments during high-speed spinning is recognized and closely related with crystallisation.

— The resultant spun filaments have a skin-core structure: the skin region is highly oriented and crystallized, but the core region has weak orientation and low crystallinity.

— The spun filaments have rather high extensibility, and accordingly are utilized only for special purposes.

— A spinning speed of 7000 m/min or more lowers the quality of spun filaments.

The necking point moves up and down within certain limits, and that crystallisation hardly occurs at all before necking, but increases very suddenly at the onset of necking. The real cause of this necking phenomenon is not yet known. One idea of the cause is based on the time dependence of elongational viscosity. The structural change due to elongational flow has a complex influence on the viscosity, such that the viscosity depends on the strain itself as well as on the strain rate. Hence, it might be deduced that the viscosity reaches its maximum during the spinning process and this triggers the neck formation. On the other hand, another view that such a maximum might be due to experimental error and cannot exist has also been presented.

A second idea as to the cause of necking is the following. It was experimentally reported that when the ratio of elongational viscosity to shear viscosity exceeds necking occurs. According to this result, we can say that necking takes place when elongational strain attains a certain magnitude during spinning. A third idea comes from attention to the structural change which occurs before oriented crystallisation. That is to say, the system itself is transformed into another state in which necking can readily take place.

Five
Spinning Methodology

Gel spinning

Gel spinning is a spinning method for high strength fibres through a gel-like state as intermediate substance. In spinning process for ultra-high strength polyethylene fibre (UHSPE), all the technical points are dedicated to reducing macro- and micro-scopic defects to produce an ideal fibre of nearly 100% crystalline structure composed of molecular chains almost perfectly oriented in the fibre direction. The reason why gel spinning has succeeded first with polyethylene may be explained by the following properties of that polymer:

— The highest values of theoretical tenacity and modulus among flexible polymers.

— A simple planar zig-zag chain structure without any bulky side group.

— High crystallinity.

— Lack of high inter-molecular weight polymerisation.

— Availability of ultra-high molecular weight polymerization interaction, like hydrogen bonding.

The degree of polymerization is the most important property. In gel spinning, ultra-high molecular weight polyethylenes (UHMwPE) having a weight average molecular weight above 600000 g/mol are used. The reason why such high molecular weight is necessary is believed to be as follows: supposing the perfect orientation of all molecular chains the chain ends still remain as defects these defects will act as the starting point of micro-crack formation which causes lower tensile properties. According to another argument an ultra-high molecular weight itself does not directly contribute to tenacity, but higher molecular weight is necessary for the drawing, in order to support the drawing force through entanglement points.

Although the molecular weight of PPTA fibres is in the low 10000s, much lower than that of polyethylene, they still possess high enough strengths and moduli. In the case of paraaramid fibres, the chain orientation is mainly due to the liquid crystalline property derived from their rigid molecular chains, therefore the high molecular weight of PE is not necessary. The effect of molecular weight on the final properties will be discussed in the next section in conjunction with the effect of concentration.

Although successful direct melt spinning of UHMwPE under the critical process window has recently been reported, generally melt spinning of UHMwPE is impossible. These polymers possess a very high number of chain entanglements per molecule, caused by their very long molecular chains; these long molecular chains cannot pass through each other in the time scale of the drawing deformation.

Therefore, they exhibit extremely high melt (shear) and elongational viscosities, which limit the processability of UHMwPE. Essential to the formation of high strength fibres is control of this entanglement. In gel spinning, the entanglements are controlled by employing two concepts. One is dilution in an appropriate solvent, and the other is morphological control through the crystallization process. Various solvents, such as tetralin, decalin, naphthalene, mineral oil, paraffin oil and paraffin wax, have been reported for gel spinning of UHMwPE.

From the viewpoint of defect reduction, since entanglement itself behaves as a defect, one entanglement per chain should be enough to transfer the drawing stress between chains. This condition will be achieved at a critical concentration (C*) at which the random coil chains composed of single molecules begin to overlap each other. C* can be formulated as a function of the average molecular weight (M)

$$C^* \propto Me/M \quad (1)$$

where M_e is the molecular weight between entanglement points. As expressed in this equation, the ideal (critical) concentration (C*) becomes lower with increase of M. In other words, this low concentration, like C*, will permit ideal molecular drawing of UHMwPE up to the theoretical maximum draw ratio. If one postulates the drawing of a single molecule from its random coil state, the maximum draw ratio can be obtained from the following equation

$$\lambda_{MAX} = cM^{0.5} \quad (2)$$

where c is a material constant. As expressed by this equation, the maximum draw ratio increases with the molecular weight (M). If the drawing of UHMwPE gel-like fibre is performed under such ideal concentration conditions, the above argument will be reasonable. However, process economics require that the actual spinning should be conducted at a much higher concentration (C>C*). This region is a 'semi-dilute' or 'concentrate' state in terms of solution rheology.

Recently, Bastiaansen has reported on the maximum draw ratio of gel-like fibres as functions of both concentration (C) and molecular weight M and formulated in equation 3.

$$\lambda_{MAX} \propto cM\text{-}0.5\ C^{-0.5} \quad (3)$$

Contrary to equation 2, the maximum draw ratio decreases with increase of the molecular weight and concentration. This can be explained by an increase of entanglement number. Therefore, as low a concentration as possible is preferable for higher drawability (C- C*). Theoretical and experimental C* values for ultra-high strength polyethylene having molecular weights above 1000 000 g/mol have been reported to be 0.5-0.7 Wt%. In the actual industrial process, the optimum concentration and molecular weight are defined.

The entanglement points of semidilute or concentrated solutions can act as permanent cross-link points even after being solidified. For a lower molecular weight polymer like conventional polyethylene, the higher number of chain ends can easily pass each other through the entanglement point to produce a high level of so-called disentanglement during the drawing process, which makes the orientation of lower molecular weight polymers very difficult, because disentangled chain ends are likely to relax to the random coil state. This is why ultra-high molecular weight is necessary for ultra-drawing of UHSPE. Even with UHMwPE, the disentanglement possibly occurs during the spinning process due to crystallization, which reduces the entanglement number to some extent. This mechanism allows production of UHSPE even at much higher concentration.

Although equation 3 was obtained under ideal drawing conditions, i.e. with an extremely low drawing speed, in actual industrial processes, which require much higher drawing speeds, the dominant factor for the maximum draw ratio will be quite different. In high-speed drawing processes, the viscoelastic properties become more dominant, i.e. the extremely long relaxation time of UHMwPE affects drawing performance.

Dissolution process

A relatively high-concentration polyethylene solution must be prepared as uniformly as possible, because any inhomogeneity will remain as a defect in the final fibre structure and reduce the final mechanical properties of the fibres. Near the melting point, a remarkable viscosity rise and the so-called Weissenberg effect are observed, and both result in inhomogeneity of solution concentration.

Furthermore, once the dissolved polymer forms a gel-like solution, the heat transfer coefficient of that gel-like solution decreases remarkably, and this also causes an inhomogenous temperature distribution locally within the solution. To avoid this problem, various dissolving methods have been reported, including the use of a screw-type extruder, pouring hot solvent on to partially swollen polymer, and forming gel-spherulites.

Spinning process

From the viewpoint of the spinning process, understanding the rheological properties of UHMwPE solution is of first importance. However, due to the difficulty of UHMwPE polymer characterisation, not many articles have been published on the rheological properties of UHMwPE solution. The fundamental rheological constants of UHMwPE solution obtained by a capillary type viscometer are compared with those for melt spinning conventional PE and PET, under typical spinning conditions for each polymer.

In this rough comparison, the characteristic feature of UHMwPE solution can be summarized as its rubber elastic property; UHMwPE solution shows a combination of lower shear viscosity and shear modulus than expected from its molecular weight, and shows a much higher relaxation time, conventionally obtained from the ratio of shear modulus (G) and shear viscosity (μ).

This higher characteristic relaxation time causes a so-called memory effect of UHMwPE solution which means the memory of the stress applied earlier in the process at the inlet part of the spinneret hole, which affects the rheological response later in the process. Therefore, careful design of the polymer flow, especially in the spinneret, is required. Over a wide range of applied shear rate this solution shows unique non-Newtonian behaviour. This solution property causes inhomogeneous distribution of viscosity at each local flow point.

Careful design of the spin-line, especially the spinneret, is necessary. At lower spinning speed, the extruded solution exhibits quite large die-swell, which is related to the highly elastic property of UHMwPE solution. With increasing spinning speed, the size of the die-swell become smaller due to the stretching under the spinneret, and at much higher spinning speed, a so-called 'pull-out' phenomena can be observed up to filament breakage, where the solution completely loses its die-swell and may even peel off from the inside wall of the spinneret capillary. This typical feature may also explain the combination of higher elongational strength of the solution and its highly elastic properties.

The characteristic feature of UHMwPE solution is its non-Newtonian and highly elastic property. One of the main technical points of UHMwPE gel spinning is the flow management of such a highly elastic solution.

Crystallisation

During this crystallization process, some part of the entanglement is considered to be lost because the entanglement points cannot be incorporated in the crystal and the chain will be disentangled before crystallization. Hence, disentanglement due to crystallization can be anticipated and this is another technical point for the success of gel spinning even at high concentration. Recently, Pennings *et al.* reported the high speed spinning of UHMwPE solution, and a remarkable tensile strength value of 26g/d at a spinning speed of 1000m/min without further drawing.

More effective disentanglement might happen during the spinning process, i.e. disentanglement due to spinning stretch. An investigation of the structure development mechanism during crystallization of UHMwPE solution may be worthwhile. Through the crystallization process, the solution is solidified into a more rigid gel-like structure having dispersed crystallites connected by a small number of entanglements remaining as pseudo-crosslinking points.

Drawing process

The drawing performance of a gel like as-spun filament is influenced by the dissolving conditions (concentration, molecular weight etc.) and also by the morphological structure of the gel-like fibre. Moreover, those influences seem to be unified by the entanglement concept as expressed in equation 3. If an actual drawing process is performed with an ideally low drawing speed, the effective and homogeneous deformation of micro-structure leads to ideal drawing as expressed in equation 3.

$$\lambda_{MAX} \propto v{\sim}1\ /\tau \qquad (4)$$

where v is the deformation rate and τ is the characteristic relaxation time. If one applies higher deformation rate ($v > 1$ /- τ) the molecular chain cannot relax any extra localised stress, so molecular chain breakage occurs. On the other hand, at $v < 1 / \tau$, the molecular chain has time to relax to some extent, which makes disentanglement possible. The value of τ is affected by the molecular structure of the as-spun fibre structure, specifically by chain entanglement, and is therefore strongly dependent on both the molecular weight and the concentration. From the molecular theories which deal with the dependence of the relaxation time on the molecular weight and concentration, τ can be generally expressed as follows:

$$\tau \propto C^{\alpha}M^{\beta} \qquad (5)$$

and from equation 4

$$\lambda_{MAX} \propto C^{-\alpha} M^{-\beta} \quad (6)$$

Values of these coefficients reported for the Graessley model are a = 1.5 and 0 = 3.5, and for the Doi-Edwards Model, a = 1.0 and 0 = 3.0. These values are much higher than those of equation 3, and we have obtained a similar result to these theoretical power laws in our high-speed drawing experiments. Since the solvent is removed either fully or partly during the spinning and drawing processes, the above ideals cannot yet be completely accepted.

However, it can be concluded at least that the entanglement density and/or entanglement structure, which are mainly determined through the solution make-up and spinning process as described in the previous sections, dominate the drawing performance of UHSPE.

Another important factor which dominates the drawing performance is the ease of pulling out molecular chains from the crystalline structure. This is particularly easy with polyethylene, because it has no strong interchain interactions like hydrogen bonding. On the other hand, this also causes lower creep resistance of UHSPE fibres.

Many applications are making progress, notably high performance ropes, high performance fabrics, and reinforcements for composites. These applications utilize UHSPE fibres' excellent properties such as light weight, super-high strength and modulus, good impact proper environmental and chemical stability. Competition among high performance fibres will prompt further improvement in UHSPE performance and productivity. In particular, strength and modulus will be improved towards the theoretical values. For example, experimentally, a strength of 72g/d which is close to a theoretical value has been reported.

Development will focus on how to realize such laboratory scale trials as actual processes at higher drawing speeds with low yarn breakage rates. Besides the tensile properties, deficiencies like lower heat resistance, poor adhesion and low creep resistance will also be improved. Improvements in productivity will also be brought about.

Success of the gel spinning process for UHSPE has prompted the application of this technology to other flexible polymers. Here the application to two representative flexible polymers, polyvinylalcohol (PVA) and polyacrylonitrile (PAN), is introduced.,

PVA polymer is the most promising candidate for the next gel spinning application. The theoretical strength of PVA is 236g/d and its crystalline modulus is 2251g/d. These values are close to those of PE, therefore higher strength and modulus can be expected. In fact, recently a strength as high as that of aramid fibres has been realized.

The fundamental concept for gel spinning of PVA is similar to that of PE as described in this article. A characteristic feature of PVA is that a major part of the effort has gone into control of the interchain hydrogen bonding. Many attempts to produce high strength PVA fibres have been reported in patents and articles. For example, in patents solvents such as glycerol, ethylene glycol and water are used for PVA having a degree of polymerization more than 2000. The gel-fibres obtained by cooling these solutions are extracted by alcohol and then stretched more than 20-fold. Achieved strengths of 22g/d (by adding boric acid), 24 g/d (by using as solvent DMSO/H_2O = 80/20 and drawing at a draw ratio of 48), and again 24 g/d (by using high molecular weight PVA having a degree of polymerization above 10 000 and applying multi-stage drawing) have been reported.

An extremely high strength of 44g/d and a modulus of 1040g/d were obtained by gel-spinning using highly syndiotactic PVA having a high degree of polymerization of 15 000 and glycerol as solvent. This report suggests that the tacticity of PVA is also important. Of course, higher molecular weight causes an increase in the tensile strength, but higher draw ratio sometimes results in lower properties. This may be explained by the pressure of strong interchain bonds.

Representative information from patents" shows that a tenacity around 20g/d has been reported by dissolving PAN having a molecular weight more than 1000000 in NaSCN/H2O to form a 5-10% solution, coagulating in a lower temperature bath to form gel-like fibre, and drawing first in hot water or glycerol then in the dry state.

Melt spinning

The ultra-high speed spinning of polyethylene terephthalate (PET), typical example of a melt-spun synthetic yarn is described here.

PET yarn has been produced by a conventional spinning and drawing process since 1958 when its domestic production in Japan started. In that process, the PET melt is extruded and then wound up at a speed of 1200 m/min. The resulting undrawn yarn (UDY) is then drawn by 3-5 times and heat-treated to give the fully oriented yarn (FOY or DY). PET drawn yarn is mostly produced according to this system. The drawing process can be omitted in high-speed spinning, and the drawn yarn be made economically in one step. This idea was patented by Du Pont in the 1950s.

However, the full development of such a one-step technology required development of the high-speed winder and this did not occur until 1988 when commercial high-speed spinning at over 6000 m/min started. The direct spin draw process was developed conventionally in the 1960s by coupling the spinning and drawing processes in series.

As the demand for crimped yam increased in the 1970s, the drawing and texturing processes were combined into one process, and a new spinning process was developed to produce partially oriented yarn (POY) with a spinning speed of 3000-3500 m/min. to produce the feed stock for integrated draw-texturing. The spinning speed increased as winder performance improved in the early 1970s, and this develop-ment encouraged the investigation of highspeed spinning.

Ueda and Kanatsuna, for example, reported the fibre structure of nylon 6 made by high-speed spinning at up to 9800 m/min in 1971. For ten years from 1975, the high-speed spinning process was extensively investigated by various researchers including Shimizu et al. who reported a series of high-speed spinning results on polyester, nylon and polyolefin.

In 1983, the Association for Efficient Synthetic Fibre Technology was established in Japan with a scheme of conditional loans for research and development of innovative technologies under the Ministry of International Trade and Industry; its spinning section coordinated a project for high-speed spinning of polyester at 9000-14000 m/min. These investigations have revealed the optimum conditions for high-speed spinning and the mechanism of the fibre structure formation during the process.

Today, high-speed spinning at 6000-8000 m/min is in commercial operation for the production of synthetic yarns such as nylon and polyester.

The yarn tenacity increases and its elongation at break decreases as the spinning speed increases. When the spinning speed exceeds 5000 m/min, the elongation falls below 70%, and the yield point in the stress-strain curve becomes less distinctive, as in conventional FOY. The tenacity exhibits a maximum at a spinning speed of 6000-7000 m/min and then decreases. (Data from Ishizaki et al. exhibit a maximum at a higher spinning speed of 8000 m/min. This may be due to a difference in the PET chemical structure, since a modified PET was used in order to improve the spinnability.)

The tenacity of the high-speed-spun yarn is in the range 3.8—4.7 g/d, which is slightly lower than that of FOY. The elongation decreases with spinning speed, and becomes less than 25% at a spinning speed of over 8000 m/min. Young's modulus increases abruptly at a spinning speed of 3000-4000 m/min suggesting a large change of fibre structure at this point. Although Young's modulus increases continually up to a spinning speed of over 6000 m/min, according to the results of Shimizu *et al* 3 and Kamide et al it may decrease when the spinning speed is further increased since it tends fo fall at spinning speeds of over 8000 m/min, like the tenacity, according to the results of Fujimoto.

The Young's modulus of high-speed- spun PET yarn reaches 100 g/d, as high as that of FOY. The thermal shrinkage exhibits a maximum (around 60%) at a spinning speed of 2000-3000 m/min, and then decreases to as low as 2-3% at a spinning speed of over 6000 m/min. Thus the thermal shrinkage stability is good in high-speed-spun PET yarns. The dye pickup for 60-minute dyeing was examined with two dyes of different molecular weights as a function of the spinning speed. Both dyes exhibited the minimum pickup at a spinning speed of 5000 m/min, with an increase at higher spinning speed.

The dye pickup of the PET yarn spun at 9000 m/min was found to be around 70% when it was dyed with a disperse dye under atmospheric pressure at 100°C. This value is not as high as the 85% found for FOY dyed with the same liquor ratio under high pressure at 130°C, but the dyeability of the high-speed-spun PET yarn is good, considering that the value of 70% was obtained at only 100°C The characteristics of high-speed-spun PET yam can be summarized as:

— The tenacity and Young's modulus are slightly lower than those of FOY.

— The elongation of the high-speed-spun yarn exhibiting the maximum tenacity is higher than that of FOY.

— The thermal shrinkage is low, and the thermal shrinkage stability is good.

— The dyeability is good.

Chain orientation can be evaluated separately in the crystalline and amorphous phases from the birefringence. The total birefringence is given In terms of the birefringence in the crystalline phase Δn_c the bire-fringence in the amorphous phase Δn_a and the volume fraction degree of crystallisation x as

$$\Delta n = \Delta n_c x + \Delta n_a (1—x)$$

$$\Delta nc = fc\ \Delta nc_0$$

Where f_c denotes the degree of orientation in the crystalline phase evaluated by the X-ray diffraction method and the limiting birefringence in the crystalline phase is calculated as Δn_{c0} = 0.212. Although the birefringence in the crystalline phase Δn_c cannot be evaluated unless the crystalline phase is formed, Δn_c is already as high as 0.16 at a spinning speed of 4000 m/min and increases to over 0.20 at a spinning speed of 8000 m/min. suggesting that the chain orientation is closely related to crystallisation.

The birefringence in the amorphous phase Δn_a reaches a maximum value of 0.05 at a spinning speed of 6000 m/min, and then gradually decreases with increasing spinning speed. The total birefringence Δn of the fibre roaches a maximum value of 0.12 at a spinning speed of 7000 m/min,. This is lower than the value of 0.15 obtained for the conventional FOY (fully oriented yarn), probably due to relatively low orientation in the amorphous phase. To sum up, the high-speed-spun yam is characterised by high crystalline orientation and low amorphous orientation.

The crystalline fraction (i.e. the crystallite thickness/the long period) evaluated from the two-phase model of repeating crystalline and amorphous phases is about 28% (cf. x = 26% estimated from the density) for the filament spun at 5000 m/min, but this value becomes too high (75%) at 9000 m/min (cf. x = 34% estimated from the density).

Shimizu *et al.* concluded that this discrepancy was caused by inter-microfibrillar voids which were not taken into account in the simulation. Ishizaki *et al.*, proposed a fine structure model based on the results of the small-angle X-ray scattering profile along the equatorial streak corrected with respect to the diffraction angle θ .

The scattering intensity decreases monotonically up to a spinning speed of 5000 m/min, while a shoulder, or maximum, is observed in the scattering curve at spinning speeds higher than 6000 m/min. Since a broad peak appears in the scattering profile at spinning speeds of 8000-9000 m/min, an approximate inter-microfibrillar distance was estimated by applying Bragg's equation.

The high-order structure, of fibre has been analysed in terms of a two-phase model composed of crystalline and amorphous phases. In this analysis, all phases except the crystalline phase are assigned to the amorphous phase, where the amorphous phase is not well defined but represents a general non-crystalline phase.

Shimizu et al. have introduced the concept of the oriented meso-phase in order to specify the structure of the non-crystalline phase. The crystallinity evaluated from the density hardly increases with the spinning speed up to 4000 m/min, although the orientation improves continuously as mentioned above. Thus the fibre structure is highly oriented but amorphous in the range of spinning speeds of 3000-4000 m/min.

Wide-angle X-ray diffraction reveals only a circular halo from the as-spun yarn at spinning speeds of 1000-2000 m/min, where the intensity of diffracted X-rays is almost equal in the equatorial and meridional directions. When the spinning speed increases, the difference in diffracted intensity between the equatorial and the meridional directions increases, and becomes greatest at a spinning speed of 4000 m/min.

Since the intensity in the equatorial direction has its maximum at $2\theta = 21°$, the molecular chain is supposed to assume a periodic structure of 4 A. Here the oriented meso-phase fraction increases and reaches its maximum of just over 20% at a spinning speed of 4000 m/min. When orientation-induced crystallisation takes place (at a spinning speed of 5000- m/min), the oriented meso-phase transforms primarily into the crystalline phase. The crystalline phase decreases and the amorphous phase increases at spinning speeds over 7000 m/min, while the oriented meso-phase exhibits a slight increase.

Solution spinning

Solution spinning is classified into two methods:

1. dry spinning and
2. wet spinning.

Dry spinning is where polymer solution is solidified through evaporation of polymer solvent.

Wet spinning can be divided further into three methods based on three different physicochemical principles:

1. the liquid-crystal method,
2. the gel method and
3. the phase-separation method.

In liquid-crystal method, a liquid-crystalline solution of a lyotropic polymer is solidified through the formation of a solid crystalline region in the solution.

In gel method, polymer solution is solidified through the formation of intermolecular bonds in the solution. This phenomenon is called gelation.

In *phase separation method*, two different phases appear in the solution, one polymer-rich, the other polymer-lean.

Spinning of actylic fibre

in the field of phase equilibrium and phase separation of polymer solutions, significant developments have been made which have led to a theoretical understanding of the spinning technology of acrylic fibres. If the temperature of a homogeneous polymer solution at point E is lowered to that at point F, the solution becomes thermodynamically unstable, which leads to the generation of 'concentration fluctuation'. The solution becomes visibly cloudy, so the point F is called the 'cloud point'. The curve which links cloud points is called the 'cloud point curve'.

A further drop of solution temperature beyond the point F leads to separation of the solution into two phases, a polymer-lean phase (A) and a polymer-rich phase (B). It has been proved by Kamide and Manabe that this phase separation occurs according to the process called 'micro-phase separation'. In the polymer solution, critical nuclei are formed because of concentration fluctuation if the temperature of the solution is lowered to a temperature below the cloud point. The critical nuclei grow to larger particles called 'primary particles'.

If the polymer concentration of the solution (V^o_x) is lower than the concentration at the critical solution point (V^c_x), the polymer-rich phase is a dispersed phase. On the other hand, if V^{o}_{x} is higher than V^{c}_{x} the polymer-lean phase becomes the dispersed phase.

Afterwards these primary particles collide and amalgamate with each other and grow to larger particles called 'secondary particles', which further amalgamate and fuse to create the fibre structure.

Such micro-phase separation phenomena can be seen only in the case of a three component solution of polymer, solvent and nonsolvent. If a dilute aqueous nitric acid solution (coagulant) E is added to a spinning solution F, the composition of a mixture changes along the line connecting F and E, crossing the cloud point curve at tile point marked by a white circle.

As the polymer concentration at this point is lower than that at the critical solution point, marked by a dotted white circle, the polymer-rich phase forms a dispersed phase.

On the other hand, if a more dilute aqueous nitric acid solution (coagulant) D is added to the solution F, the concentration of the resulting mixture changes along the line connecting F and D, crossing the cloud point curve at the point marked by an open square. As the polymer concentration at this point is higher than that of the critical solution point, in this case the polymer-lean phase forms a dispersed phase and the polymer-rich phase forms a continuous phase. F When the concentration of coagulant increases, at first dr_{max} decreases gradually and then it increases rapidly after reaching a minimum. This minimum concentration is called the critical concentration.

Generally, the method of spinning with coagulant concentration below this point is called 'low concen-tration spinning' while that with coagulant concentration above this point is called 'high concentration spinning'. When spinning is carried out in the low concentration region, a continuous layer (skin) appears on the surface of the spun dope, then the nonsolvent in the coagulant diffuses through this skin into the spun dope inducing coagulation inside it and a change in volume.

As the skin is rather rigid, it cannot deform in proportion to the shrinkage of the inside volume caused by the amalgamation of polymer particles. This is the reason macro-voids are formed inside the fibre. The more the concentration of the coagulant decreases, the greater the number and the larger the voids that are formed inside the fibre. These voids often induce opacity in a fibre. If the elongation and drying of a fibre are properly carried out, a transparent fibre without voids can be obtained.

On the other hand, if spinning is carried out in the high concentration region, the coagulated fibre does not have a skin but has a structure formed uniformly by aggregation of polymer particles. In this case, coagulation does not proceed as rapidly as in the case of low concentration spinning, but because of the lack of skin, both solvent and nonsolvent diffuse smoothly between the inside of the fibre and the external coagulant, which makes the fibre structure uniform. As the phase separation occurs in the coagulant at a higher concentration of solvent than in the case of low concentration spinning, the polymer particles contain a larger amount of solvent and are more easily elongated and fused with each other under extensional forces in the spinning process than in low concentration spinning.

However, high concentration spinning has some defects. Firstly, a fibre of this type has very low tenacity in the coagulation bath and is easily broken by extensional forces. Secondly, a larger amount of Polymer comes out into the coagulant than in low concentration spinning.

In the history of the development of acrylic fibres, the manufacturing method for staple fibre was developed first, then that for filament yarn on the basis of the manufacturing technology for staple fibre. The manufacturing technology for staple fibre is that of the manufacture of fibres in the form of a tow which has a total denier of several tens of thousands, so the spinning velocity is generally less than a few hundred meters per minute.

There are two methods of spinning an acrylic fibre. One is an immersed-jet method where spinning dope is extruded through a spinneret which is immersed in a coagulation bath. The other is a dry-jet wet spinning method where a dope is extruded through a gaseous atmosphere from a spinneret which is set above a coagulant bath. In the case of the immersion method, the spinning dope starts coagulating immediately after it is extruded from a spinneret, so it is difficult to draft filaments in the coagulation bath at a high rate, especially in the case of low concentration spinning.

On the contrary, it is easy to draft extruded dope at a high rate while it is in the air in the case of the air-gap method. In addition, filaments made by this process have a smooth and glossy surface compared with those made by the immersion process. The manufacturing technology for acrylic filament yarn has been developed on the basis of these two spinning technologies.

Immersion method

Spinning dope made of polyacry-lonitrile or an acrylonitrile copolymer dissolved in *ca* 70% nitric acid solution is extruded into a coagulant bath containing ca 30% aqueous nitric acid solution at -3°C. The reason for drying the fibre in two stages is to obtain good mechanical properties. In the first dryer, the fibre shrinks by 5-10%; in the second dryer it is elongated by 0-10%. By controlling the shrinkage and elongation rate, good mechanical properties can be obtained. The characteristics of the fibre obtained by this process are an excellent lustre and a handle like that of silk. This silky handle is derived from micro-stripes on the fibre surface. This fibre has high tensile strength and low tensile elongation.

Air-gap spinning method

Spinning apparatus utilizing the air-gap spinning method developed by the Monsanto company Spinning dope made from a 26% PAN solution in N,N"-dimethylacetainide (DMAc) is extruded from the spinning nozzle into the air. After running for 1.3 cm in the air, it enters a coagulant bath containing 50% aqueous DMAc solution. The fibre is elongated in the coagulant bath to some extent by the tension applied by a roller, then removed from the coagulation bath at a velocity of 9.3 m/min. Then it is elongated 6.1 times in an elongation bath containing hot water at 100°C. The fibre is cleared of solvent with hot water at 50-80°C while it runs 30-40 times over rollers. The fibre is dried on drum dryer after being treated with oil in a bath. The fibre velocity on the drums is about 46 m/min. The characteristics of this process are air-gap spinning and drying without tension after shrinking the elongated fibre in hot water. By this process, a fibre with a smooth glossy surface and high toughness can be obtained.

Highspeed spinning

Following requirements should be fulfilled in order to achieve highspeed spinning in the manufacture of an acrylic filament yarn:

1. *Rapid coagulation.* In acrylic fibre manufacture the fibre is elongated by up to several tens of times, after coagulation, to obtain appropriate mechanical properties through molecular orientation and densification. The fibre velocity in the coagulation bath is not so high as that for a regenerated cellulose, which is not substantially elongated after coagulation if the same winding velocity is used, but much higher speed is necessary compared with a conventional acrylic spinning method.

The following are measures required to achieve high speed coagulation:

(a) In the case of an immersion method:

(i) High velocity of spinning dope at extrusion when spinning in a low- concentration spinning region.

(ii) High velocity of spinning dope at extrusion and a large draft ratio when spinning in a high-concentration spinning region.

(b) In an air-gap spinning method, high velocity of spinning dope at extrusion and a large draft ratio. Resulting from these measures, the maximum velocity of a fibre in a coagulation bath is only a few tens of m/min in the case of low-concentration spinning utilizing an immersion method due to the increase of pressure behind the spinneret, an increase of the fibre tension in the coagulation bath, and low dr_{max}. Consequently, the other two methods have been employed in the development of high-speed spinning.

2 *Rapid removal of the solvent.* As mentioned before, elongation of the fibre after coagulation is indispensible in acrylic fibre spinning in contrast to regenerated cellulose-fibre spinning. This permits relatively low fibre speeds in the coagulation bath for acrylic fibre spinning but makes it difficult to utilize a net conveyer system after removing the solvent.

The following are the measures for rapid removal of solvent using highspeed spinning:

(a) Low resistance of washing liquid and high efficiency of washing in a washing process such as the Hoffman type (straight type), or

(b) sufficient retention time of fibre on Nelson-type rollers.

The former method is advantageous from the viewpoint of saving space and cost of equipment, but it is difficult to balance the washing effect with the resistance of the washing liquid. The latter method is advantageous from the viewpoint of balance but requires larger and more expensive equipment.

From the viewpoint of mechanical properties it is desirable to dry the fibre at low tension.

Highspeed spinning apparatus for spinning in the high concentration region using an immersion-spinning method of the Monsanto Company. The following is an example of spinning conditions used in this process. A spinning dope made from a 25% PAN solution in DMAc is extruded into a coagulant bath containing 83% aqueous DMAc solution at 30°C. and is drawn out from the bath by means of the rollers R-1 and R-2 in an air atmosphere. The solvent is removed from the fibre on the rollers R-2 and R-3 with deionized water at 70°C. The fibre is elongated with steam at 105°C (8) between washing rollers.

The fibre is then elongated again (8'), which is heated electrically at 250°C, treated with a finishing agent, dried on the rollers R-4, and wound up on a bobbin. In this process the tension of the running fibre is controlled at an appropriate level, especially during washing and drying when it is kept at a low level. If the fibre is elongated in the tube 8', a fibre with high strength and low elongation is obtained, but if the fibre is shrunk in this tube a fibre with low strength, high elongation and low shrinkage in boiling water is obtained. Additionally, the shrinkage in boiling water is lowered if the fibre on the bobbin is treated with steam. Spinning speeds up to 1000m/min are available using this process.

The spinning dope, a PAN solution in DMAc, is extruded downwards from the spinneret, falls 1-20 mm in air and enters a coagulant bath containing aqueous DMAc solution (for example, 70% at 40°C). After coagulation the fibre is washed with hot water, elongated 1.8-4.5 times in boiling water, and then elongated 6-12 times with steam at 2-4 kg/cm^2. After the elongation, the fibre is dried and then shrunk using a hot roller, a hot plate or high pressure steam. The first elongation, with boiling water, has a great influence on the second elongation, with high pressure steam. Unless the fibre is elongated to the appropriate extent in the first stage, a high elongation rate cannot be obtained in the second stage.

If the fibre is elongated 2-4 times in the first stage, a high rate of elongation is possible in the second stage and a maximum velocity of 2160 m/min can be obtained. By employing an air-gap method, the velocity of the spinning dope before coagulation can be increased, but the high resistance of the coagulant liquid has to be overcome. If the resistance is too high, the fibre breaks in the coagulant bath, so high speed cannot be obtained. In this apparatus the coagulant liquid, introduced through an inlet, flows down through a spinning funnel. In this funnel, excess coagulant liquid overflows into an outer funnel and flows out through an outlet,maintaining the liquid head at a desired level.

Velocity of the coagulant liquid in the straight part of the funnel can be controlled by changing the inner diameter of the funnel. This downward flow of the coagulant liquid decreases its resistance to the fibre compared with a static coagulant bath, so the fibre is elongated and coagulated smoothly. By employing this spinning funnel and a net (mesh) conveyer for drying, a spinning velocity of 1000-2000 m/min can be obtained.

Table 1 shows the mechanical properties of a conventional acrylic filament manufactured by an immersion process in the low-concentration region and that of a filament manufactured by the highspeed spinning process with an air-gap method. The fibre obtained from the highspeed process has higher tensile elongation, knot strength and abrasion strength and lower shrinkage in boiling water than the conventional fibre.

Table 1

Properties of fibre from the conventional spinning method and the highspeed spinning method

	Conventional	Highspeed spinning
Tensile strength (g/d)	5.1	3.0
Tensile elongation (%)	13.9	27.8
Knot strength (g/d)	2.6	10
Knot elongation (%)	7.5	25.2
Maximum twist number (t/m)	1092	1928
Shrinkage in boiling water (%)	6.8	1.5
Fibrillation grade	2nd	5th

These advantages of the fibre from the highspeed process are the result of employing an air-gap method and drying without tension on the net conveyor. The micro-stripes are thought to be formed through depression of voids in the fibre which are common in fibres made in the low-concentration region when the fibre is elongated in the coagulant bath.

On the other hand, the fibre made in the highspeed spinning process is elongated mainly in air just after extrusion from the spinneret and only slightly in the coagulant bath. This is thought to be the reason why this fibre has a smooth surface.

Acrylic filament yam has been used rarely in the high fashion field. However, as the highspeed process has realized large improvements both in quality and cost, it will in future be widely used in general textile and industrial fields, like regenerated cellulose filament yarn which is already used in such fields.

Spinning of Bemberg rayon

Technology for manufacturing Bemberg rayon was developed in 1918 by J P Bemberg in Germany. Thereafter, many companies worldwide introduced this technology and started the production of Bemberg rayon. Nowadays only a few companies, including Asahi Chemical Industry in Japan and Bemberg SpA in Italy, continue to produce Bemberg rayon. This is due to its lack of competitiveness against viscose rayon arising from the use of expensive materials such as copper and ammonia to dissolve the cellulose. In manufacturing Bemberg rayon, cotton linters are used as the raw material.

Cotton linters are short fibres which are rubbed off cotton seeds after cotton fibre is cut from them. Refined linters are obtained by boiling raw cotton linters with alkali solution and then bleaching them. The refined linters are characterized by a narrow distribution of degree of polymerization, chemical purity and low content of oxidized groups.

Copper hydroxide is dissolved by aqueous ammonia, forming a complex salt (tetra-ammonium copper hydroxide). The refined linters are added to copper ammonium solution which contains copper hydroxide as a precipitate. Cellulose forms a complex with tetra-ammonium copper hydroxide which dissolves in the solution. Meyerio proposed the following chemical formula for the complexed product.

Spinning technology of Bemberg rayon is based on the method developed by Thiele in 1901 in Germany. The spinning dope extruded from a spinneret flows down with hot water (coagulant) through a spinning funnel in the shape of a cone. In the funnel the spinning dope is coagulated gradually while being elongated several hundredfold and thus the fibre is formed.

Hank-spinning method

Hank-spinning method is one of the oldest Bemberg spinning methods and is a batch process which uses a winding frame called a Hank in Gemany. The fibre on the Hank is taken off it in the shape of a ring and then regenerated and dried. The spinning speed is 40-80 m/min. The cellulose cuprammonium solution is extruded from a spinneret with a diameter of 0.6-1.0 mm into hot water (the spinning water) in a spinning funnel. The extruded spinning dope flows down in the funnel, being coagulated and elongated at the same time.

Generally, the degree of coagulation depends on the ratio of the ammonia and copper which is removed from the fibre to the amount of ammonia and copper initially present in the fibre. In the upper part of the funnel, spinning dope extruded from the spinneret flows down under gravity, gradually growing thinner by elongation. During this time, ammonia diffuses into the hot water through the surface of the fibre and so coagulation starts from the surface.

The elongation at this stage causes cracking of the surface layer, diffusion of ammonia from the new surface layer ensues and coagulation proceeds. Through repetition of these processes, coagulation and elongation continue. When the coagulation rate reaches a certain point, the fibre changes to an insoluble complex called a blue yarn.The viscosity of the fibre rises rapidly and it losses its fluidity.

In the middle section of the funnel, cellulose molecules, which still form a complex with copper, are oriented longitudinally by means of a winding force transmitted from the lower part of the funnel. In the lower part of the funnel, the fibre is elongated only slightly by the winding force. After the fibre leaves the funnel outlet, it is regenerated with acid and dried in later processes without substantial elongation.

The fundamental structure of the fibre, including the orientation of molecules and the degree of crystallization which control the fibre properties, is considered to be determined at the stage of the formation of the blue yarn. So the extent of elongation in the upper part of the funnel and the tension imposed on the blue yarn from its formation to the stage of regeneration have a decisive influence on the fibre properties.

Bozza and Elsasser thoroughly researched this spinning process. Bozza expressed the differential increase of fibre velocity dvf by the following equation using fibre velocity, *vf*, at a distance *x* from a spinneret, tension imposed on the fibre at that point *f*, cross section area of the fibre *q* and viscosity μ.

$$dvf = (1/3\mu)\ (f/q)\ dx$$

Elsasser determined the tension *f* and viscosity μ of the fibre at a series of distances from the spinneret by inserting d*vf*/d*x* into this equation calculated from the diameter of the fibre in the funnel, which was measured directly.

From these results he introduced the idea of 'optimum coagulation state' and concluded that the tension imposed on the fibre at the optimum coagulation state determines the strength of the fibre. According to his calculation, the fibre at this state has a viscosity of 56500 poise which equals that of rather soft asphalt.

Therefore, it is considered that the fundamental structure of the fibre is formed at an early stage of coagulation in this spinning method.

The blue yarn which comes out from the bottom of the funnel with the spinning water changes its direction and is separated from the water by means of a guide set under the funnel, and is wound up on a frame after being treated with 6% aqueous sulphuric acid solution for final regeneration.

This solution is poured on to the fibre on the frame during winding to remove ammonia and copper. The Hank yarn is manufactured without twist and is woven or knitted either without twist or after being twisted. There is a unique feature of the Hank process called Reiter colligation that makes it possible to handle Hank yarn without twist in the spinning process and the later processes. The Reiter is a small instrument set just before the apparatus for sulphuric acid treatment.

When the blue yarn comes into contact with the sulphuric acid solution, rapid regeneration occurs with generation of active OH groups and elimination of water from the yam. If filaments in the yarn are in close contact with each other, they bond to each other by means of chemical bonds based on OH groups. The Reiter with an appropriate curvature at its bottom for the passage of the yarn is set at the point where regeneration of the yarn takes place most intensively in order to get the filaments into close contact with each other and bind them with OH bonds. These OH bonds are formed intentionally so that they ensure that yarns can be handled easily in the manufacturing processes during spinning, knitting or weaving. At the same time they also ensure that filaments can move freely enough apart in the fabric to give it soft touch and good uniform appearance. For this reason, the Reiter colligation should be reversible. The extent of colligation is controlled by changing the position and the curvature of the Reiter.

The yarn wound on the Hank is then conveyed to a regeneration apparatus where it is further regenerated, washed thoroughly for several hours, treated with finishing oil and then dried in a dryer for several hours. In the Hank process, the spinning speed is restricted by two factors. One is the use of a Hank frame for winding. If the spinning speed is increased, the increased tension of the yarn tightens the yarn wound on to the frame and binds the filaments together both within the yarn and between the yarns, which leads to insufficient regeneration and drying. The other restrictive factor is the spinning condition in the funnel.

Continuous-spinning method

There are mainly two types of continuous-spinning apparatus, the Hoffman type and the Duretta type. The main differences between them are in the regeneration and drying processes. Only the Hoffman process will be described here. In the Hoffman apparatus, the fibre, which comes out of the funnel, runs straight through the regeneration stage and the drying apparatus and is wound up continuously on a winder. The spinning speed in this process is 100-150 m/min. One of the technological improvements which make a higher speed possible is the employment of the double spinning-funnel method.

In the single spinning-funnel method of the Hank process, an increase of spinning speed requires improvement of funnel dimensions and changes in the amount and temperature of the spinning water. However, if these conditions are changed to facilitate elongation at high speed, the fibre comes out of the funnel uncoagulated. This problem is solved in the double spinning-funnel method by separating the role of spinning water into coagulation and elongation.

In this method, the temperature of the 'first' spinning water used for the upper funnel is lower than that in the Hank method, to facilitate elongation, but the temperature of the second spinning water used for the lower funnel is higher to ensure sufficient coagulation. Additionally, in the lower funnel, turbulent flow is generated by mixing the first water and the second water; this accelerates coagulation. The degree of coagulation is very low up to the outlet of the upper funnel but rises rapidly after the fibre reaches the second water.

If the temperature of the first water is too high, coagulation proceeds too far and copper hydroxide from the fibre sticks to the outlet of the upper funnel. This causes problems such as a change in velocity of the water and breakage of the fibre.

On the other hand, if the temperature is too low, insufficient coagulation causes problems such as breakage of the fibre and deterioration of fibre properties. The other technological improvement required for a continuous-spinning process at high speed is an acceleration of regeneration.

In the Hank-spinning method, it takes many hours to regenerate and dry fibres as they are tied up closely in a bundle. On the other hand, in the Hoffman process, the regeneration is finished in a few seconds because the fibre runs straight through a regeneration bath which, in any case, should not be too long because of the cost of the machine. In order to accelerate regeneration, replacement of water around the fibre is important. It is also essential to keep the fibre structure in a state which facilitates diffusion of water and of ions such as sulphuric acid and copper.

The sulphuric acid solution flows in the regeneration bath against the flow of the fibre. The water layer which covers the yarn is removed by suppressing and supporting dams. A most important point is not to keep the filaments in the yarn bound together but to keep them apart from each other in the bath. The water layer can then be taken off smoothly and replaced with fresh water which has lower ammonium and copper ion concentration. This condition can be attained by ensuring that the coagulation level is sufficiently high before the fibre reaches the regeneration bath.

In addition to these factors, it is important to keep the fibre structure, especially that of the surface, rather porous in order to accelerate diffusion of ions in the regeneration bath. As the acid concentration increases, the copper concentration of the fibre just after the first acid bath decreases but that of the final product increases.

This means that the acid concentration of the first acid bath should be kept low, for example lower than 0.5%, in order to attain a low level of copper concentration in the final product. The Hoffman-type spinning method is superior to the Hank-spinning method because it is continuous and permits higher spinning speed. However, it still has the following drawbacks:

1. Low spinning speed: almost twice as high as that of the Hank process, but much lower than that of synthetic fibres. Higher speed brings about deterioration of fibre properties and leads to fibre breakage in the process.
2. Frequent contact of the fibre with parts of the apparatus causes filament breaks (generation of fluffs) and even yarn breaks.
3. Problems with residual copper: even slight changes of spinning condition tend to cause increased residual copper which has a large influence on the dyeabllity of the fibre.
4. Due to the regeneration and drying under high tension, the tensile elongation is small and shrinkage at the boil is large. These properties are sometimes useful during handling but restrict the fibre's range of use.

NP-type spinning method

A spinning speed of about 400 m/min is realized in the NP method. In the double funnel method of the Hoffman process, the following conditions lead to the highest spinning speeds:

1. Lower temperature and larger amount of the first spinning water.
2. Higher temperature and larger amount of the second spinning water.

As the spinning speed rises, the resistance of the spinning water to the fibre in the second funnel increases, the fibre properties deteriorate and many fluffs are generated. The limit of Hoffman double funnel is about 200 m/min. The NP-type spinning apparatus comprises an upper funnel, an instrument called a CJ (short for 'coagulation jet') and a lower funnel. The upper part of the upper funnel contains a mesh for smoothing the flow of the spinning water in order not to entangle filaments just extruded from the spinneret and not to enhance coagulation.

The shape of the upper funnel is designed so that the filaments can be highly elongated smoothly without enhancing coagulation. The apertures, with diameters of several mm, open in a circle, the centre of which coincides with the centre of the running fibre on the undersurface of the CJ. The second spinning water is supplied from these apertures. No further spinning water is supplied to the lower funnel, but the first and second waters flow into it and mix there. A controlled head of water is maintained in this funnel.

It is not realistic to apply the regeneration and drying apparatus of the Hoffman process to highspeed spinning at several hundreds to 1000 m/min because of the high tension which will produce frequent fibre breaks and high boil shrinkage, and also increase investment cost. In the NP process a net (mesh) conveyer is employed to regenerate and dry fibre. After being treated with sulphuric acid the fibre is drawn by a DKR (double kick roller) down on to a reversing roller.

The fibre is oscillated transversely to its direction by an instrument with an amplitude of several cm just before the DKR, so that the fibre on the roller forms an endless narrow belt with a width of several cm. The fibre belt is transferred from the roller to the net conveyer upside down so that the fibre can be withdrawn from the fibre belt in an orderly fashion. The fibre belt on the main net is treated with sulphuric acid and finishing oil, then dried and finally humidified to a water content of 11%.

The fibre belt is covered with a thin net while it runs through these processes to maintain its order. The withdrawing apparatus has two functions:

1. To withdraw fibre from the fibre belt and let it run forward.
2. To control the position of the end of the belt where the fibre is drawn out.

Sometimes the fibre is withdrawn from the fibre belt with a short section not undone. This can lead to three effects:

1. Undoing of the belt to a straight fibre.
2. Forming of a knot (or loop).
3. Fibre breakage.

These effects causes quality problems and reduce throughput. Therefore, preventing these imperfections is an important matter. The positioning of the end of the belt is controlled as follows. The endpoint of the belt is detected by means of a light sensor system, where a light is set above the main net and a photo cell is set underneath it. If the withdrawal speed is too low, the belt cuts the light beam. The winding speed is raised to a higher level until the photo cell receives the light; once the photo cell receives the light, the winding speed is reduced to a lower level.

There are many reasons for changes in the end point of the belt, such as differences in length and denier of the fibre and difficulty in withdrawing the fibre from the belt. The merits of employing a net conveyer for the high speed spinning process are:

— The much lower speed of the net conveyer compared with the spinning speed provides sufficient time for regeneration, drying and humidifying of the fibre.

— Fibre with high tensile strength and low boil shrinkage can be manufactured since it is treated in the spinning process without tension.
— No fibre breaks occur on the net. Even if the fibre is broken at winding, an operator can withdraw the fibre from the fibre belt on the net and re-start winding.
— The investment cost and maintenance charge are reduced because the net speed is low and the number of machine parts is small.
— It is theoretically possible, using a net conveyer, to realize highspeed manufacturing at several thousand m/min, if suitable highspeed spinning technology can be developed.

The NP and Hank fibres have high tensile elongation and low boil shrinkage compared with the fibre from the continuous process, because of the treatment under low tension in the regeneration, drying and humidifying processes. The fibre from the continuous process has the smallest number of fluffs per unit fibre length, the second best is the NP fibre. The neps found in the NP fibre stem from loops. From the viewpoint of ease of feeding, fibre properties and fibre quality, the NP fibre is considered to have a good aptitude for the weft of woven fabrics. Recently, the NP fibre has attracted notice because of its high aptitude for the air-jet loom process, introduced mainly for the weaving of regenerated cellulose fibre. There are drawbacks in the NP fibre such as low abrasion resistance after resin treatment and a tendency to fibrillate. These faults become more apparent as the spinning speed increases, probably due to structural defects in the surface layer as a result of highspeed spinning.

UNP-type manufacturing method

The UNP method was developed to attain higher productivity and to overcome the drawbacks of the NP method and has the capacity to spin at a speed of 1000 m/min. It employs the same technology as that of the NP method, especially for the processes after spinning. However, in order to attain higher spinning speed and better properties such as abrasion resistance after resin treatment, the following requirements should be fulfilled:

— Increase of coagulation ability of the spinning funnel.

— Achievement of high elongation.

— Optimization of elongation and coagulation.

A straight funnel causes turbulence of the spinning water and therefore the fibre path was disturbed and even broken. A new type of spinning funnel was introduced in order to solve this problem. This new type of funnel has a tapered end with the smallest diameter at the foot.

The aim of this funnel is to prevent breakage of the fibre by turbulent water and at the same time to attain high elongation by increasing the speed of the spinning water. In addition to this, it was shown that the second funnel, which was important to achieve the necessary coagulation level in the NP method, produced a large resistance against the fibre in the UNP method.

Therefore, a second CJ was introduced instead of the second funnel to decrease the resistance from the water and to increase the coagulation ability. In addition to this, the freefall length was increased.

The frequency of loops in the UNP process is one tenth of the NP process. This is considered to be because entanglements in the fibre belts occur less often using DKR drawing and it becomes easier to withdraw the fibre from the fibre belts at high speeds. The effect is considered to stem from the fact that fibre drawn by the DKR reaches the net conveyer before the crimp produced by the blades of the DKR disappears.

Spinning of spandex fibres

The IG company developed Perlon U, which however was a non-elastic polyurethane fibre rather like nylon. The elastic polyurethane fibre 'Lycra' was developed in 1959 by Du Pont, and thereafter many companies started developing elastic polyurethane fibres. The segmented polyurethane used for elastic polyurethane fibres is a copolymer of a soft segment and a hard segment. Rubber-like elasticity is given by combining a soft segment which gives polymer elon-gation and a hard segment which gives polymer strength. In the polymerization process, a high molecular-weight diol is converted to a prepolymer which has an isocya-nate group at each end by combining it with two molar equivalents of disocyanate.Polytetramethyleneglycol (PTMG), a polyadipate, or polycaprolactone are used as the high molecular weight diol and diphenylmethane 4,4' -disocyanate (MDI) or toluene-2,4-diisocyanate (TDI) is used as the capping agent. This prepolymer is then converted to high molecular weight polyurethane by combining it with a chain propagation agent such as a diamine or some other bifunctional active hydrogen compound such as a diol.

The urea bonds (in the case of diamine) or urethane bonds (in the case of diol), which form in this reaction, produce hard segments. Hydrazine and ethylene diamine are the most commonly used diamines. As there is a large amount of free disocyanate in the pre-polymer, the polymer produced has the following structure.

—IAIAIAI—I-I-I—IAIAIAIAI—1-1-1—IAIAIAI—

Here I is disocyanate, A is diamine and —is high molecular weight diol. The sequence IAIAIAIAI corresponds to a hard segment and I—I—I— corresponds to a soft segment. Generally, a dry- or wet-spinning method is used for manufacturing spandex fibre but the melt-spinning method is also applied.

There are two methods of wet spinning, one using a solution of the final polymer and the other a prepolymer. In the former method, the polymer solution is extruded into a coagulation bath through a spinneret and after coagulation, combination and fusion between filaments take place, the fibre is wound up.

When using prepolymer, the solution of prepolymer is extruded into diamine solution where chain propagation takes place. Therefore this spinning method is often called reaction spinning. In the case of dry spinning the heated polymer solution is extruded from a spinneret into a hot gaseous atmosphere in a spinning tube, where the solvent is removed. The filaments are combined to form a yarn, fused with each other and wound up.

Dry spinning

Structural formation of the fibre in dry spinning is more complex than in melt spinning, since the former is a two-component system, while the latter is a one-component system. However, assuming that there is no change of phase due to vaporization of solvent and that the fibre can be treated as a continuous body, the spinning process can be analysed theoretically like the melt-spinning processes. The region surrounded by two horizontal planes which are separated by a vertical distance Δz and a cylindrical surface of the fibre is considered. For this region, four equations define the balance of materials (polymer and solvent), momentum and energy. By transforming these equations, four independent equations can be introduced that define the weight ratio of solvent, sectional area of fibre, spinning tension and fibre temperature, and express the spinning conditions.

The diffusion coefficient is considered to decrease as the solvent concentration decreases, so it takes much longer to remove the solvent completely. The temperature of the fibre drops at first, then remains constant for a while and gradually rises to the temperature of the circumferential gas. The first drop is the result of the vaporization of the solvent which takes latent heat from the fibre. Then the temperature reaches wet-bulb temperature and remains there because the latent heat equals the heat transferred from the circumferential gas to the fibre. Thereafter, the temperature starts to rise as the amount being vaporized decreases. The cross sectional area drops rapidly at first because of elongation and then decreases more gradually because of the vaporization of the solvent. Thereafter, as the amount of solvent vaporization decreases and the fibre becomes solid, the change of cross-sectional area diminishes. The tension of the fibre, which is very small at first, rapidly increases as the solvent vaporizes, but soon reaches a plateau. These four values shift by a factor of two along the horizontal axis if the amount of spinning dope increases twofold. This means that if the amount of spinning dope is increased in order to increase the spinning speed, the length of the spinning tube should be extended proportionately to the increase in the amount of dope.

The polymer solution, which is already de-aerated, filtered and heated up to the required temperature, is extruded from a spinneret into a spinning tube of spinning apparatus for dry spinning of spandex. From the top of the tube, inert gas such as Kempf gas is introduced into the tube. The solvent is removed from the fibre, which becomes thinner as it passes down the tube. After emerging from the tube, the fibre is twisted. The twist travels upstream along the fibre to a point in the upper part of the tube where the filaments comprising the fibre fuse together and form an aggregate of filaments. This fusion is indispensable for subsequent processing of the fibre if it is not to be damaged. Various twisting devices such as air jet, liquid flow or roller can be used. The twist imparted is removed by the time the fibre reaches the first roller by means of the tension of the fibre itself. The fibre then receives finishing oil by contact with the finishing roller and is wound up by way of the second roller. Various technological improvements have been made to obtain stable spinning and diminish denier fluctuation. The heated gas flows down through a ring-shaped passage formed between the spinning tube and a cylindrical body set under the spinning nozzle and is removed from the tube at a point sufficiently far from the nozzle. This flow control prevents the oscillation of filaments and minimizes denier fluctuation.

Generally, in dry spinning the heated gas is supplied in parallel with the direction of the fibre either co-currently or counter-currently. The velocity of the gas is 1-30 cm/sec.

Highspeed spinning

In the spinning of spandex, an increase of the fibre tension causes undesirable changes such as an increase of modulus and a decrease of tensile elongation, Therefore, lowering the fibre tension is the main theme of the technological development in order to attain highspeed spinning. It is also necessary to increase the rate of solvent vaporization. The developments required are:

— *Method to supply the heat energy needed to evaporate the solvent.* The amount of solvent to be evaporated increases proportionally to the increase of spinning speed, yet it is not desirable to lengthen the spinning tube proportionately from the viewpoint of economy and fibre tension. Therefore, the residence time of the fibre in the tube must become shorter. An increase of the gas supply rate causes turbulent flow. An increase in temperature of the gas is limited by the melting point of the fibre.

— *Technology for diminishing fibre tension.* As mentioned before, an increase in the fibre tension causes a rise of modulus and a decrease of tensile elongation. The velocity of the gas becomes lower than that of the fibre. The resistance of the gas to the fibre increases as the fibre velocity increases.

— *Highspeed twisting technology.* As mentioned before, the fibre is twisted after it comes out of the tube by means of an air jet, liquid flow or rotating roller. The rate of revolution of the twister must be increased to attain higher spinning speed.

— *Highspeed winding technology.* It is difficult to wind up spandex yarn as it has low modulus and high tensile elongation.

Spinning of nonweavens

Spinning stage of the flashspun process, the filaments are obtained from a polymer solution of an organic solvent which has a low boiling point, is inactive to the polymer, and does not dissolve the polymer at room temperature but does dissolve it at a high temperature and pressure.

A mixture of polymer and solvent is brought up to a high temperature and pressure by heating to obtain a solution. The solution obtained is flashed through a small orifice into the atmosphere at room temperature to form filaments, and is therefore a type of dry-spinning. In the spunbonded and meltblown processes and in normal dry-spinning, only one filament issues from each orifice. However, flash-spinning is distinctive. It enables the polymer solution to form many filaments from one orifice. These filaments are termed plexifilaments and form a three-dimensional structure.

Spunbonded process

A spunbonded process commonly used by many manufacturers, shows the filaments being withdrawn by air-jets, but the filaments can alternatively be withdrawn by rolls instead of air-jets. There are two types of spinneret in commercial use; one is circular and the other rectangular. There are also two types of air-jet, circular and rectangular. The most important point in producing nonwovens is opening and arranging the filaments into uniform webs.

There is no definite combination of the spinneret and the withdrawal device to achieve a uniform web. The producers have developed many technologies to improve filament opening suitable for making webs with good uniformity of appearance: air diffusers fitted at the outlets of air-jets, static electricity generated by rubbing the filaments on metal plates, corona charging by passing the filaments through a corona discharge device, and traverse devices, for example.

Any filament-forming polymer can be used in the spunbonded process and for making spunbonded fabrics. Among these polymers are polyethylene tereplithalate (PET), polyolefines, polyphe-nylene sulphide (PPS), polybutylene tereplithalate (PBT) and polyamides. The spinning speeds are generally between 3000 and 6000 m/min. The selection of polymers depends on the end-uses. Combinations of polymers are also adopted to meet the needs of varied applications and nonwovens with high performance.

For example, there is Unitika's spunbonded fabric under the trade name 'ELEVES®' which has excellent strength and softness. This spunbonded fabric is made of PET and polyethylene (PE) and makes use of the characteristics of the two components: the high strength of PET and the softness of PE. 'ELEVES®' consists of continuous bicomponent filaments having a core component made of PET and a sheath component made of PE. Some producers are making new laminates of spunbonded fabrics consisting of different polymers. One of these products is Unitika's 'ELFIT', which was first publicised in April 1991, which is a laminate of two kinds of spunbonded fabric. One side of the laminate is PET spunbonded fabric and the other side is 'ELEVES®' consisting of bicomponent filaments with PET core and PE sheath. The polymers on each side have different melting temperatures. Thus 'ELFIT' improves the processability in combination with other materials, making it easier to produce composites and to meet the versatile needs of nonwovens.

There are nonwovens made of ultra-fine filaments with a fineness of 0.5 denier or less. These nonwovens are produced from webs consisting of multicomponent filaments such as the sea-island type or the dividable type which are composed of two kinds of polymers immiscible with each other. Nonwovens made of ultra-fine filaments are created either by dividing multicomponent filaments in raw nonwoven form after consolidating the webs or by dividing the filaments and consolidating the webs at the same time. The division technique used with the sea-island type is the removal of the sea section polymer in a solvent.

After this dissolution, the island portion is left behind to create ultra-fine filaments. This method is a complicated process because of the necessity to remove the sea portion, but this technique now provides the finest filaments. The technique was first developed by Toray. Researchers at the Okamoto laboratory have already developed the finest PET fibre with a fineness of 0.00009 denier and a diameter of 0.1 gm. They claim to produce the finest in the world.

The division technique for the dividable type is separation of the two polymers forming the filament by use of mechanical force, thermal action or impact generated by highly pressurized water. The division method with highly pressurised water causes separation and entanglement of the filaments at the same time to consolidate the web into an end-product consisting of ultra-fine filaments; this method is well worth noting. Among polyolefine spunbonded fabrics, poly-propylene (PP) is the most widely used. PE spunbonded fabric is also produced but the output is now very small.

Among the PE resins, linear low density polyethylene (LLDPE) has good spinnability. LLDPE can be easily melt-spun into filaments at a high speed, over 3500 m/min, in conventional equipment by conventional techniques, It provides a spunbonded fabric consisting of filaments having a fineness of 2-3 denier. The tensile strength of LLDPE spunbonded fabric is inferior to that of PP spunbonded fabric but it exhibits an exceptional softness unattainable by PP.

A higher spinning speed can be obtained by using a blend of low density polyethylene (LDPE) and PP. In the patent examples, a series of blends were formed from LDPE having a density of 0.9096 g/cm^3, a melting temperature of 103.4°C, and a melt index of 70 and PP having a density of 0.9022 g/cm^3 a melting temperature of 164.0°C, a melt flow rate of 8.7 and a Q value of 8.8. The filaments were melt-spun using a spinneret plate having 70 holes of circular cross-section at a polymer flow rate per hole of 0.90 g/min, and were withdrawn by a roll. LDPE blended with a small amount of PP increases the spinning speed.

Analysis of the filaments melt-spun from blends at higher speeds showed that PP dispersed in LDPE takes the form of droplets in the filaments, mostly about 5 μm in diameter by about 7mm in length. It is believed that PP droplets in LDPE enhance the crystallization rate of LDPE and consequently the blend polymers can be melt-spun at much higher speeds than unblended LDPE. On the other hand, blending PP with a small amount of LDPE reduces the spinning speed relative to unblended PP. It is also believed that LDPE in PP hinders the crystallization of PP and so the blend detrimentally affects the spinning speed.

Meltblown process

Meltblown process was initiated in 1951 by the US Naval Research Laboratories in an effort to develop organic microfibres of less than 1 μm in diameter. The researchers aimed to produce fibres which were to be used for microdenier filters to collect radioactive particles in the upper atmosphere. This initial research and development work on meltblown processes was continued by an Exxon affiliate in the mid 1960s, and Exxon successfully demonstrated the first meltblowing unit for producing microdenier webs in the early 1970s. The structure of the die used in meltblown processes differs greatly from that commonly used in spunbonded processes.

In meltblown processes the distance from die to conveyor is very short, i.e. 20-50 cm, compared to 100-200 cm in spunbonded processes. This is a process in which high velocity gas blows molten polymer to form fine fibres. The die has a row of small holes of a diameter of less than 1 μm, which are 0.5 min apart, centre to centre. Along the row of small holes, the die also has slits through which gas, heated to a temperature above 300°C, blows on to molten thermoplastic polymer coming out of each hole. Generally the heated gas is air. Many different polymers have been used in the meltblown process, most commonly PP, but also LDPE, high density polyethylene (HDPE), PET, polyamides, polystyrene, polyurethanes, PBT and PPS.

Meltblown process consumes a large amount of heated gas to obtain microdenier fibres. The consumption of gas depends on the polymer, the molecular weight of the polymer and the polymer flow rate per hole. This process normally consumes forty to fifty times as much air by weight as the polymer flow rate and sometimes consumes a hundred times. Meltblown processes therefore require a large amount of energy. The force of gas attenuates the fibre at a very high speed. For example, when fine fibre with a diameter of 3μm is being produced at a polymer flow rate of 0.2 g/min per hole by using PP with a density of 0.900 g/cm^3, the spinning speed is calculated to reach around 31000 m/min, about Mach 1.5.

It is necessary to decrease the temperature and consumption of gas to produce fine fibres at a lower energy. This means that it is advantageous in terms of energy consumption to use a polymer with a lower melting temperature, or with a higher flow index, or with both a lower melting temperature and a higher flow index. However, the fibre must also have the properties required for its practical use and this sets a limit to the choice. Shambaugh has reported a study of energy consumption in PP meltblowing, which can be summarized as follows:

1. The attenuation of fibre is mainly dependent on the gas kinetic energy.
2. Most of the gas kinetic energy is wasted without being effectively utilized when coarse denier fibres are obtained even though a sufficient amount of gas is supplied.
3. The actual fibres have a wide diameter distribution, but the diameter distribution should ideally be controlled to be monodisperse.

When a polymer is being attenuated into a fibre, the fibre kinetic energy E (erg) can be expressed as:

$$E = 1/2MV^2 = 8M^3/(\rho^2 \pi^2 d^4) \quad (1)$$

Where M is polymer flow rate (g/sec), V is fibre velocity (cm/sec), p is polymer density (g/cm. *3*) and d is fibre diameter (cm). Shambaugh calculated the fibre kinetic energy for different fibre distributions with the same average fibre diameter (10μm) using the above equation (1). The comparisons are as follows:

$$E_1 : E_2 : E_3 = I : 3.8 : 27.7 \quad (2)$$

Where E_1 is the energy for a monodisperse distribution with a fibre diameter of 10 μm, E_2 is the energy for a bimodal distribution of a 50:50 mixture (by number of fibres) of 3 μm and 17 μm and E_3 is the energy for a bimodal distribution of a 50:50 mixture (by number of fibres) of 1 μm and 19 μm. As the actual fibre distributions are not so simple as these examples, the above comparison data are only approximate.

However, the data indicate that a monodisperse fibre distribution requires much less energy than a polydisperse distribution with the same average fibre diameter. It is a great disadvantage to energy conservation to produce finer fibres than are necessary for the practical use. It can easily be understood without calculating a more complicated equation, that from the equation

$$E = 8M^3/(\rho^2 \pi^2 d^4) \tag{3}$$

The energy E increases when *d* decreases at a constant value, of *M*. It is necessary to equalize the polymer and the gas flow rates at each hole to get a monodisperse distribution. A redesign of the meltblowing die' *1* has been carried out by Nippon Kodoshi to improve the uniformity in the polymer and the gas delivery. This die is designed for the heated gas to blow through a labyrinth. The lamination of meltblown fabrics with other materials is employed to improve the nonwoven properties.

Spinning of aesthetic fibres

Aesthetic fibres are highly fashionable materials which have superior aesthetic and sensual factors such as appearance, colour, handle and touch, softness, bulkiness, and special texture. Highly aesthetic thin fabrics are used for costly dresses. The medium and thick fabrics are used for suits, skirts, slacks, formal wear, coats and sports/casual wear. Silk fabrics have been used for women's dresses and blouses for hundreds of years.

First generation silk-like fibres appeared in the 1960s. They have a triangular cross-section and a luster similar to silk. The non-circular cross-sections give the fibre not only a different luster, but also a remarkable change of bending stiffness, coefficient of friction, softness and handle.

A regular triangular cross-section gives, for example, a fibre with 1.2 times larger bending stiffness compared with that of a round section. The fibres with flat cross-section, on the other hand, have much lower bending stiffness and softer handle. The handle (hand values) can be measured objectively by Kawabata's Evaluation System (KES), developed recently.' The hand values are expressed by various factors such as:

— stiffness.
— spread and anti-drape.
— fullness and softness.
— crispness.
— scroopy feeling.
— smoothness.
— flexibility with soft feeling.

Second generation silk-like fabrics appeared in the 1970s, with a much refined appearance, softness and bulkiness. When fabrics composed of a blend of two types of filaments with different shrinkabilities are heated during the finishing process, a difference in filament length occurs and makes the fabric much bulkier and softer. The fabrics are also treated with an aqueous solution of sodium hydroxide to remove about 25%, by weight, of the polymer. This alkaline reduction treatment gives the fabric excellent softness. These second generation silk-like fabrics became the most important material for women's blouses and dresses until 1990 because of the excellent appearance, handle and texture obtained by applying these technologies.

Third generation appeared in the 1980s through applying:

— Highly specialized non-circular cross-sections.
— Blends of filaments having 'super differential shrinkability'.

— Splitting of bicomponent composite filaments.
— Surface treatment to produce complicated porous or micro-groove structures in the surface of the filament.

These textiles are produced through a series of processes, including polymerization, spinning, drawing, fibre-blending, texturing, weaving, knitting, dyeing and finishing. In this chapter, the technologies for fibre production will be described and, in addition, the combinations with texturing, dyeing and finishing technology will be explained.

Regular melt-spun fibres hive -circular sections due to the round orifices of the spinneret. Most highly-aesthetic fibres have non-circular sections produced with non-circular orifices. Various types of specialized section have been developed to give various and delicate luster, handle and texture to the fabrics. These specialized sections are produced with special orifices, such as a slit, L-shape, T-shape H, W, X or similar modified slits, combina'ion of circle and slit, and arranged plural circles.

Woven fabrics composed of blended yarns which have 'differential shrinkage' are widely used for the second and third generation silk-like fabrics. Highly bulky and soft structures can be obtained by heating blended yarns in which highly shrinkable filaments and less shrinkable filaments are mixed together. The blending of a number of filaments may be carried out during the spinning, drawing, doubling, twisting or false-twisting processes.

Various kinds of air-jet nozzle are also employed to produce uniformly or randomly blended and entangled filaments which give the finished fabrics various and delicate appearances and textures. Highly shrinkable filaments are produced by copolymerization which reduces the crystallinity of the polymer, and/or by removal of the heat treatment process after drawing of the filaments. Less shrinkable filaments are, on the other hand, produced by stronger heat treatment after the drawing, or by 'super-high-speed spinning' which has been developed recently. Most conventional differential-shrinkage yarn is a mixture of filaments heat treated after the drawing and untreated filaments.

Recently, super-high-shrink filaments made of a copolymer and self-extensible filaments have come into practical use. The differential-shrinkage yarn has been replaced by 'super-differ-ential-shrinkage yarn' which gives the fabrics extremely high bulkiness, softness and excellent texture.

The principle of a self-extensible filament was known many years ago, however, it was not applied until the appearance of the third generation silk-like fabrics. Polyester filament yarn is drawn at a lower temperature and with a smaller draw ratio than usual. These drawn filaments are relaxed (shrunk) at a low temperature (around 100°C) to produce a special filament yarn having a low crystallinity and orientation. This is the self-extensible filament yarn.

Self-extensible filaments extend themselves (become longer) due to an increase in crystallinity and orientation on treatment at a high temperature (more than 100°Q during the dyeing and finishing of the fabrics. Filament yarns that have various shrinkabilities and extensibilities are produced by controlling the crystallinity and orientation using the technologies of copolymerization, spinning, drawing and heat treatment.

Mixed-spinning

One of the objectives of mixed-spinning is to increase the specific gravity of the fibre and improve the drapeability of fabrics by mixing with inorganic particles which have a high specific gravity. Metallic compounds having high specific gravity and white colour, such as titanium oxide, zinc oxide and barium sulphate, are suitable. A specific gravity of 1.5 is the most desirable from the viewpoint of drapeability.

Generally, the mixing is carried out at the polymerization process, but it can also be done between polymerization and spinning, or at the spinning process. The content of inorganic particles should be less than 10% by weight, usually less than 5% to avoid the risk of frictional damage to the apparatus during the spinning, drawing, weaving or knitting processes due to the inorganic particles of the fibre.

A particle diameter of less than 1 μm, and preferably less than 0.5 μm, is desirable to obtain better spinnability. Most fabrics of high specific gravity have a dull luster due to the mixed pigment particles. The surface of alkaline-treated fabrics of high specific gravity fibres has innumerable micro-holes due to the higher degradation rate of the polymer near the particles. The porous structure gives the fabric a dry and cool handle. This type of Shingosen is called 'Rayon type' because of its high drapeability, dull luster and cool and dry feeling. The other purpose of mixed-spinning is to produce numerous microholes, micro-craters and/or micro-grooves by a post-treatment (alkaline reduction), giving the finished fabrics a deep colour, a good appearance, and a good handle.

Various kinds of metallic compounds such as titanium oxide, zinc oxide, kaolin, alumina, calcium carbonate, barium sulphate, zeolite and silica can be applied for this purpose. Various kinds of polymers having different alkaline degradation rates are also mixed- spun or conjugate-spun to form microporous structures or micro-grooves in the surface of the fibre.

Splitting of conjugate fibres

The most important applications of conjugate fibres is the production of superfine fibres and special cross-sections by the splitting of the original conjugate fibres.

The five major applications of superfine fibres are:

- Artificial suedes.
- Second generation artificial leathers.
- Moisture-permeable, water-repellent, high density fabrics.
- Silk-like fabrics.
- High-performance wiping cloths.

Bicomponent conjugate fibres are split by:

- Dissolution or degradation of a component polymer.
- Separation of the two components caused by swelling and shrinkage of a component.
- Separation of the components by mechanical distortion.

Combinations of two components which have a large difference in solubility, degradability or swelling and combinations which have poor adhesion are chosen for the conjugate fibres.

Furthermore, a suitable conjugate arrangement must be chosen to promote easy separation. A fabric made from the radially conjugated fibre has an extremely soft and smooth handle and delicate appearance due to a superfine pile (micro pile). In this case, the component shrinks only a little. This causes the polyester superfine fibre to be raised from the substratum structure to form a pile, making the fabric very bulky and soft. A flower-like conjugate fibre in which two components are combined.

One of the components, for the core and the eight petal-like segments, is polyethylene tereplithalate. The other component, between the polyester segments, is a readily soluble or degradable modified polyester. The readily soluble polyester has a very high rate of degradation, ten to a hundred times that of regular polyethylene tereplithalate.

A fabric in which highly shrinkable filaments are blended so as to raise the superfine fibres made by the splitting of the flower-like conjugate fibre to form a pile, giving the structure higher softness and bulkiness. Some superfine fibre is produced by direct melt spinning, which is limited to a linear density of 0.4 denier. Superfine filament yarn having a linear density of 0. 1 denier, for example, can be produced today by highly advanced melt spinning technologies. However, it is very difficult to handle the superfine filament yarn at the drawing, texturing, knitting and weaving process.

Recently, 'funny fibres' or 'very interesting fibres' became topics for the fibre industry. The funny fibres or fabrics have Practical, or sometimes impractical, properties such as thermochromic, photochromic, perfumed, antibacterial, deodorant, heat-storing, water-repellent, water-absorbent and electro conductive effects. Some of these funny fibres have recently been developed by specialized spinning technology, such as perfumed conjugate fibres composed of a terpe-ne-containing polymer and a fibre-forming polymer, antibacterial fibres in which zeolite particles containing silver ions are blended, light-to-heat transferring fibres in which carbonised zirconium particles are blended, and water absorbent fibres having a hollow and porous structure or a slit as a water passage.

Spinning of optical fibre

Optical fibre is composed of a light-transmitting, transparent core material coated with a material with lower refractive index. They are classified into three groups according to the types of core material, quartz, multi-component and plastic optical fibres (POF). Quartz optical fibre is used for long-distance optical communication including public trunk lines because its transmission loss is as low as 1 dB/km or under. The multi-component optical fibre is used for middle-distance communication of 1-2 km including local area networks (LAN) in plants and fibrescopes. The plastic optical fibre has advantages in that its inexpensive, flexible, light and easy to process, though the transmission loss is as high as 120-130 dB/km.

Plastic optical fibre

Structure of plastic optical fibre is classified by the transmission methods into the step index (SI) and graded index (GI) types.

Commercial plastic optical fibre is of the SI type. The GI type has not been commercialized yet. It is interesting that the transmission loss and transmission bandwidth of the GI type plastic optical fibre are 134 dB/km and 360 MHz. km, respectively Recently, a single mode plastic optical fibre has been proposed and manufactured on an experi-mental basis and the types are being rapidly varied. The structural dimensions of the plastic optical fibre using PMMA as the core material are being standardized in such a way that the core diameter and sheath thickness of a plastic optical fibre 1000 mm in outer diameter are 980 and 10 mm, respectively. The area ratio of the core is so large that it is characterized easily by connecting an optical fibre to a light source and another optical fibre in alignment.

Materials of both the core and sheath of the plastic optical fibre require high transparency. Although commercially available PMMA and polycarbonate (PC) are generally used as the core material, silicone and thermosetting resins, MMA-methacrylic anhydride copolymer, MMA maleic anhydride copolymer, MMA-methacrylicimide copolymer and ionomers are being investigated. Since the refractive index of the sheath material should be lower than that of the core material, fluoroplastics including poly (vinylidene fluoride), Teflon FEP, Teflon AF, fluorinated methacrylate and fluroinated polycar-bonate are used as the sheath material. Polymethyl-pentene is used as the sheath material for a plastic optical , fibre with a relatively high refractive index of 1.59 using fluorinated polycarbonate as the core material.

Causes of the transmission loss of the plastic optical fibre are classified into the loss inherent in the material itself and the external loss from the manufacturing technology. Kaino investigated the internal losses theoretically including the losses on absorption and scattering for a plastic optical fibre using PMMA as the core material and estimated that the limit of the internal loss was 106.2 dB/km at a wavelength of 650 nm in the visible LED. Although the transmission loss at a wavelength of 568 nm is 60-70 dB/km which is 30-40 dB/ km smaller than the limiting loss, it is considerably lower than the value for the product manufactured on the industrial scale. This transmission loss is 120 dB/km at a wavelength in the vicinity of 650 nm in the visible LED used for communication which is close to 106.2 dB/km, the limiting loss obtained by Kaino. The process for commercially manufacturing a low-transmission loss plastic optical fibre using PMMA as the core material will now be described.

Mitsubishi Rayon started to produce high-purity PMMA for the first time by an industrial continuous bulk polymerization of MMA in 1970. Based on the actual results obtained by the operation of the process, Mitsubishi Rayon put Eska Extra, the plastic optical fibre for communication, on the market in 1983 by combining the continuous polymerization technology of MMA with the melt spinning technology of polyester and polypropylene fibres. The transmission loss of this product was half that of conventional plastic optical fibres and the transmission distance was increased to as long as 150 m.

MMA contains a polymerization inhibitor, which should be removed by distillation. When a hydroquinone derivative, generally used as the polymerization inhibitor, remains in the final product, it absorbs visible wavelengths. The dissolved oxygen in the monomer reacts with the monomer or molecular weight modifier in the polymerization process and forms a peroxide which easily colours PMMA. MMA peroxides contained in the monomer should also be removed. These peroxides can be removed by pretreatment with a reducing agent followed by distillation.

Various methods for removing compounds contained in the monomer affecting the visible wavelengths have been described. After removing the polymerization inhibitor and molecular weight modifier from the monomer by distillation and also thoroughly removing impurities by vapour and liquid-phase filters, the monomer is ready for polymerization. A vapour phase filter using hollow yams with an aperture of 700A is effective. Various other purification processes for the monomer have also been proposed. The bulk polymerization process is most suitable for the manufacture of plastic optical fibres because polymerization additives, other than the polymerization inhibitor and molecular weight modifier, are not used.

Mitsubishi Rayon has developed a process for manufacturing PMMA involving continuous bulk polymerization of MMA followed by a process for removing volatile matter such as unreacted monomer. PMMA is manufactured in this newly-developed process in such a way that MMA is polymerized using tens of ppm of the polymerization initiator and molecular weight modifier at 130-180°C for several hours at a yield of approximately 60 wt% and the volatile matter, including unreacted monomer and molecular weight modifier, is then removed.

This polymerization process is an integral part of the manufacturing process of Eska Extra. It is important for stable polymerization to produce a uniformly mixed blend of monomer and polymer. Since the termination reaction is retarded by the increase of the viscosity in the polymerization reaction, the polymerization sometimes proceeds rapidly by the gel effect into a runaway reaction. It is, therefore, important to remove the heat of polymerization effectively by reducing the viscosity to below a specified value and uniformly stirring the polymerization product. Since variations in the degree of polymerization and the viscosity of the blend cause variations in the blend transportation and volatile-removing process, the transmission loss of the plastic optical fibre can vary. The polymerization temperature is preferably kept low so that there is no gel effect.

Oligomers including MMA dimer are produced as by products by increasing the polymerization temperature. Since the oligomers are so thermally unstable that they are easily coloured, the absorption of the plastic optical fibre is increased. Important features of the volatile-removing process are to remove the volatile matter including monomer, at a temperature as low as possible, to avoid locally heating the polymer by high shearing, to prevent any dead space from forming in the equipment and to inhibit the generation of impurities from the equipment. Two processes are proposed for the volatile-removing process.

In a conventional extruder with a degassing vent, an upward degassing vent is connected to the evacuation line ahead of the blend-feeding hole and directly connected to the extruder cylinder. In the newly-developed extruder, however, the degassing vent is fixed behind the blend-feeding hole so that part of the blend is sent to the rear of the shaft of the screw through an inverse pitch screw channel, so that the volatile matter is steadily discharged together with the blend from the system without mixing the impurities generated by rubbing at the shaft seal with the polymerization product. Since the direction of the degassing hole is horizontal, the polymer discharged from it together with the monomer does not return to the screw channel. Impurity-free polymer is, therefore, continuously extruded from the end of the extruder.

Spinning techniques

Attention has to be paid to the following matters in the spinning of plastic optical fibre:

1. Avoiding long residues of the polymer in piping and equipment
2. Preventing extraneous matter being generated from the equipment
3. Designing a high-level spinning nozzle.
4. Optimizing the viscosities of molten core and sheath materials.

It is necessary to shorten the length of the piping after the polymerization process as much as possible and to electropolish the inside surface of the pipe to reduce the surface resistance. It is also necessary to increase the bending radius of the pipe as much as possible. It is important to conduct dead-end polymerization to prevent the polymer from staying in the piping end of the equipment.

Dead-end polymerization is a process in which polymerization does not proceed after a specified time has passed. Even if any dead reactant space remains present in dead-end polymerization, the reactant is not polymerised there in practice. For preventing the generation of extraneous matter from the equipment, the volatile-removing equipment has a mechanism for discharging contaminant polymer from the shearing part and degassing hole. It also has a constant-volume gear pump which steadily discharges the contaminant produced from the rotating-shearing part.

The transmission loss caused by imperfect fibrous structure, including irregular interface and unequal core diameters, is mainly derived from the spinning process. Optimum design of the spinning nozzle and adaption of the fluidity of polymer to the spinning conditions are required for reducing the loss. The transmission loss of the plastic optical fibre is increased by the colour developed by heating the core material, it should be spun at as low a temperature as possible. The melt viscosity of the core material is, however, raised to tens of thousands of poise at such a low temperature. The operational conditions including molecular weight, temperature, inner diameter of nozzle and output should be optimized by keeping the shear stress in the nozzle at 10^6 dyne/cm^2 or less to prevent the development of melt fracture.

Although composite melt spinning is effectively used for a composite fibre and multilayer film, the instability of the shape of the interface is interesting. A low viscosity material generally encapsulates a high viscosity material during passage through a circular die because the low viscosity material migrates to the high shear region at the die surface. Since the smoothness of the interface between the core and the sheath is important, the melt viscosities of core and sheath should be optimized. Research into reducing the transmission loss of plastic optical fibre has been energetically pursued and values for commercially available plastic optical fibre products are as low as 120 dB/km at a wavelength of 650 nm. Since the value for the plastic optical fibre using PMMA as the core material should still be capable of reduction by a further 20 dB/km, improvements in the process and material are expected.

For further decreases in the transmission loss of the plastic optical fibre, the development of transparent materials including floropolymers is expected. When these are developed, the transmission loss may theoretically be reduced to 5 dB/km.

The plastic optical fibre using PC as the core material has a heat resistance of 120°C or higher which is 30°C or so higher than that of the plastic optical fibre using PMMA as the core material. After commercialization of this plastic optical fibre by Mitsubishi Rayon in 1986, Fujitsu, Teijin Kasei, Idemitsu Petrochemical and Asahi Kasei have also successfully commercialized it. PC polymer is dissolved in an organic solvent containing methylene chloride, and unreacted substances and by-products are removed from the solvent solution by washing.

The polymer is recovered by removing the solvent using a spray drying method. This recovered polymer is usually pelletized by melt extrusion at a temperature higher than the crystalline melting point of 245°C, but the polymer thermally degrades at 280-320°C. Even though pellets of such a PC polymer containing thermal decomposition products can be used for the melt spinning of plastic optical fibre, high-transmissibility product cannot be obtained. It is, therefore, necessary to directly carry out the melt spinning of polymer recovered from the polymerization process without pelletizing it to produce a plastic optical fibre with high transmissibility. It is also necessary to inhibit crystallization of polymer during the melt spinning. Since the crystallization point of PC reaches its maximum at approximately 190°C, the molding temperature should be 210°C or higher.

The plastic optical fibre using organic silicone as core material is characterized by flexibility and resistance to heat and chemicals. Sumitomo Denko has commercialized such a fibre composed of silicone rubber as the core and Teflon FEP as the sheath. Three manufacturing processes are as follows:

— A mixture of vinyl alkyl siloxane and a platinum catalyst is filtered and the filtrate is injected into a hollow tube of a tetrafluoroethylene/ hexafluoro-propylene copolymer (FEP) under vacuum followed by thermal polymerization.

— Using a mixture of liquid siloxane polymer and a hydrogen chloroplatinate as the core material, and liquid siloxane polymer with lower refractive index that of the core materials as the sheath material, both materials are fed at the same time through nozzles 2 mm and 4 mm in, diameter, respectively to a thermal cross-linking stage in a heater.

— A fibre of the core material is manufactured in the same way as in 2 and the sheath material is coated by dip coating.

Since the plastic optical fibre using thermosetting resign as core material has good retention of shape at high temperature, Hitachi Densen has placed it on the market. It is composed of a thermosetting design as the core material and Teflon FEP as the material. The monomer is fed through a pump into a stainless steel tube lined with Teflon. It is polymerized in a hot water tank so that the viscosity of the polymer reaches 10^4 poise. A fibrous resin is extruded from the nozzle and heated by an infrared heater to form the core. The resin is then coated with a cladding material.

Multi-picture element plastic optical fibre

Sheet and block-type Multi-picture element plastic optical fibres are presently manufactured by accurately arranging a filament, this process requires much time. An integral melt spinning process is being developed.

A sheet-type plastic optical fibre is used as an optical line sensor and image guide for reading drawings and detecting defects. It is manufactured as follows. The core and sheath materials are spun through a composite spinning nozzle in the same way as the single filament plastic optical fibre except that the spinning nozzle has many circularly arranged orifices.

Many fibres are brought near to each other along the spin-guide and are stuck together in the form of a circular arc on a sticking guide located slightly apart from, and directly below, the spin-guide. They are then passed through an arranging guide located below the sticking guide and the fibres arranged in a straight line are drawn off by the nip rolls. Since the transit distances of the fibres from the spinning nozzle to the spin-guide are equal, uniform sheet type optical transmitters can be manufactured without deformation by processing.

An image fibre composed of a bundle of many ultra-fine optical fibres has been used for endoscopes and the like. Since multi-component glass and quartz are brittle, further development of plastic image fibres is expected. In 1988 Mitsubishi Rayon developed and commercialized a plastic image fibre composed of a bundle of approximately 1500 stepindex type plastic optical fibres 10-20 μm in diameter based on their precise composite melt spinning technique.

Following further programs for thinning the fibre and improving the resolving power, a plastic image fibre composed of a bundle of approximately 3000 ultrafine optical fibres 10 μn or less in diameter was developed in April 1991. It reveals that the circular plastic image fibre with a diameter of approximately 0.5 mm has approximately 3000 plastic optical fibres very closely packed.

Each fibre corresponds to one picture element and is approximately 9 mm in diameter. The diameter of core and the thickness of sheath are approximately 7 mm and 1 mm, respectively. The plastic image fibre is characterized by higher flexibility, greater flexing resistance and resolving power and a brighter image than those of a glass image fibre. The modulus of elasticity of the plastic image fibre is 1/10 or less that of a quartz image fibre and it is very flexible.

The brightness of image is expressed by:

$$E = FK_e \quad (1)$$

where E = brightness of image, F = performance index of the plastic optical fibre constituting a plastic image fibre and K, = ratio of core area to the total cross-sectional area of fibre. Using fibres with the same K, , E is proportional to F. F is expressed by the following formula:

$$F = (NA)2\ 10(-Od/10) \quad (2)$$

where NA = number of apertures, a = transmission loss and I = length of fibre. Although the plastic image fibre has a number of apertures as large as 0.5 and the transmission loss is as high as 600 dB/km, the plastic image fibres that are only a few metres long have larger F values than those of image fibres composed of other materials. The molten core material fed to the nozzle is divided into core-forming plates and the sheath and intervening materials are fed to the circumference of the core inside the nozzle.

A fibre composed of concentrically arranged core-sheath intervening components is discharged from the outlet and integrated into a uniformly arranged plastic, image fibre at the integrating nozzle. Since organic optical fibres have special features for short-distance optical transmission media including low transmission loss and high heat resistance, various applications are expected. It is important to develop more reliable products as well as to reduce the transmission loss and develop wide range fibres for extending the present applications.

Spinning of ultra-fine fibres

The definition of ultra-fine fibre has varied according to the convention employed. For instance, a micro-denier fibre is a fibre finer than 1.2 dtex for polyester and finer than 1.0 dtex for polyamide. Although a rather thick (1 denier or more) fibre is sometimes claimed as an ultra-fine fibre commercially, an ultra-fine fibre should preferably be specified as a fibre of less than 0.5 d. Ultra-fine fibres are classified into two types:

1. A continuous-filament type and
2. A random (staple) type.

Continuous-filament type

Ultra-fine fibre of the continuous-filament type is now produced by a variety of methods including:

1. Direct spinning
2. Conjugate spinning:
   a) islands-in-a-sea type;
   b) separation type or splitting type;
   c) multi-layer type.

Random (staple) type

Ultra-fine fibres of the random type are produced by:

1. Melt-blowing or jet spinning.
2. Flash-spinning.
3. Polymer-blend spinning.
4. Centrifugal spinning.
5. Fibrillation or violent flexing.
6. Turbulent flow-moulding
7. Bursting.
8. Other methods.

Different ultra-fine fibres are designed to provide the following characteristics:

1. Softness, flexibility and smoothness.
2. Fine textile structure.

3. Micro-pockets in fabrics.
4. High filament density at the textile surface.
5. Large surface area per unit weight, and a characteristic interfacial property.
6. Small radius of curvature (resulting in luster and characteristic colour)
7. Large aspect ratio and easy entanglement.
8. Good interpenetrating capacity in other materials.
9. Quick stress relief.
10. Low resistance to bending.
11. Bio-singularity relative to living tissues and fluids.
12. Fine, sharp edges.

Since the cross-sectional area A, the second moment of the cross-section M and the torsion I_p are given by $A = (\pi/4)D^2$, $M = (\pi/64)D^4$, and $I_p = (\pi/32)D^4$, with D being the diameter of the cross-section of a filament, these values decrease exponentially as the diameter D decreases. Thus the flexibility of ultra-fine fibres is the result of a small cross-sectional diameter.

Ultra-fine fibres are applied to the fabrication of silk-like materials and have revealed characteristics surpassing natural silk. As a result, ultra-fine fibres of 0.1 to 0.5 denier have attracted much attention in Europe and the USA. Ultra-fine fibres were produced by melt-blow spinning and flash spinning in the late 1950s. 1-5 .

These fibres were not of the continuous filament type but were fine staple fibres of random length which found no application except for being processed into nonwoven sheets immediately after spinning. Ultra-fine fibres of a continuous-filament type have a relatively recent history. A petal-shaped conjugate fibre described in a Du Pont patent was probably the first example of a potential ultra-fine filament.

This patent was issued in 1961 as one of several patents for the production of fibres with a triangular cross-section. It was aimed at producing a fibre with a sharp edge by utilizing the boundary of two components *A* and *B*. Another patent, issued simultaneously from Du Pont, described splitting two-component conjugate fibres of non-circular cross-section into the two separate components after weaving. No attention was paid at that time to combining these technologies to produce ultra-fine fibres, since the fibre with a sharp edge was the primary concern.

Okamoto *et al.* of Toray developed conjugate spinning technology for the production of ultra-fine filaments in the mid 1960s by increasing the splitting number of *A* and *B* components. Here two components, *A* and *B*, are arranged alternately and extruded to yield a conjugate filament which is split into ultra-fine fibres after processing. This was the first attempt to produce an ultra-fine fibre intentionally. Ultra-fine fibres can be extruded by reducing the polymer output at the spinneret and drawing with a large draw ratio. However, polyester for instance, cannot be extruded at less than about 0.15 g/min, because the monofilament will break during the fibre-forming process just after the extrusion. No drawn ultra-fine fibre less than 0.3 denier has been obtained by conventional extrusion.

Spinning of the continuous-filament type

Direct spinning

Direct spinning method is an extension of conventional spinning, where the spinning conditions are optimised so as to be suitable for the production of ultra-fine fibres. In the application of conventional melt spinning, the following problems can be foreseen:

1. Fibre break-down (dripping).

2. Variation of filament thickness.
3. Spinneret clogging.
4. Denier variability among filaments in a single yam.

The following precautions are taken in order to avoid these problems:

1. Optimization of polymer viscosity
2. Optimization of the spinneret design
3. Optimization of the ambient temperature underneath the spinneret
4. Optimization of filament assembly
5. Optimization of spinning draft
6. Lower rates of extrusion
7. Purification of spinning polymer

Conditions for production of ultra-fine fibres of less than 0.3 denier are-that the polymer melt viscosity should be adjusted to be less than 950 poise, the cross-sectional area per spinneret hole should be less than 3.5×10^{-4} cm^2, the ambient, temperature at 1-3 cm underneath the spinneret should be kept below 200°C, and the extruded filaments should be assembled at 10-200 cm underneath the spinneret. Asahi Chemical Industry Co. has succeeded in producing ultra-fine polyester fibre of less than 0.15 denier by extruding polyester of melt viscosity less than 480 poise through a spinneret with over 300 holes, of less than 1×10^{-4} cm^2 cross-sectional area per hole, arranged concentrically.

However, the extruded polymer tends to form droplets and e xhibits no drawability unless the thermal environment immediately below the spinneret is suitably controlled. The ambient temperature at cm underneath the spinneret holes must be kept below 150°C by blowing cold air from the circumference of the spinning threadline to enable the polymer to be drawn into filaments.

These concentrically arranged filaments should all be cooled at the same rate. Then the filaments are assembled at 20-70 cm underneath the spinneret holes, and wound up as undrawn fibre. This undrawn fibre can be drawn conventionally to yield ultra-fine fibre of less than 0.15 denier. The Teijin Co. has investigated the influence of air friction on the high-speed spinning of ultra-fine fibre. Although the PET filament is drawn only 4-6-fold in a conventional process, it can be drawn 10-20-fold in a particular condition called superdraw.

Du Pont has proposed a method for producing ultra-fine fibres by super-draw, but no industrial application has been implemented so far because of the unstable and restricted conditions required. Ultra-fine fibres can be produced by wet spinning. The following points should be observed in the technical application:

1. The solvent should be chosen so as not to form a porous structure in the resulting fibre, and the solution concentration should be adjusted to the optimum level for ultra-fine fibre spinning.
2. The spinning solution should be filtered through a fine filter to eliminate particles larger than 1/3 of the nozzle diameter.
3. The nozzle diameter should be less than 30 gm and a multi-hole system is desirable for industrial purposes.
4. Drawing can be performed by a conventional technique.

In the case of acrylic fibre spinning using a polyacrylonitrile/vinyl acetate/sodium methacryl-sulphonate (92.5/7.0/0.5) copolymer, an ultrafine acrylic fibre of 0.06-0.4 denier with a tenacity of 3.0 g/denier and 26% extension is produced under the following spinning conditions.

1. Specific viscosity: 0.17-0.19.
2. Solvent: dimethylacetamide or dimethylformamide.

3. Concentration: 16-19% solute.
4. Filter: sintered metal filter of less than 10 m filtration cut-off.
5. Nozzle diameter: 20-30 mm.
6. Number of nozzle holes: 40 000-80 000.

A single-component ultra-fine fibre is obtained by direct spinning, and the later processes require no complicated processing such as splitting into two components or removing a second component.

Conjugate spinning

The idea of conjugate spinning predates direct spinning for the production of ultrafine fibres. Okamoto *et al* (Toray) and Matsui *et al* (Kanebo) investigated the extrusion of conjugate fibres with a cross-section consisting of highly-dispersed conjugate components by modifying the spinneret structure. Okamoto suggested that the resulting conjugate fibres should be termed 'alternately-arranged-polymer fibres' in order to express correctly both the morphology in the longitudinal direction and the islands-in-a-sea structure in the lateral direction.

Alternately-arranged polymer spinning is classified into two types from the technical viewpoint:

i) the islands-in-a-sea type, where the sea component is removed by dissolving it in a solvent, and
ii) the separation type or splitting type, where Breen of DuPont's patent has been applied to ultra-fine fibreization. In either case, no drawing is required at spinning and the micro-fibreization is performed in the form of fabrics.

No special technical problems arise at later processing compared with conventional spinning. The number of two-component polymer flows in a bundle determines the thickness of the resultant filaments. Although it depends on the assembling process of two-component polymer flow, the sheath-and-core type has an advantage with respect to obtaining the desired number of split filaments since the components in the splitting type may mingle during the assembling process. Polyester, nylon, polypropylene, polyethylene and polyphenylene sulfide are among the polymers employed as island components.

A sea-component, such as polystyrene, a 2-ethylhexyl acrylate copolymer or a copolymer of ethylene terephthalate and sodium sulfo-isophthalate, is removed by dissolving it in a solvent after conventional processing into woven, knitted or nonwoven fabrics. Thus there is no fundamental difference in spinning and further processing from conventional melt spinning. For example, the extrusion temperature is 275-300°C when PET is employed as an island component.

The micro-fibreization takes place after the macro-filaments have been processed conventionally into fabrics. This technology has provided a means of industrial production of suede-type artificial leather, silk-like fabrics, wiping cloths and fine filters made of ultra-fine fibres. The number of islands in the ultra-fine multifilament yam is specified by the design of the spinneret. The ratio of the island component to the sea component is determined by the extrusion rate of each component.

Three-component spinning can be carried out with two island-components by designing a three-component spinneret assembly. The sea-component can be reduced to 2-10% of the total components from the purely technological point of view, but the space between the ultra-fine filaments is also reduced and this may lead to poorer handle of the products.

When the sea-component is small in amount and not miscible with the island-component, the splitting can be carried out mechanically. Since the ultra-fine filaments are sheathed by the sea-component in the islands-in-a-sea type, they are protectedfrom damage during later processing. This technology is capable of producing a PET filament of 0.00009 denier. Only 4.16 g of such a filament would be enough to stretch from the earth to the moon.

The technology has been further extended to spin a multi-component conjugate fibre, and a suede-type artificial leather of high dyeability has been developed with a three-component conjugate extrusion where the two-component (polyester and nylon 6) ultra-fine fibre had a sheath-and-core structure. Many variations will be found in islands-in-a-sea spinning, such as extremely-many-islands-component spinning for wiping cloths, non-circular cross-sectional or non-even lateral surface island-omponent spinning, and blended island component spinning.

Splitting type spinning

This type of spinning aims to utilize the second component in the final product as well as the first by splitting the two components mechanically instead of removing the second component by dissolving. The fundamental principles of this technology will be found in the inventions by Breen and Tanner of Du Pont, although these inventors had no intention of applying their idea to the production of ultra-fine fibres. Since the commercial success of the artificial leather made from the alternately-arranged two-component fine fibre, this alternative spinning technology has been refined by Kanebo, Teijin and Toray to produce ultra-fine fibres.

Their ultra-fine spinning technology consists of the combination and separation of PET and nylon, the use of benzyl alcohol for effective shrinkage of the nylon component, and the establishment of dyeing technology for dyeing PET and nylon of different dyeing characteristics simultaneously with high colour fastness. These ultra-fine fibres have been developed mainly into moisture-permeable and water-repellent fabrics, along with suede-type artificial leather, silk-like fabrics and wiping cloths.

The ultra-fine fibreization is performed by a mechanical or chemical process in the splitting and separation types of spinning. Here the point is how many divisions of two components can be achieved. The commercial ultra-fine fibres are now produced by a specially designed spinneret.

Toray and Kanebo employ a spinneret with a*-shaped cross-section, which is a modified version of that described in Breen's patent. The fibre, with a + -shaped cross-section, divides the second component into four wedges in this process. Kanebo has added another wedge component to each of the four wedges in order to increase the splitting probability in later processes. Its cross-section looks like a *-shaped conjugate fibre. Teijin produces hollow-cylindrical conjugate fibre with a petal-shaped cross-section. The basic design of the spinneret is similar to those of Du Pont and Toray for the petal-shaped conjugate fibre. The hollow was introduced to avoid flattening and sharp edges in the resulting filaments even when the splitting number is increased.

A good handle will be achieved when the spacing between ultra-fine filaments is large in the fabric. The hollow portion preserves the spacing between filaments after splitting, although the split filaments tend to arrange with the original cross-section before splitting because of the spatial restrictions in the fabric. A proper choice of the spinneret and component polymers is vital in ultra-fine fibre spinning by this technique.

PET and nylon 6 form the most popular combination found in the commercial products, since both components have a similar temperature range for extrusion and drawing. Fluffing during the drawing or weaving process can be avoided by improving the adhesion of two components, for example, by using the copolymer of PET and sodium sulfo-isophthalate as the PET component. Splitting during the spinning process can be reduced by increasing the spinning speed so that the PET and nylon exhibit similar shrinking behaviour.

Multi-layer type spinning

Liquids can be multi-layered by static mixers, which have been applied to multi-layer type spinning. Kanebo, Kuraray and Toray investigated this multi-layer type spinning technology. Kuraray introduced the first commercial multi-layer type ultra-fine fibre product. Here the two components, polyester and nylon 6, are spun into a conjugate fibre of multi-layered structure with an oval-shaped cross-section, which is micro-fibreized into filaments of 0.2-0.3 denier during the dyeing process.

Random-type spinning

Melt-blowing

Melt-blowing method is employed for the production of nonwoven fabrics of polypropylene ultra-fine fibres. The polymer melt is blown apart immediately after extrusion by an air-jet stream in this method, so it is sometimes termed 'jet spinning'. Thus, this method is an application of spraying technology rather than true spinning.

The melt viscosity is lower than that of the conventional polypropylene used for melt spinning, and an appropriate range of melt viscosity should be chosen to achieve the required result. The spinneret has a sharp edge and the jet stream blows off the extruded polymer melt into ultra-fine fibres that are collected as nonwovens. New technology has been developed for the production of electrets on these polypropylene nonwovens to meet the requirements for a clean environment.

Flash spinning

Flash spinning technology was found by Du Pont accidentally while examining the explosion behaviour of organic solvents for safety research. As an example of the process, polyethylene is dissolved in hydrocarbon or methylene chloride, heated under pressure, and jetted from a nozzle into a micro-networked fibre termed a 'plexifilament'. Ethylene chloride and fluorocarbon have been used as solvents, but they are now being replaced with other solvents which will not destroy the ozone layer.

This technology was first aimed at producing pulp for synthetic paper, but has been converted to produce wrapping materials including wrappings for domestic use and envelopes. The spinning speed is too high to reel in the product in the form of fibre, so the product is made into a sheet. Polymer is dissolved in liquid gas and made into transparent solutions at high temperature under high pressure.

The spinning solution is then liquid-liquid phase-separated to make a turbid solution, which is jetted out of a nozzle into air to form a fibrous network. The homogeneous polymer solution (prepared by extrusion or in autoclave, and kept at a high temperature under high pressure) is extruded through point a and the orifice in the pressure-reducing chamber *b*. Since the pressure at point a is reduced in chamber *b*, the polymer solution separates into two phases, and is then jetted into air through the nozzle.

In the process from b to c, the solvent is gasified instantly and produces a jet stream. The temperature drops to room temperature, and the dissolved polymer is solidified and drawn to form a fibre of high strength. Since the micro-phases of solvent are dispersed in the polymer gel which expands explosively at the time of jetting, the resulting fibre is composed of an extremely thin network of non-circular cross-section fibrils like a cobweb.

Polymer blend spinning

In polymer blend spinning, the conjugate fibre is produced by extruding and drawing a blended polymer melt of two components. The arrangement of the dispersed and non-dispersed (matrix) components is determined by the mixing ratio of the components and their melt viscosities. UCC and others found that discontinuous ultra-fine fibres could be obtained by removing the matrix component while investigating gut extrusion. Fukushima *et al.* of Kuraray successfully applied this method in the production of artificial leather.

A conventional spinning facility can be easily converted for this type of polymer blend spinning by adding a mixer-extruder. Here, the fibre fineness cannot be controlled and the fibre often breaks during spinning, although the spinning stability is strongly dependent on the combination of polymers. Since the dispersed polymer phase is drawn to yield ultra-fine fibres, no continuous-filament type of ultra-fine fibre is produced at present by polymer blend spinning. Other random-type spinning processes for ultra-fine fibre are:

1. Ultra-centrifugal spinning, where ultra-fine fibre is spun like a cotton candy.
2. Fibrillation by beating, where a fibre or film is beaten to fibrillate it.
3. Fibrillation by turbulent flow, where a polymer in solution is coagulated in a zone of turbulent flow.
4. Burst spinning (blown sheet method), where a blowing agent or gas is introduced into the polymer to burst it apart and form ultra-fine staple fibres.
5. Surface dissolving method, where the surface of PET fibres etc. is dissolved in alkaline solution and the fibres are thereby made thinner.

Knowledge-based expert system in spinning

The present management and control devices have increased their efficiency to such a point that a different kind of software is needed. The software must carry out analysis in relation to the different kinds of data, so that it can help the expert in his/her own analysis.

The computer scientist has resorted to conventional data processing for a long time; however, limitations of this approach have forced the scientist to explore other techniques, specifically the application of KBES to solve the problem. KBESs are making inroads into the framework of control and prediction within the spinning process. Before giving examples we define and analyse a KBES.

Knowledge-based expert systems are software, designed to replace or rather assist humans in fields where human expertise is required. Such expertise is important because it is composed of a set of disparate methods; it can also be revised or supplemented with the accumulated experience. They belong to the field of artificial intelligence (AI) which aims at solving delicate and specific problems which require knowledge that is specific to a defined technical area.

With the help of a computer, what a human being would do where deterministic algorithms cannot be used, or would not be efficient, they make it possible to find a solution that is compatible with the state-of-the-art knowledge according to a strategy which leaves a certain intiative to the machine, Bonnet.

This definition allows us to highlight the different functionalities that such an efficient system should possess:

i) The possibility to easily acquire the "know-how", i.e., the system of knowledge representation should be as near as possible to the wording expressed by the expert.

ii) A maximum utilisation of all the elements of the "know-how", i.e., it should be possible to combine and/or link sets of knowledge so that new kinds of knowledge could be deduced as well as new judgments, plans, evidences, decisions, predictions and new reasonings.

iii) An easy alteration of knowledge and reasoning, i.e., to make it possible to easily alter the knowledge base in case of addition, alteration or suppression of knowledge.

iv) Provision to explain the reasoning process when questioned.

Within the frame of a KBES, two major types of representation have been developed:

i) The declarative declaration

ii) The procedural declaration

Each representation meets a, specific question: "to know what" in the case of declarative representation and "to know how" in the case of procedural representation. Each representation has its own specific advantages and disadvantages.

— *Declarative-type knowledge*: It has a simple syntax; it is easy to modify and it needs the procedure type knowledge at run-time. The set of the declarative type structure is generally called data structure.

— *Procedure-type knowledge*: it has a rigorous and complex syntax and it is difficult to modify. The procedure type knowledge is used for the interpretation of the declarative knowledge.

A KBES comprises an inference engine, which is a programme capable of moving from formal deduction to formal deduction by applying formal rules on symbolic facts and axioms so that a solution can be found (diagnosis or action). It is often independent of any application area.

There are three types of actions on the knowledge base:

i) checking or questioning the validity of knowledge;

ii) enriching the knowledge and

iii) triggering off specific actions according to the state of knowledge; in general this entails alterations of the basic knowledge, particularly in the fact part, but occasionally in the rule part.

The knowledge that can be split into:

i) a base of facts, comprising observed events entered by the user in response to system questions. Therefore, facts are knowledge which make it possible to describe specific situations either established, that is to say that they can be proved, or to be established that it is hypothetical or are to be reached. In some cases, to describe blurred or, uncertain facts, a coefficient of likelihood can be attached.

ii) a base of knowledge, comprising axioms ("trivial facts") which are always verified, rules and relations which can be applied to these axioms (IF <condition> THEN <action>).

The rules are operational knowledge which represent expert know-how in a specific application area. They indicate the consequences to be deduced and/or the action to be achieved or carried out when one or a combination of facts corresponding to an established situation or situation to be established, is faced. From a logical point of view, a rule can be defined as P => Q, i.e., if all the conditions of P are true, then H is true, and the action of Q can be effected. The rules are generally of a declarative type, i.e., they can be readily understood.

iii) a consultation module which is used to carry out the interaction. This module is also denoted as "the user interface". Natural language is used as far as possible. It can also integrate a set of sensors. It also enables the computer to communicate the result of the reasoning as a graphic display on the screen or pulse operating a relay. In most cases a KBES provides the user with the reasoning process, the objective to be reached and the rules that are applied.

iv) a module of knowledge acquisition. This module is used to update the knowledge of the usable system.

v) an explanation system, which fulfills the function of the help module.

The reasoning moves on through successive trial and error tests with a heuristic process, i.e., a non-deterministic partly intuitive process search of solution that might be compatible with the system of knowledge. The qualitative treatment prevails over the numerical calculation and may lead to several responses which are equally valid according to the fact that has been ascertained or the acquired knowledge or none. Contrary to an algorithmic programme, KBES can

— indicate the objective to which it tends (answer the question "why?"

— list the process of reasoning in progress (answer to the question "how?"

— enrich its base of knowledge as new experiments are carried on (learning).

Most of the early KBES used to be specialized as well. But the current tendency is to develop KBES shells comprising an inference engine, a particular syntax to represent the rules as well as different tools of development so that the user interface can be constructed. We now take a closer look at how an inference mechanisms that define the power and the capacity of a KBES to closely match human way of reasoning.

The different existing inference mechanisms are derived from two principles of first order logic:

i) the "Modus Ponens" which is based on the following statement:

If P => Q and if P is true, then Q will be true.

ii) the "Universal Specification" is based on the following statement:

If R(x) is true whatever x may be, then R(a) will be true.

Inference mechanism

An inference engine successively examines the basic rules of the knowledge base. The inference process can be guided either by a fact that has been observed (forward chaining) or through the objective which is being looked for (backward chaining).

Forward chaining

A forward chaining denotes the process which starts from the facts to be reasoned with to deduce conclusions. Most of the time this scanning is effected in depth. A rule can be represented by an expression of the type "P => Q" and the inference engine which works in pure forward chaining proceeds along reasoning which says that if P => Q and "if P is true", then Q will be true. The programme looks for the rule RULE1 whose premises are indentical to the fact; the conclusion triggers off looking for the rule RULE2 whose premises are indentical to the previous conclusion until progressively all the rules contained in the base are exhausted.

"Security software" tracks the rules which are used, so that risks of infinite loops are avoided. Before all the rules have been explored, the inference engine stops the process and displays the result or concludes with an exhaustion failure. The different stages during the inference cycle are as follows:

— selecting a subset of knowledge-base;

— comparing the premises of the selected rules with the fact (filtering);

— choosing the rule to be effectively applied;

— applying the rule, modifying the base based on the conclusion of the rules and deactivating that rule, etc.

The advantages and disadvantages of such a forward chaining system are as follows: the inference engine cannot question the user during the cycle;

— quick response: it does not use a lot of memory, the hypothesis to be checked is not stored;

— monotonous: the value of the hypothesis can only be evaluated once;

— irrevocable: the choice of releasing a rule is irremediable and if the way that has been covered in the tree does not lead to any solution, another one cannot be covered. The problem of irrevocability can be resolved by applying a variance of forward chaining called "Strategy by attempts" which allows the system, in case of failure, to use a rule that has been previously discarded.

Backward chaining

Backward chaining aims at verifying the hypothesis or target by comparing it to the facts. Typically, the search is breadth-wise. From a hypothetical conclusion, CIBLE, the programme moves through the base of knowledge to look for the rules whose conclusion is equal to CIBLE. These rules involve CIBLE premises which the inference engine compares to the real facts.

The process is repeated until all the premises of the CIBLE N rule and real facts are identical or sufficiently similar. At that moment, the inference engine stops working and displays the results, failing which, it concludes with an exhaustion failure. The engine therefore tries to establish that a Q hypothesis is true, and so it reasons as follows:

— it looks for all the "Q => P" type rules;

— it evaluates all the P hypotheses and for those whose true value is not established,

— it looks for the "R => P" type rules and then evaluates R and so on and

— if R is true, then P is true and consequently Q is also true.

At each level, the inference engine selects the rules depending on their conclusion by covering a cycle whose stages are the following:

— selection of a subset of the base of knowledge among active rules;

— comparison of the conclusion of the selected rules with the hypothesis to be tested and comparison of the premises with the observed fact (application of rules). If the difference is big, there is an alteration of the target in relation to the premises, the questioning, etc.

It is a mechanism which uses a lot of memory space; the increase of the evaluation tree is exponential. It presents a risk of memory explosion in the case of P =>Q, Q =>R, R=>P type rules. It is revocable and monotonous.

Mixed-chaining

An inference engine combining both forward and backward mechanisms works in a mixed-chaining procedure. It is a mechanism which has the same memory problems as backward chaining; it is revocable. Conversely, it is nonmonotonous, that is to say, the value of a hypothesis can be questioned again. The system agrees upon a CIBLE from which it tries to implement a backward chaining; meanwhile it undertakes a forward chaining from the observed fact.

Working cycle of an inference engine

Whatever the type of chaining, the inference engine follows a working cycle which comprises two phases: the evaluation phase and the execution phase. The evaluation phase comprises three stages:

i) The "selection" or "restriction" stage, which determines from a stage of the base of knowledge, on Fl sub-set of the base of facts as well as an RI sub-set of the base of rules which after initial analysis deserves to be compared during the following filtration stage.

ii) During the filtration stage, the inference engine compares the releasing part of each RI rule to the F1 set of facts. One of the R2 sub-set collects a rule whose release condition has been satisfactory, owing to the different criteria according to the system through the state of Fl. R2 is denoted as "a set of conflict".

iii) During the last stage of the "resolution of conflict", the inference engine determines a rule to decide which of the R3 or R2 subsets should be effectively released. If R3 is empty, the cycle will not comprise any execution phase. According to the different systems there are different criteria for resolving the conflict. For example, the first n rules of an arbitrarily ordered list are selected, or preferentially the rules that have been mostly used are selected, or those which are assessed to be the least complex fewer conditions to be checked, few variables to be fixed before releasing the procedure.

During the execution phase the inference engine controls the implementation of the action defined by the R3 rules. The procedure to be used when R3 comprises more than one rule can be different from one engine to another.

Ideal knowledge-based expert system

To define the different sectors in which a KBES can be developed, and to see what its functions would be, two lines can be envisaged, one deriving from a descending analysis of the process, the other one an ascending analysis. Either method is going to highlight the need for KBES at different stages of the process.

Ascending analysis of the process in spinning

Several KBESs are needed at each decision stage of the spinning process and even of the overall process of transformation.

Knowledge-based expert system 1

This system would be used to determine the most appropriate spinning process for the fibres, or fibre blend, desired by the industrialist, by providing the different technical adjustments of the process and the resulting physical and mechanical properties of the obtained yarn. Currently, there are KBESs which enable the first defined function to be achieved, and one of them is discussed later.

Knowledge-based expert system 2

This system will use the characteristics of the produced yarn to indicate the different problems which took place during the spinning process as well as to show the causes and possible remedies. The system is far from being utopic and an application is currently being performed in our laboratory.

Knowledge-based expert systems 3 and 4

In relation to the characteristics of the obtained yarn, the KBES puts forward the different types of textile transformation (knitting, weaving) and in relation to the characteristics of the transformation (pattern), it defines the characteristics of the final product.

Descending analysis of the spinning process

In the case of a descending analysis of spinning process other KBESs come up with many other functionalities.

Knowledge-based expert system 1

This KBES utilizes the characteristics of a product (fabric), to define the spinning process as well as the raw material to be used. For the time being, such a system is more or less an utopia but it would be the most rational approach to the product in terms of product analysis.

Knowledge-based expert system 2

This KBES utilizes the characteristics of the fibres and of the different spinning processes to determine the adequate spinning lines as well as the different technical adjustments which are to be made to this line.

Knowledge-based expert system 3

This system is meant to control the quality of the spun product in relation to the characteristics of the spun yarn. It should be able to determine and locate the different causes of a defect.

These analyses are not exhaustive and some other KBESs could be developed in the spinning process. Some of them are still utopia, but others have already been built and validated, and some are already being marketed. Other knowledge-based expert system already in industrial use. It is quite clear that we have moved onto the aspect of manufacturing techniques.

Within the frame of Computer Integrated Manufacturing (CIM) a more complex data processing set including production management, cost calculations, material management, product and material management should be found in any firm. This set should obviously include an already existing KBES. The connection between the different manufacturing and management systems should bring about additional strength to the company. We shall now move onto the question of building a KBES.

Implementation

The analysis of the domain and the construction of a KBES can be entrusted to an individual who is in charge of the expertise and who is sufficiently trained and has modem tools (overall system) at his/her disposal or to a team (an analytical system) composed of: one or more specialists; a knowledge engineer and a programmer specializing in different AI languages and tools.

Overall system

The overall system has been favoured by the appearance of KBGS which are more and more friendly. It is quite clear that a specific and rather good training used to be necessary so as to handle such tools.

The advantage of such a system is that it is quite easy to implement; a single individual can perform all functions. Its main disadvantage is the non-optimization of the product implementation as the KBES might not be performing as fast. In addition, not having a third person (knowledge engineer) working on rephrasing the reasoning mode of the expert may result in not taking a part of his/her reasoning into account and thus depriving the model of a big part of the expertise.

This approach can not only be adopted for building a simple KBES but can also appear as an acceptable compromise for a first approach to the problem, particularly for a small or medium sized company that might be afraid of the cost of developing quite a big KBES and which has a top level specialist at its disposal for a few months on the basis of an industrial contract.

Analytical system

Development of an application according to this method means following the stages:

— *Stage 1*: First of all, the users are to fix clearly the target to be reached. These include: assisting the expert to carry out his task by supplying him with a first approach (help for decision making);

— spreading the expertise (training KBES);

— automatically controlling an industrial process;

— assisting the expert to work the empirical practices.

— *Stage 2*: Recruiting the development team: This stage, which proves more and more indispensable, is essential for developing application of a certain volume, and to reduce the total time for the development cycle. The expert is selected according to his/her know-how (reasoning strategy, selection of adequate questions, etc.) than because of the scope of his knowledge. He/she adapts his reasoning strategy to the problem which is actually posed. He/she reasons logically in spite of testing all the hypotheses. He/she looks for the links of causality between the facts which are certain and not only the plausibility coefficients. The knowledge engineer is both a psycho-sociologist well-versed in the art of making the expert speak and a computer scientist specializing in AI tools.

— *Stage 3*: Transfer of the expertise: This involves the crux of the matter of the expert because he/she is the one that determines the field of the base of knowledge and the key concepts. He/she formalises the rules by focusing on the crucial concept and shapes the conclusion. The transposition of a specialist know-how in a KBES cannot be reduced to a simple computer knowledge canning. The exchange between the expert and the knowledge engineer is often difficult because of the expert mode of reasoning. The role of the knowledge engineer, during this stage, is to help the expert communicate his know-how. This is one of the most delicate tasks for the knowledge engineer and for the expert: one has to know how to make the expert speak without inhibiting him, the other must analyse his reasoning which is often intuitive, so as that transcription of this one by the knowledge engineer can be possible. The knowledge engineer has the expert to analyse and reword all the sets of his method of reasoning as well as his intuition, innuendo and the different kinds of knowledge which are the bases of his conclusion or his action.

— *Stage 4*: Theoretical design of a system and determining the sources of the fact which are subject to an expertise. The present stage is that of the transfer of the expert knowledge to its computerized form. This is the role of the knowledge engineer, naturally assisted by the expert. The expert, after a worded interview, describes the nature and the origin of the facts to be reasoned and defines the proper means to acquire them:
  — the inside of the computer structure (ratio, statistical calculation, etc.);
  — manual, vocal data acquisition, with the help of a scanner, etc., so that the expertise can be properly captured;
  — acquisition by the real time system (detection, automatic diagnosis, etc.).

— *Stage 5*: Test of opportunity to select appropriate KBES methods; from the different types of knowledge described by the expert, the knowledge engineer will be able to determine the type of inference engines to be used by taking into account the expert's mode of reasoning; the structure of the knowledge; the target to be reached and the computer constraints. Once the inference engine has been chosen, the knowledge engineer translates the processes covered by the expert into the syntax imposed by the chosen software.

— *Stage 6*: Construction of a prototype: This phase involves the knowledge engineer that decided the type of KBSG or the type of inference engine to be used. He/she builds a prototype comprising a reduced base of knowledge, so that the prototype can be tested. At this level, the selection can be re-evaluated.

— *Stage 7*: Construction of a KBES and selection of the equipment: This is the most costly stage, and it cannot be easily started. Once the equipment has been bought, the knowledge engineer builds the KBES. As for the expert, he/she supplies a first set of tests and evaluates the answers that have been supplied by the system.

— *Stage 8*: Final evaluation: The final evaluation is meant to see how much the objective initially assigned to system has been achieved. It aims at reducing the gap by improving the system. It is cleverly carried out by groups of human experts.

— *Stage 9*: Maintenance of knowledge base, implementation: Implementing a KBES does not put an end to the job of the team whose role is to maintain the base of knowledge. When compared to other computer applications, a KBES has the advantage of being permanently maintained and it is the expert that will be in charge of maintaining it.

KBES in spinning area

A few KBESs are sold in the spinning area. One of them is the "COROSULTO©" system implemented by Schlafhorst. The system is meant to choose, for the Autocoro© spinning line, the optimum spinning element which allows the industrialist to obtain "good yarn" in relation to the raw material. The COROSULT system was developed with the IBM software (KBGS) ESE -Expert System Environment and it runs on the 3090 IBM family.

COROSULT can be consulted by means of a dialogue display on a screen. This dialogue is determined by the user's questions and introductions. Although this application is implemented under ESE on the IBM 3090 family, just interrogating the system can be done on an IBM PC family computer. ESE is a KBSG, comprising an inference engine, a base of rules and a base of knowledge. Schlafhorst's experts fill the biggest part of the base of knowledge and the base of rules; these bases reflect the actual state-of-the-art in rotor spinning area. A typical consultation session with COROSULT may be as follows:

— COROSULTs user identifies himself or herself with: spinning line characteristics (number of heads) and the intended use of the yarn which will be produced (weaving, knitting).

— For a specific end use COROSULT indicates what kind of yarn must be produced. In fact, the knowledge base "knows" few of the final uses and the characteristics of the appropriate yarn.

— The user can indicate his own yarn characteristics: hairiness; regularity and strength.

— The user indicates the raw material: type of fibres; blending ratio; fibre properties (fineness, fibre length) and maximum speed of rotor.

— The COROSULT utilizes the user's data to return: the breaker lining; rotor geometry and rotor lining.

— The user indicates the mass per length unit of the yarn, COROSULT returns the rotor diameter;

— The user gives the mass per length unit of the sliver ribbon, COROSULT computes: the drawing range; number of fibres per area and the critical area and in relation to all these data, COROSULT determines the optimal rotor diameter.

— COROSULT proposes three different degrees of quality, once a degree is chosen by the user, COROSULT proposes, based on all the data acquired, a first choice of spinning elements.

— This prototype KBES has been working for 250 working hours on the shop floor and it is in its validation period. This validation is being done in Schlafhorst all over the world. The maintenance of the knowledge base, is done by "COROSULT Redaction", from the Schlafhorst International Expert.

The full automation of "Open End" spinning with the Autocoro spinning line has led to an increase in implementation of OE spinning lines in mills. The characteristics of OE yarn can be determined by few elements as: the inside lining of the rotor; the surface of the rewinding buses and the torque-stop. The influence of the spinning elements on the characteristics of the yarn can be reproduced. Then, with the OE spinning line, it is possible to produce a yarn with specific characteristics in relation to its final use. For these reasons, it is essential to specify the optimum spinning element, to obtain a better quality yarn.

Monitoring systems

Computer aided-design and computer-aided manufacturing are beginning to make inroads into spinning industries, but, in such industries, the monitoring concept is more developed. In the near future, the control of each production position in spinning and the total control of the entire plant (computer integrated manufacturing-CIM) will gradually emerge. But, KBES (knowledge-based expert systems) which will be able to supervise all the decisions of the plant (technical or management decisions) are awaited.

Substantial progress has been made since the invention of the microprocessor in 1971 by INTEL Corporation and the invention of the microcomputer a few months later. These computers, from the smallest to the biggest, perform computations at very high speeds (hundred to thousand Mips). After the mechanical industries, which were the first to use "EDT", some areas in the textile industry are using such advanced technology.

Many plants use monitoring systems to control and to manage their production. The latest developments in data control are about KBES. They are used in many industrial fields, but there are only a few applications in the textile industry. Some of them are actually running but others are only laboratory prototypes. On the other hand, monitoring systems, which are genuine control systems of production, have spread.

Some specific ones are integrated in production machines, others, more versatile ones, can be integrated in different kinds of machines on production lines. The mill is monitored to rapidly and continuously get the information required for a streamlined management, both in production and quality. The data acquisition has to be automatically carried out to get accurate and reliable data, and to avoid all human errors.

Data regarding the working teams, running machines, machine positions and devices, raw material and product flows and quality are captured by the monitoring system. Based on these data and information, a production management programme, a quality management programme and a provisional maintenance programme can be implemented.

While both production and quality management programmes are quite easy to implement, it is quite difficult to implement an efficient provisional maintenance programme. Therefore, it can be said that it is necessary to have continuous information about the yarn being processed.

The information collected from the production of a specific machine or a complete plant helps the user to obtain a judgement about materials being processed as well as the conditions and the machine settings, and to derive conclusions about possible deviations or alterations. Let us take a spinning room equipped with N spinning frames as an example. Each spinning frame is divided in sections, each section with 4, 6, 8,... positions. Each position of the spinning frame is equipped with specific sensors. These individual sensors provide data which are first stored in a concentrator and then sent to a node of the network system. Eventually the information is sent to the supervisor computer. The data are displayed and edited as requested by the user. Thus the three main components of the monitoring system can be summarized as follows:

— the sensors,

— the transmission network and

— the processing software.

Based on a spinning frame, the required information can be split into three sets as follows: data pertaining to the frame; data pertaining to the spinning position and data pertaining to the yarn being spun.

— *Frame data*: The machine is running or is stopped. In the case of a shutdown or downtime, the case has to be identified.

— *Spinning position data*: The data entities pertaining to the spinning position are many and their acquisition is more difficult. Here are a few examples: rotation speed of rotor; delivery speed; spindle is running/stopped; yarn presence detection; sliver presence detection, etc.

— *Yarn data*: Data entities pertaining to the yarn include: produced yarn length and package weight; quality of produced yarns; number of defects, etc. The increase in efficiency of monitoring systems is linked to the development of sensors, particularly for the evaluation of the yarn quality and for determining the appropriate time for maintenance.

— *Run/stop sensor*: The information is easy to obtain and is given by the state of the power supply of the main electrical motor. The detection of the state of the spinning position is given by an optical sensor.

— *Rotation and delivery speed*: This information is given by the preset value (frequency, tension) given to the position driving motor. The delivery speed is calculated from the speed rotation multiplied by the diameter of the driven cylinder.

— *Sliver and yarn detection*: The detection of the presence of sliver or yarn is given by a switch.

— *Yarn quality evaluation*: The evaluation of the quality of the produced yarn needs more complicated sensors because of the large variety of materials and types of produced yarns. Based on the same spinning machine example, the evaluation of the yarn quality needs the measurement of the following properties: thin places; thick places; moire and fibre contamination. The measurement techniques are more sophisticated, such as capacitive or optoelectronic techniques.

Through continuous monitoring during yarn production, such a system detects all the irregularities in the yarn. If thick places in the yarn occur several times with the same period and with a diameter higher than the allowable diameter deviation, the monitoring system will detect a moire. So, the spinning position has to be stopped for a cleaning operation.

Fibre preparation

A monitoring system developed for fibre preparationc is quite interesting because it takes into account the fibre flow from fibre preparation to carding operation. This fibre preparation line consists of a bale preparation station, multiple mixers and cards. Each component of this line is equipped with its own monitoring system and these are connected together through a five level architecture network.

Level 0

Level 0 is the sensor level and actuator level. Sensors are indispensable for the useful application of machine control. In such a preparation line, sensors measure, for example, the sliver count at the card, and the web thickness. They also measure delivery speeds, pressures in chute, distances, the bale height etc. Actuators adjust, for example, the deflector blades and chute walls, control speeds, or stop the machine when the door is open while the process is running.

Level 1

Level 1 is the machine control level. It consists W individual special controls in a modular system as follows:

— *Blend commander© for bale preparation.* This system requires the following elements for running the working area (right or left), the number of bales, the number of lots of bales, the bale height and the quantity of material taken by the opening rolls at each travel cycle.
— Mixcommander© for multiple mixers.
— *Cleancommander© for cotton*: This system controls, for example, the deflector blades in front of the moving knives in order to control the amount of waste and the degree of opening, the amount of air suction for the fibres and the wastes.
— *Cardcommander©*: The following data can be entered in the card monitoring system: the sliver count, the delivery speed, the total draft, the length of sliver in the can, the pressure in the chute, the deflector blade adjustment and the reference value for auto-levelling and control. With such data, all the functions of the card are controlled

including the high speed coiler, the high speed can changer and the auto-levelling system.

Level 2

On Level 2 there are installation control units as well as production and quality data collection systems. Systems belonging to this level are, for example the overall electrical control, the overall electronic installation control, the overall installation feeding control and the carding room control. For the Trutzschler fibre preparation installation, the feeding control is effected by the Feedcommander© system. It requires the following data for running the technical specification of the raw material being processed, the material removing vertical step height for the bale, the production of the carding room and the pressure in the chute.

The carding room is controlled by a card information system KIT. By means of a specific network, KIT gives quality and production information about the connected group of cards. It condenses data provided by the cards, establishes spectrographs, makes the length variation curves of the card sliver, compares the real measured values to preset values.

Level 3

Level 3 is the process level control which represents an important management instrument for the spinning mill manager. This high level system summarizes all the relevant mill, production and quality data for the opening, cleaning and carding sections. The process control system should condense and evaluate the on-line data in such a way that data needed for decision-making are quickly and freely accessible.

Level 4

Level 4 is the highest control level of the mill. It consists of a host computer giving an overview of all the production of the mill, so that the different kinds of process control systems could be connected.

Control fibre preparation

Many sensors, devices, and process controls have been developed to control fibre preparation. But, as far as fibre preparation is concerned, the main functions are: removing the trash card dust, splitting the flocks and individualizing the fibre. This efficiency of fibre preparation, including these three functions, is evaluated by the degrees of cleaning and opening. The efficiency of a fibre preparation monitoring will depend on the accuracy of cleaning and opening degree sensors.

Many monitoring systems have been developed to track the quality of roving and sliver. They are based on a pneumatic or capacitive count measurement. The data are taken on-line and analysed. The deviation from a given preset value is highlighted. When the deviation is considered harmful to yarn quality, the machine is stopped.

Efficient systems monitor the spinning of conventional and unconventional yarns. These monitoring systems introduce a new concept: the information exchange could be bidirectional. This concept includes the data acquisition from the machine and the data transfer from the computer to the machine. This concept allows an auto-control of the spinning position. Consider the example: the Informality© system of Schlafhorst Autocoro. The Informator offers comprehensive data acquisition and data transfers with the following features:

> setting the spinning machine, the automated units, the yarn control device Corolab© and the piecer carnage, acquisition and provision of production data, acquisition and provision of quality insurance data and assumption of machine and handling system control tasks

Each group of 24 spindles is linked to a section computer which is linked to the Informator. Events and signals are exchanged between the section computer and the Informator. The spindles use a wireless communication system for contactless requests of the piecer carriage, package doffer, and for exchanging data with the piecer carriage. Based on the set of acquired data, in the event of dysfunctions, the Informator sets a flag to inform the spinner.

The Peyer CAQ concept is another example of interactive monitoring system applied to winding. Based on a standard IBM computer equipped with standard interfaces, open architecture and conversational mode. Such a monitoring system is particularly suited for producing a variety of yarns. Setting is quickly and efficiently performed without any human intervention.

Predictive maintenance

Development of predictive maintenance requires specific sensors which are really complicated. Corolab can be considered as a predictive maintenance device. Take for example the control of a nozzle in air jet spinning. The quality of the yarn is related to the injection air pressure in the nozzle and especially the variations of this pressure. On-line pressure checking is quite impossible because of the limited accuracy of manometers. But, the variations of pressure in the nozzle induce vibration frequency variations.

So, the vibration frequency analysis will be equivalent to a yarn quality analysis. Such an analysis needs an accurate accelerometer sensor, a high data acquisition speed and an on-line and real time spectrum analyser. There is no problem in performing such an analysis in a research laboratory. However, due to the costs of sensors and spectrum analysers, and the complexity of this analysis, it is nearly impossible to equip each spinning position with such a device.

Network

Different manufacturers do not use the same network and the same communication protocol. Consequently, buying equipment from several manufacturers forces the spinner to manage different kinds of incompatible networks. Schlafhorst, Zinser © and Trutzschler © have recently created Texnet ©, a standard network for spinning mills.

The monitoring system gives the spinner a very large amount of raw data which has to be processed to extract the information that needs to be highlighted. The monitoring system is able to deliver more than 200,000 basic units of information for 1,000 spinning positions. These data have to be written on the same media to be easily interpreted.

All data are not simultaneously useful for the management of the spinning mill; so the data has to be sorted before being edited. Only the few following specific reports have to be created: general production report, exception report and statistical analysis. Considering the case of a running production, the exception report is the only useful one to move towards the "zero defect" concept.

In the production of a new yarn, all information has to be collected and analysed until the required quality has been reached. The monitoring system is an accurate and reliable tool for spinning mill management. But, as far as these monitoring systems are concerned, the most obvious disadvantage lies in an insufficient predictive maintenance. The gap will be filled by developing new measurement methods and new sensors. The development of such methods and sensors will be very long and very expensive.

Six
Textile Weaving

In weaving, the warp and the filling may be interlaced in many different ways. The particular method that is used to interlace the warp and filling is called the weave. It is very interesting to study the various weaves; and it is important, too, because the weave greatly influences the texture of the woven cloth. Design that are woven in the cloth are plotted on design paper. This squared paper is arranged so that the vertical, or up-and-down, rows of squares represent the warp.

The horizontal rows of squares represent the filling. This is merely for convenience in counting the squares; it has no influence on the design. A riser is a painted block on the design paper. It indicates that the warp is raised over the filling at the point of interlacing. A sinker is an unpainted block and signifies that the filling is over the warp at the point of interlacing. In plotting or laying out ordinary weave constructions, the warp is painted on the design paper, the filling is not. Keep in mind that the warp is white, but it is indicated by painted blocks because the warp is always represented by painted blocks on design paper. Therefore this design on paper looks like a negative of the pattern in the cloth.

Plain weave

The plain weave is the most popular. Interlacing of the plain weave, which is also called taffeta weave, linen weave, calico weave, or tabby weave. You'll notice that each end goes over every second pick. Also, every pick goes over every second end. The weave repeat is therefore only 2 ends and 2 picks. If you don't quite understand this, take some trips of paper or pieces of string and interlace them in the manner. This little experiment will show you how the weave works. The plain weave has the shortest repeat and the tightest interlacing of any common weave. That is, while the ends could pass, or float, over more than one pick, they could not possibly float over less than one pick.

With a given number of ends and picks per inch, the plain weave will give you a stronger and stiffer fabric than any other weave. As you'll see later, there are a great many possible variations in all other types of weaves, but there is only one plain weave. While the plain weaves is always the same, you can use it for a great number of different fabrics. For example, you can use more ends per inch than picks per inch. You can introduce colour into warp and filling. You can use different yarns and fibers.

Let's look at a few of the stable materials in the trade today made from these variations of the plain weave construction. A duck fabric in which heavy cotton ply yarn is used both in warp and filling. This is one of the strongest of all fabrics. The body of the cloth consists of coloured warp and white filling in a linen fabric. Variety is added by warp stripes in bright colours. The plaid dress goods clearly shows one of the many colourful variations possible in plain weave. The linen fabric shows irregular filling yarn, which gives the cloth a homespun appearance and texture. You might note at this point that warp yarn is usually more regular and straighter in a fabric than filling yarn, which is under less tension in the loom during weaving. The result is that the warp yarn is bedded down in the filling yarn, and hardly shows on the surface.

The poplin is characterised by a fine, tightly set warp and a slight cord effect, or rib, in the filling direction. Heavy, cylindrical filling yarn tends to give this surface effect in the cloth.

Seersucker, is made with a permanent crinkled or puckered effect in the warp direction. The effect can be put in during weaving, but it is introduced more often by a caustic print treatment in the finishing of the goods.

Plisse fabric, made to simulate seersucker, is often not permanent in finish. Moire, or watermarked effects, are often seen on taffeta and similar fabrics. Fine warp and cylindrical filling are used to obtain the surface effect, which is enhanced by the moire treatment applied by engraved rollers in the finishing of the cloth.

A crepe fabric made with the plain weave in which certain risers are left out of the produce the crepe, sand, or granite feel and effect. The rayon crepe is made with the regular plain weave. Extra high twist in warp and filling yarns brings out the pebble effect in the texture of the fabric.

Twill weaves

The simplest and smallest twill that can be made is on three ends and three picks. It is sometimes called the prunelle weave, or the jean twill. Twill weaves produce diagonal lines on the face of the goods. In the great majority of cases the lines run to be right on the face of the material. The twill lines run from the lower left-hand corner to the upper right-hand corner.

However, some few cloths made with twill weaves have a left twill effect on the face of the fabric, running from the upper life-hand corner to the lower right-hand corner of the goods. The interlacing of one of the most common twills is the 2-up and 2-down twill, which is usually written 2/2. It has an effect formed by light-and dark-coloured yarns in warp and filling. It is a tweed fabric made from a 2/2 right-hand twill weave.

A solid-coloured Harris tweed made from a right-hand twill weave. There is a woollen fabric made from a twill weave with fancy or novelty warp yarn. A chalk stripe fabric made with a twill weave is a banjo stripe fabric. The same 2/2 twill weave is used in the black and 6-white check-effect woollen cloth. In the common twill weaves the diagonal lines make angles of 45 degrees with the filling. For example, in the 2/2 twill weave, one repeat requires the use of four ends and four picks. The rule is to go up one pick for each successive warp end in a 45-degree twill weave.

To make the second repeat of the twill, as x-marks, the procedure is as follows: the 5th end and the 5th pick weave the same as the 1st end and the 1st pick, respectively; the 6th end and the 6 pick weave the same as the 2nd end and the 2nd pick, respectively; the 7th end and the 7th pick weave the same as the 3d end and 3d pick, respectively; the 8th end and the 8th pick weave the same as the 4th end and the 4th pick, respectively. In a 45-degree right-hand twill the riser moves up one pick for each successive end. The diagonal line goes to the right. In a 45-degree life-hand twill the riser moves down one pick for each successive warp end. For some purposes it is desirable to have the twill line steeper; for other purposes, not so steep. In the 63-degree twill, in the riser moves up two picks. In the 70-degree twill, the riser moves up three picks, and so on.

Reclining twill weaves are twill weaves in which the angle between the diagonal lines and the filling is less than the usual 45 degrees. Some goods are made with the regular 2/2 twill, or another regular twill, but still show a step twill line. If, for example, the goods have twice as many ends as picks per inch, the twill line will be 63 degrees, even though a regular twill weave has been used.

Effect and flush

The terms effect and flush are used to describe weaves with respect to the appearance noted on the surface of the cloth. There are three types of effect.

1) *Warp effect*: In a warp effect, or war-flush weave, there is more warp than filling on the face of the cloth. For example, the 2/1 twill, has 2 ends up and 1 end down.
2) *Filling effect*: In a filling effect, or filling-flush weave, there is more filling on the face of the cloth. In an even-sided effect, or equally-flush weave, like the 2/2 twill, there is the same amount of warp and filling on the face of the goods. These terms for the three kinds of effect also apply to other types of weaves, such as satins.

Twill weaves we have seen thus far were relatively simple. Now let's look at applications of twill weaves that are a little more complicated. A cavalry twill fabric made from 63-degree weave which is sometimes called elastique. The tricotine material in sample is characterised by the double-diagonal twill line. It is made from 3/1 3/1 1/1 1/1 twill of 63 degrees. It is the same weave as that used for the cavalry twill. The fabrics differ only in the yarns used and in the finish given to the cloth. There is no set rule that specifies whether or not a cloth must have a right-hand twill or a left-hand twill construction.

Custom, deep-rooted tradition, local circumstances, usage of the material, and the appearance are all basic factors in determining the weave direction. Some twill fabrics may be either right-hand or left-hand in the diagonal twill line effect. Drill jeans, and certain other small twill-effect constructions are often left-hand twill on the face of the fabric. The twill may be broken and reversed in the fabric. A broken-twill fabric, known as herringbone. The weave is 2/2 twill, with 8 ends of right-hand twill followed by 8 ends of left-hand weave.

A woollen fabric made with a broken-twill weave. The border or selvage, of the cloth may be observed at the left. A broken-twill fabric made with a 2/2 twill weave. It has 2 ends of right-hand twill followed by 2 ends of left-hand twill. This too might be called a herringbone fabric. Just like the plain weave fabrics, you can vary the twill weave fabrics by using yearns of different colours. A worsted fabric made with applied colour effect called glen Urquhart or glen plaid. It is made with a regular 2/2 twill weave, and the plaid is only a colour effect.

The woollen fabric also made on the twill weave and shows a variation of the glen plaid. A worsted suiting made of twill construction, with a 1 light, 1 dark colour effect usually called sharkskin. In this particular case further variety is added by arranging the twill in herringbone fashion. The novelty worsted fabric made with a colour effect on a twill weave is intended to show a design of hair-line and tricot effects.

Many further variations of the twill weaves are possible. For instance, if you'll look once more at you'll notice that the cloth is based on a combination of twill weaves. This is known as a fancy entwining twill. You'll realise that a long and thorough study of designing will be necessary to known and to be able to originate all the various designs.

Satin weaves

Satin weaves do not have a clearly distinguishable twill line despite the fact that it is actually present in cloth made of these weaves. The eye, however does not discern these lines on the face of the cloth. For this reason, one may speak of a satin weaves as devoid of any characteristic twill line.

The absence of the twill lines in a satin weaves is brought about by the way in which the interlacing of warp and filling is arranged. The few points where the filling is up in a warp satin are covered by the adjacent ends. The long stretches of warp on the surface will crowed together in a tight weave construction and over the few points where the filling is up.

In goods is covered with either warp yarn or filling yarn, depending on whether the weaves are warp flush or filling flush. The fine diagonal lines are not plainly visible, and to find them you must look carefully and closely at the material. Regular satin weaves repeat on as low as five ends. The order of interlacing in any regular satin weave may be found by the use of a base, or ćounter. This is determined by dividing the number of ends in the repeat into two unequal parts. Every end in the satin weave interlaces at some point with each pick.

There can never be two interlacings at any point on any end or pick within the confines of the repeat of an ordinary satin weave. Satin weaves are used to make brocade, brocatelle, cape or cloak fabric, cotton sateen, coverings, curtain material, damask, dress silk, evening gowns and warps, fancies and novelties, furniture fabric, jacquard fabrics of many types, runners, slipper satin, sport fabrics made of silk or synthetics, materials with striping effect, tablecloth and napkin material, tapestry, tie fabric, and other fabrics.

In textiles the word 'satin' implies a rayon, silk, or similar fabric made with a satin weave. The word sateen implies a cotton material made with a satin weave. Satin weaves give a more solid and glossier appearance on the face of the goods than any other type of weave. This explains their extensive use in the materials previously named.

The types of yarn used affect to a large extent the brilliance in fabrics made with the satin weave. Satin weave fabrics do not possess the strength of equivalent plain cloths, or even of twill- woven cloths, because of the loose plain in interlacing and the length of the floats in the weave. If you hear of an 8-shaft, or 8-harness, satin, there is one interlacing in every eight ends. That is, each end interlaces once in every eight picks and makes a float where the thread is not tied down. The float may be on the face or the back of the cloth, as the case may be. The length of the float in ordinary satin weaves is one number less than the number of ends in the repeat of the pattern weave. Thus, an 8-end satin weave would have a float of seven.

Unless the fabric has an extremely high number of ends and picks per inch, the long floats may pull out. To avoid this, so-called double satin weaves with extra binding points are used. Such satins, however, never have quite the same glossy even surface as a well-constructed cloth with a regular satin weave.

Basket and rib weaves

In a simple basket weave the warp is divided into two parts, as in the case of the plain weave, but with this difference: this basket weave is called a 2 x 2 basket because the ends and picks are arranged in groups of two. In a simple basket weave the shuttle or shuttles pass twice through the same shed. Consequently, ther are two picks in each shed. You seen how a simple basket weave looks on design paper. This can be varied by having three or more ends work alike. Since there are fewer binding points, basket weave fabrics are fuller and looser than equivalent fabrics in plain weave.

Basket weaves give a good appearance to certain types of fabric-monk's cloth and Oxford shirting, for example. However, the yarns in a basket weave may have the tendency to move about and become rather loose. Consequently, the material may give some trouble in sewing. Also, the strength of basket weaves does not compare favourably to equivalent plain-weaves construction. A 2 x 2 basket weave is popular in hopsacking, sample which is a suiting material made of woollen or worsted yarn. With some exceptions, basket-woven materials are not desirable for apparel since they do not withstand friction and abrasion, chafing, and wear. There is considerable call for basket-weave fabrics, however, in decorative materials such as hangings, portieres, and curtainings. Rib weaves are another development of the plain weave.

These weaves are derived from the plain weave by causing two or more successive ends or picks to weave alike. A group of yarns that weave alike will form a rib in the material and are said "to weave as one yarn." The rib yarns used indicate the direction of the rib or wale in the fabric. The rib line or effect may be made to go in the either warp or filling direction. Remember the rib weaves are similar to the plain wave in working properties and that the set of yarns forming the rib is usually heavier than the rest of the yarn in the material. Warp rib weaves have their rib effect running in the direction of the filling, and filling rib weaves have their rib effect going in the warp direction.

Incidentally, rib weaves afford a chance for the use of waste or poor yarn, since the rib yarns are covered by the close texture of the yarns interlacing with them. This effect may be seen in hatband fabric, bengaline grosgrain, and ottoman. Hatband fabric is a warp rib weave because the rib effect runs in the filling direction. Simple filling rib weaves similarly repeat on two picks. A further development is corded weaves, in which the effect is strengthened by combining the rib principle with the plain weave.

Weave combinations

The number of weaves, that can be made when features of various weaves are combined is much greater. Furthermore, when you consider the various effects of differently coloured yarns in warp and filling, the possibilities stagger the imagination. No wonder, then, that new combinations are put on the market every season by our weaving mills.

A fine example of a combined weave and colour effect is the worsted bird's-eye suiting in sample. It is constructed with two ends of light and two ends of dark yarn alternating in the warp. Similarly, two light and two dark picks alternate in the filling.

Warp and filling floats, as has been shown in connection with satin weaves, cause the dark yarns to slide over the light yarns in most of the weave. Only on spots planned by the designer are the light yarns allowed to show, forming the light bird's eye that give this cloth its name. Not to be confused with the suiting is the bird's-eye diaper cloth in sample. This, of course, is all-white. The effect is formed purely by the weave. Diagonal lines of points where warp and filling interlace from the diamond-shaped pattern, and a little bird's eye of warp floats is in the center. Similar arrangements of diagonal lines and warp floats are used by the designer to form the matelasse.

Warp floats, arranged in clusters and bound by lines of tightly interlacing warp and filling, form the honeycomb design in the printed fabric of sample. Don't confuse the weave effect of the cloth with the birds, which have been added later by printing. The many possibilities of design are studied by the textile designer. A great deal of specialised training is needed to understand all of them. For your present knowledge, you'll do all right if you grasp the general principles involved.

Designs that must be woven with a special loom attachment, called a dobby, are often simply classified as dobby designs, such as the one in sample. The dobby, or head motion of the loom, is a mechanism that raises and lowers the harnesses which control he warp in the order planned by the designer. Ribs can be formed in the cloth by simple variations of the plain weave.

Diagonal ribs, such as the whipcord fabrics, are formed by special twill weaves in combination with a preponderance of warp over filling. These simple weaves should not be confused with the pique weaves. These, as well as the Bedford cord, sample are special fabrics of intricate construction. A simple Bedford cord design is shown on design paper. In this weave the cord is composed of four ends which weave in a plain-weave order on alternate pairs of picks. The cords are separated by two ends in a continuous plain weave.

Painted blocks signify warp risers over picks. The x-marks signify plain-weave risers that produce a sharp groove between the ends that form the cords. The plain-weave ends also prevent the cloth from slipping. When it is desired to have more pronounced cords, thick stuffer ends are introduced into the design. These ends are placed in the cords.

The stuffer ends are completely covered by the regular warp, and are held in the cloth by the filling floats on the back. The stuffer ends, however, do not interlace with the filling; hey are merely held in place for the purpose of accentuating the cords. The cords, or wales as they may by called, can be arranged high or flat, narrow or wide. The weave and the number of ends and picks per inch, as well as the yarns used for the cloth itself and for the stuffer ends and picks, all influence the appearance. In evaluating textiles, you must keep in mind that a loose construction and long floats always have an adverse effect on the resistance of a fabric to wear and tear.

But there are other fabrics that are so interact that an attempt to put them on design paper would only confuse you. We'll therefore leave the problems of presentation to the designer, and simply look at the actual construction of the fabrics. Suppose you want to make a fabric with a herringbone face. On the back of this same fabric you want a check. You can do this by weaving two fabrics in one operation.

These fabrics held together by a few binding points or binder ends. Such double cloth, or ply fabric, was very popular for coatings in former years. But modern living has little use for heavy fabrics. The trend is away from heavy fabrics, and lightweight fabrics are more popular than ever. Instead of heavy fabrics, special linings, or better yet, linings fastened by zippers, are used. These can be removed or inserted as desired, and they give the garment a much wider range of usefulness. If you were to make, for instance, a flimsy curtain material in plain-weave construction, the ends and picks might slip.

Consequently, a special kind of weave, requiring doup attachments on the loom, has been developed. In the weaves that are made with doups, called gauze or leno weaves, adjacent ends cross each other and grip the picks firmly. Note how one end goes over every pick, while the end that crosses it goes under every pick. A variation, called half leno. Here an end weaving in plain-weave fashion is held in place by an end weaving in leno fashion. The most common application of leno weaving is in marquisette. However, doup weaving is sometimes used to get novelty effects in dress goods.

Another variation in weaving, called lappet weaving, is sometimes used to produce spot effects. Each spot is made from one end, controlled by a special needle motion on the loom. The back of a fabric with a lappet effect, and the face of the same fabric.

Another method is of getting spot effects. Here a contrasting filling is allowed to float on the back may be clipped off during finishing, hence the name clip-spot, often used for these fabrics. Similar fabrics can be made by using an extra warp to form the spots. Very intricate designs can be made with a loom attachment known as a jacquard. In sample you see the face of a jacquard upholstery fabric. The back of the same fabric is in sample.. You'll notice the fine, plain warp yarn and the fancy, heavy filling yarn which forms most of the surface.

Another variation of jacquard upholstery fabric is shown in sample. In this fabric a tight weave alternates with a loose weave. The loose-weave portions appear to be raised above the tight portions. In sample you'll see a damask for table linen. This type of jacquard weave alternates warp stain and filling stain to show the design.

The most intricate designs are used in carpet weaving. A portion of the warp or the filling in these constructions is woven so that loops are formed on the cloth. These loops may be cut open and brushed in order to form a pile. Sketch shows and artist's drawing or motif for the surface design of a carpet. You'll realise how intricate the interlacing of warp and filling may be as you study sketch, showing a section through a Wilton carpet. There are many varieties of jacquard designs. We'll just look at a few more.

The texture can be in the weave and the yarn, which is in the Oriental, or Moresque, style; or the texture can be carved into an even pile surface. Still another pile carpet effect, made by alternating high and low pile, is illustrated. By now you'll be able to recognise quite a few common woven fabrics. Don't confuse them with knit good. Also, you'll understand that, even though you can easily lean to recognise fabrics, you need long specialised study to lean textile designing.

Face and back of fibres

Anybody who handles textiles, from the designer and weaver in the mill to the ultimate consumer, should know the correct manner in which to recognise and to manipulate woven materials. Certain methods are employed to distinguish the face from the back of the goods. Knowing the face from the back is valuable because it will assure proper handling of the goods in cutting, in fitting, in sewing, and in trimming.

Every woven fabric has two sides, the face and the back, or the right side and the wrong side, and you should be able to ell the one from the other where possible. The face and back of some fabrics are alike. These are sometimes called reversible goods. Duck, as you have seen in sample falls in this group as do canvas, burlap, mail bagging, and linen. With the exception of plaid-back over-coatings such as the cloth as in dress goods, some silks, umbrella fabric, and novelties.

Face- finished fabrics use the more attractive side for the face. These include beaver, bolivia, boucle, broadcloth, camel's-hair fabric, chinchilla, kersey, melton, Montagnac, Saxony, tree bark, zibeline, and many others. Most fabrics are made so that only one side is suited to be used as the face. Long floats, knots, and extra yarn stitching on the back usually render the back unsuitable.

In some goods, such as crepe-back satin or a rib-back satin, either side may be used as the face, though the smoother satin side is the real face of the fabric. In print goods, one side of a print is the clearer and cleaner. Cretonne, shirting prints, dress goods, and decorative fabrics are often printed. Fabrics decorated with fancy yarns, nubs, and bright spots have that side as the face which clearly shows those effects.

A fabric with diagonal or twill lines, when held with the warp vertical, will usually show the twill lines slanting to the right of the cloth. This effect is noticeable in cassimere, charmeen, covert, diagonal suiting, elastique or tricotine, gabardine, piquetine, Poiret twill, serge, car seat covers, tartan plaid, tweed, and whipcord. A few fabrics have a "left-hand twill" on the face: twill lines running from upper left to lower right. This is noticeable in denim, drill and middy twill, galatea, jean cloth, nurses' uniform cloth, some cotton linings, and some cotton twills.

Some ribbed or corded fabrics have a more pronounced rib on the face. Bedford cord, ottoman, grosgrain, bengaline, corduroy, and pique are characteristic of this group. It is of particular importance to those interested in garment making that, unless only the face of the material is used as the exposed side of the garment, there may be different shade-of-garment appearance caused by a difference in colour or by a difference in design. If the sleeve, for example, is made from the back of the goods and the rest of the garment is made from the face of the goods, the sleeve will make the garment an imperfect, or a second. The direction of the design in the material must also be considered. Stripes, plaids, checks, and floral effects should be in proper alignment and should be properly matched. If each stripe or block effect were of different colour, a matching problem would arise-all parts of a garment should match. Surface effect or texture must be kept in mind; for example, in deciding when to use a lustrous satin face and when to use a dull back-of-fabric effect. If the former is used as body of the garment, the latter may be used for cuffs, collar, lapels, and trimming.

Fabrics with raised designs, such as sprigged dimity, dotted swiss, and flock-dotted fabric, should have the raised effect on the face of the goods. In twill fabrics care should be exercised to see that all parts of the garment have the twill serge or gabardine would be spoiled if the sleeve were made inside out and had a left-hand twill effect used for the face. Knots, blemishes of several types, press marks, flaws in weaving, and flaws from dyeing should be brought to the back of the goods, so as not to show on the face of the goods. Some knitted fabrics, such as those shown in samples, are made to simulate woven fabrics. Sometimes it is all but impossible to tell from the face of the finished goods whether they are woven or knitted textiles.

Knitted fabrics

Knitting is defined as an interloping of one or more yarns to make a fabric. Look a the sketches which show a plain-knit fabric. You'll immediately notice that it is entirely different from the plain weave you have seen in woven fabrics. There are a few definitions you must learn in order to study knit goods. Wales in knitted cloth may be compared to the warp direction in woven material; courses may be compared to the filling direction in woven goods.

A knitted fabric is entirely different in construction when compared with woven fabric. Knit goods are often made from a single continuous yarn, folded into rows of loops. Each row of loops is drawn through the preceding row of loops. In such a knitted fabric, if the yarn is severed at any point, it will cause the material to ravel, and may cause the loops to give way in many directions. That is, if a loose end is caught up, the whole structure of the fabrics may disintegrate. This explains the "run" which occurs in women's hosiery when a yarn breaks.

Knitted fabric in its elementary form does no lend itself to garments which encounter wear and ear. On the other hand, dependable textures are attained, since every loop is connected to its neighbour above, below, and at either side. Thus elasticity, despite friction and chafing, is found in knit goods, as in knitted underwear fabric. To determine the best loop for specific knitwear, there are the horizontal and he vertical factors to consider.

In general, the loop should be symmetrical in form, and it should cover about the same space in both horizontal and vertical directions in order to give an even balance. For some purposes, however, a loop may be elongated to cover more space vertically than horizontally. Care should be exercised in selecting a yarn for knitting that is not too fine in diameter for the set of loops. If the yarn is too fine, the fabric will be loose, irregular, and unstable. There will be an elongated appearance and a lack of balance in the goods. On the other hand, a thick thread will give an irregularly spaced and congested type of goods in which the elasticity will vary. Consequently, care must also be exercised in inspecting the yarn for thick threads.

A loom may weave various fabrics: bulky, coarse, fine, or sheer. Weaving, as you know, involves two sets of yarns; warp and filling, interlacing at right angles with each other in a flat plane on the loom. The number of ends and picks per inch, or thread count, is very important in woven fabrics. In knit goods, of course, there is nothing you can compare exactly to the thread count in woven goods. However, in descriptions of knit goods you'll often find the term gauge used. You'll hear that a high gauge is used to produce fine or sheer fabrics, while a low gauge is used to knit coarse or bulky fabrics.

The word gauge stands for a unit of measurement. In flat knitting, such as in full-fashioned hosiery, the word gauge refers to the number of knitting needles in 1½ in. That is, gauge refers to the needle spacing on the machine, and it determines the fineness of the fabric. A gauge of 60 would mean that there are 40 needles to the inch in the knitting machine. The higher the gauge of stocking, the higher will be the number of needles per inch. On circular machines, the thickness of the needle determines the gauge. Fineness of circular-knit fabric is expressed by the total number of needles in the cylinder, and by the cylinder diameter.

Knitting can be done more rapidly than weaving, and it is often cheaper, because in knitting, a number of yarns may be fed into the machine simultaneously. Thus, if 8, 24,40, or any number of yarns are fed into he machine, the higher the number of feeds, the greater will be the production.

Compare a knitting frame with 24 feeds of yarn with a loom in which one pick at a time is woven, and you will understand that there are actually 24 machines combined into the one knitting frame. Another item to be considered in knitted fabric is that in loop formation the thread is subjected to considerable strain, which axes the elasticity of the yarn. Too much strain will result in poorly knitted cloth.

Sometimes, however, his may be alleviated by the fact that he passage of the yarn between the needle and the sinker in knitting is oblique, not straight as is the case when the ends pass through the loom in weaving. Proper yarn lubrication may also be of value in overcoming irregularities in the yarn being knitted. Double work in knitting consists of running two yarns where one would ordinarily be used. Fancy effects are obtained in double work by running two colours instead of one. The tendency is for one yarn to twist around he other, thereby making fancy effects.

Just as there are different weaves in weaving, there are different stitches in knitting. Various types of needles are used to produce these stitches. One needle that is very common is the spring needle. The spring needle is mostly used for fine fabrics. Another type of knitting needle is the latch needle. This type of needle is used mostly for coarse fabrics. The latch of this needle swings loosely on a rivet in a hollow part of the needle, called the cheek. Again, the names of the needle parts are given in the legend of the illustration. A third type of needle, the tubular, is used in warp knitting on some machines which make very wide fabrics. This needle allows a very high production. Since we only want to get a general idea here, we'll not go any further into special idea here, we'll not go any further into special types of knitting needles. Instead we'll see how the needles are used in the formation of loops.

Plain knitting stitch is commonly used for thin and sheer fabrics. Notice that the tops and bottoms of the loops are always on the back of the fabric. In another common stitch, the purl stitch, this procedure is reversed. That is, the face, of knit goods made with the purl stitch interlaces like the back of the plain fabric. You'll note that it causes successive courses of loops to be drawn to the face of the fabric. The purl stitch is sometimes called links-and-links. This is derived from the German word links, meaning left. In that language the face is called right and the back is called left, so links-and-links really means that the purl stitch looks like the back of the plain stitch. The surface appearance of the plain-knit stitch is quite different from that of the purl stitch. Therefore, many different designs can be made by combining the two stitches. It alternates one wale of plain stitch with one wale of purl stitch. This stitch produces lines of wales on both sides of the material.

There are many other knitting stitches besides the plain stitch and its derivatives, which you just studied. One stitch which is very common is the truck stitch. In this stitch there is one wale of the plain stitch alternating with a wale in which the needle holds one or more loops and then cats them all on the next loops. The face of the goods has a gridiron or honeycomb appearance. The knitting stitches used for special fabrics, such as run-resistant fabrics, tricot, and so on, are very Looking at a diagram of such stitches would make you dizzy. You could not understand it without a special study of knitting. Still further variations are possible by letting the knitting needle form several loops at the same time. That is, several yarns run parallel, just as in the basket weaves in woven fabrics. Knit stitches made in this manner are called plaited stitches.

Full-fashioned hosiery is knit on a flat knitting machine. It is shaped during manufacture by an inward transfer of the loops from the selvage. Since full-fashioned hosiery is woven flat, it can be recognised by the seam up the back, which extends from top to toe. Another characteristic is the fashion marks, or narrowing marks, which appear as small dots in the leg and foot adjacent to the seam. Most full-fashioned hose are made with the plain stitch. The leg is made uniform in width down to the calf, where the narrowings are performed according to the rate of diminution required.

The greatest labour and ingenuity, however, must be used when the heel is reached. It is necessary to work he heel in two sections at each side. Full-fashioned type hosiery may be made at the heel in a rather square shape, and of any convenient size, by enlarging or contracting the heel portions. This type of heel is called the English heel. It can be recognised by the seam which always occurs along each side of the foot and down the back of the heel. In the French type of foot, which is more common, the seam occurs along the center of the sole of the foot.

The French style is ideal when clocking or embroidered patterns are to be worked into the article, and there is also a saving of time in making this type heel. The upper and the lower portions of the foot are made in one width and afterwards are folded over with only one seam along the middle of the sole of the foot. In seamless, or seamfree, hosiery the fabric is knitted circular. The entire stocking can be made on one machine, ready for finishing. Seamless hosiery is recognised by the absence of fashion marks.

However, there is a type of hosiery called mock-fashion hosiery. This is made from seamless stockings which are sewed up he back to give them a full-fashioned appearance. Like the seamless hosiery mock-fashion hosiery is usually priced lower than true full-fashioned hosiery. The full-fashioned hosiery keeps its shape better than the seamless types. The narrow places at the ankle of seamless stockings are formed only by having the fabric shaped, or set, after knitting, rather than by having the fabric actually knitted narrower.

Socks are stockings that are not full-length. That is, they do not go over the knee. These include the ankles, the short socks which come to just below the calf of the leg, and the full-length socks which reach above the leg calf. There is another group, called golf or leisure-wear socks, which are really 5/8 and 7/8-length stockings and are made for men, misses, and children. Most socks are made on circular knitting machines and comparatively few are produced on full-fashioned knitting frames. Socks usually have a single fabric cuff portion which is made of rib-stitch fabric, but the body is plain knit.

The rib cuff is made as a continuous cuff section on a separate rib-knitting machine, with a cylinder diameter or needle count corresponding to the body of the machine. The cuffs are separated and transferred, stitch, to another machine which knits he leg and the foot portions. Less expensive socks have the cuffs sewed to the leg. The lowest-priced socks have an automatic top, that is, a cuff made by a form of rib knitting on the machine. This arrangement knits the entire sock in one operation. Rubber yarns are often incorporated into the fabric. These produce an imitation rib fabric which processes ankle-supporting and leg- hugging qualities.

Misses' and children's socks and anklets often have a longer doubled-over fabric portion at the top. This is, in turn, folded down again in the finishing, producing the foldover-cuff socks, as against the regular stand-up -cuff types. The same is often true of golf socks made for men and boys. These usually have a ribbed fabric cuff which, when worn in folded position, brings, the height of the sock to just over the calf in he 5/8 length and immediately to the knee joint in the 7/8 length. Regardless of the types or the style, practically all socks are made to foot sizes. These present he length in inches from the outer center of the toe fabric to the outer fabric of he heel, when the sock. It is merely a separate and washable absorbent shoe liner made of knit fabric for use with bare-leg or stockingless costume.

Knitted underwear includes fabrics which are worn under clothing and next to the skin. It does not include cardigan jackets, sweaters, and comparable fabrics or garments. Knit underwear fabric must be elastic and have considerable yield with the body movements; it must be hygroscopic and hygienic, more so than other knitted fabrics. Contraction and shrinkage of knitted fabrics and garments must be given close consideration. Combined contraction and shrinkage is caused by the formation and by the yarn composition.

Ordinarily, knit fabric will contract when released from the knitting machine. The openings or interstices of the loops caused by the needles and sinkers allow the material to contract in both length and width. Contraction and shrinkage on circular machines is greater than that encountered on straight-bar machines. In theory of the full width of a fabric as it comes from the machine should be equal to the circumference of the machine.

The fabric, however, is made on a needle circle in the machine and the actual width of the goods is practically only 2/3 of the theoretical width. If the material is afterwards boarded out to a greater width, the extra width will be lost the first time the garment is laundered. Underwear may be made from flat, knitted web which comes in lengths wound up on rolls, and which is finished. It can also be cut from circular-knit or full-fashioned fabrics, in which case allowance must be popular. It allows net measurements to be used.

Furthermore, the finished web lies flatter, and will not have the tendency to curl, as it does in the cut circular-knit or full-fashion fabrics. In these later fabrics the respective parts, when being made into full-fashioned garments, must be salvaged to shape. Seamless underwear is made on flat knitting frames and is finished after the making-up.

Knitted fabrics for the coating trade appeared in the United States about 1915 and steadily increased in popularity. At the present time, a large percentage of fleece coatings sold in both the men's and women's wear fields are knitted fleeces. The knitted fleece has several advantages over the woven fabrics. The knitted fabrics give better wear and greater warmth for the same weight, and because of their construction, they have an ease of wearing not obtainable in the woven garment. The wool and hair fleeces knitted on a cotton back also produce a fabric of luxury at a price that could not be duplicated in a woven fabric.

On the other hand, the knitted coating is more likely to get baggy. Also, because the back is often unsightly, it must be lined throughout. In surface appearance, the coat made from a knitted fabric cannot be distinguished from any other fabric by the layman, and many consumers never realise that their fine coat was made from a knitted fabric. Originally, only the heavier type fleece coatings were made on knitting machines, but later developments have brought out lighter-weight fabrics in both smooth and rough finishes.

Another development in the knitted and 50 percent cotton back, contains 50 per cent cotton back. The Government has recognised the advantages of the knitted construction furs and moutons are being produced that are difficult to distinguish from the genuine. There are two types of circular knitting machines used to produce coating fabrics. The spring-needle machine is the original type. The second type is the latch-needle machine, which is coming into wide use because of its faster production and greater pattern possibilities.

Several different stitches are used for coating material-the plain, the tuck, the lay-in, and the welt stitch. These stitches, used alone or on combination, produce all designs and patterns of knitted coatings. The finishing of knitted fabrics is more complicated than the finishing of woven goods. It is really more of an art than a science, as no rules can be applied.

Success of the knitting mill is very dependent on knowledge gained through trail-and-error methods in finishing. The fabric comes off the machine in tubular form. After fulling—that is, shrinking under pressure in hot, soapy water—the tubular cloth is cut, and the wide fabric goes through the other finishing processes. The gray weight of knitted coatings is normally heavier than that of woven fabrics for the same finished weight. The head shrinkage is also more and will usually average at least 20 per cent. The gray width is about one-third greater than in woven fabrics.

Any finish applicable to woven fabrics is usually suitable for knitted coatings this applies to water repellency, shrink proofing, mothproofing, resin treating and so forth. In the manufacture of knitted fabrics, new methods are being adopted continually. New end uses are being found for the product, and great improvements are being made in the fabric itself. The possibilities for the end uses of these fabrics are only limited by the ingenuity of the knitting-mill technologists.

Colouring

The knitting machine permits flexible control of the individual or multiple yarns and of the fabric-forming members, or knitting needles. Fancy effects or motifs can be produced in a great variety of colour flashes, or by the variations which are possible in the basic fabric stitch. Continuity of design, reversals, or intermittent repeats with plain or pattern combinations are characteristics of knitting techniques, particularly with weft-knitting machines.

Small allover pattern repeats in the predominantly vertical motifs are more the work of warp-knitting machines. Colour patterns in weft-knit fabrics, other than simple horizontal stripes, are produced by plaiting one yarn over another. Certain yarns are made to appear on the face of the fabric, but others are knitted to the back of the goods. This plan can take place from needle to needle of from course to course, and it can be alternated when reverse plaiting is desired. Examples of this technique are the two-colour fabrics which have a face of one colour and a back of another colour.

Imitation Argyle socks are made by plaiting in which the diamond effects are formed by reverse plaiting. Colour patterns in knitting may result from the use of differently coloured yarns with the same dye properties or from the use of yarns which can be cross-dyed. Very often the plaiting process is used in conjunction with tuck stitches to produce still more pronounced fabric effects. Other patterns are produced in weft knitting by floating, which is forming loops of one yarn upon certain needles while another yarn is carried in a nonknitting position past those needles which are knitting the first yarn. This second yarn is caught subsequently and knitted into face loops by other pattern-producing needles. By the use of this technique, the floats on nonkint yarn appear on the back of the fabric, which is usually of plain-knit stitch.

Eyelet or lace effects in knitting are made by keeping yarns off some needles, as in the case of the end-out warp-knitted fabrics. They can also be produced by needles out of play, by nonknitting needles on circular machines, or by loop transfer on full-fashioned machines. Tuck stitching, which is holding loops upon a needle from one to eight courses, also produces a holelike effect in knit fabric. Clocks and other decorations are sometimes used in stockings. They are supposed to have been used first to cover up a seam. Clocks may be embroidered by hand or by machine.

Lace clocks, such as Paris clocks, can be made in the knitting process, or they may be made by a process similar to drawn-work thread. In this last type of clock, the threads are dropped, forming a ladder effect which can be hemstitched on both sides. Clocks should branch out at the lower end. In the lower-quality stockings, this is not always the case, and it may show up when worn with low shoes.

Braiding

In braiding, the yarns are not interlaced at right angles, as in weaving, nor are they looped together, as in knitting. Rather, the yarns are connected by twisting, by entwining, or by knotting them together. Braiding of a little girl's hair into a pigtail is a simple example of the principle of braiding. Of all plaited and braided fabrics, lace is the most important. Commercial braiding and plaiting are usually done by machine in mills, whether the material is shoelace or lace tablecloth. The following sentences explain the differences among the various methods of making braided or plaited fabrics. In crocheting, separate loops are thrown off and finished by hand successively.

Netting consists of knotting threads into meshes that will not ravel. Chinese-type lace and fish net have a knot at every intersection. Knotting is done through actual knotting of the parts of one or more threads so that they will not slip or loosen. Tatting is used to make banding, edging, or insertion which is lacelike in formation in the finished condition. It done by means of a small shuttle. All these methods may be carried out either by hand or by machine. In the making of braided or plaited fabric, a single yarn could theoretically produce the material, since the yarn is made to interlace, entwine, and twist in several directions. More than one yarn, however, is used to make lace by machine. The action is like that of the several feeds of yarns entering the machine used to make knitted or woven fabrics.

Lace

Major laces of today include curtain and table laces, filet net, novelty effects, combination effects, and rough-weave and shadow-weave effects. Lace has been with us for a long time. A crude form of meshed cord for ornamentation was used in Peru over 4000 years ago. Ancient Egypt used a form of lace to cover mummies as far back as 2500 B.C.

The history of lacemaking further reveals that it was made in the early Christian era, that its use increased greatly in the fifteenth century in Italy and Flanders, or Belgium and parts of France and the Netherlands. After this time, fashions and styles changed as the growing industries made people wealthier. England, France and Italy began to use a considerable amount of lace on clothing.

Lace was used in a lavish way; men used lace cravats and lace cuffs and collars; even their boots were trimmed with lace. By the eighteenth century, lace was common all over Europe, and its use reached the heights of extravagance. Handmade lace is now made in Austria, Belgium, China, France, India, Ireland, Italy, and Syria. The lace is the result of long, tedious, trying work, which therefore causes the price to be rather high. Handmade dress flounces, for example, may range in price from about ten dollars to about four hundred dollars a yard.

There are four types of handmade or real lace. Needlepoint lace is the most expensive and most difficult type of lace to make. It is made with a needle. The first step is to sketch the pattern on parchment, which is then stitched down upon two pieces of linen. The thread is then laid on the leading lines drawn on the parchment and fastened to the parchment here and there by stitches. The solid parts are filled in by the needle with buttonhole stitching. The meshes, or ties, are manipulated so as to link the different parts into the one fabric.

A knife is next passed between the parchment and the linen, thereby releasing the completed lace. One variety of needle-point lace is called Alencon. The name comes from the city of France where it was first made. Birds, flowers, and other motifs form the background of Alencon. The groundwork of this lace is hexagonally shaped in mesh construction of double-twisted thread. Venetian-point lace has floral patterns in which the design is marked with regular open-worked vine effects. Rose point resembles Venetian-point lace.

Bobbin lace is made on pillows, and so is often referred to as pillow lace. A twisting and plaiting action brings the threads into the motif. The pattern is first drawn on a piece of paper and pricked with holes which determine where the pins shall and pricked with holes which determine where the pins shall be placed for guiding the thread. The pattern is then fastened to a pillow. The end of each thread is held by one of the pins. A small bobbin holds the thread supply. The lace is formed by throwing the bobbins over and under each other, so that the threads are plaited about the pins to form the fabric. One variety of bobbin lace is uncut-thread lace. This variety of single-piece lace includes Binche, Cluny, malines. Old Flanders, point de Lille, point do Paris, common torchon, and Valenciennes. The meshes are hexagonal, round, or square. From these types the motif is developed. Heavy outline threads are employed to set off the design.

Another variety is the united lace, in which individual details are combined to give the finished fabric. Black and white Chantilly, blonde, and Bruges duchesse, and Brussels duchesse are the more popular types. Relief motifs are a feature in these laces. Coarse Flanders and point d'Angleterre laces are made from a combination of needle point and bobbin lace. The latter term was originally used for very fine Flemish lace of the eighteenth century.

Crocheted lace, sometimes called Irish lace, is made with a crochet hook. It is not as fine in texture as needle point.

Syrian lace resembles Irish crocheted lace and is used chiefly for handkerchiefs. Darned lace is made with a chain stitch that outlines the motif on a background of net or some other suitable fabric. In the variety called antique, a heavy linen thread is used in a large, rectangular-knotted mesh effect. Filet lace has square mesh in which the patterns are made with animal and tree effects.

Some of the most beautiful and intricate handmade laces have for centuries been made in convents and convent schools throughout the world. This work is exceptionally fine in detail and superb in motif. Machine-made lace came into being because of the great demand for lace.

The famous Nottingham lace machine has the following features: Patterns are made on the principle of the cards used in weaving jacquard designs in woven fabrics on a jacquard loom. A warp is used the same as in making woven fabric on a loom. Separate spools furnish yarn in different quantities, as required by the motif. There is no filling yarn employed in the strict sense as is used in making woven cloth. Fine yarn is wound on small brass bobbins and set in frames known as carriages.

It darts back and forth, spiraling around so as to tie in the warp yarn and yarn from the spools used for the motif. Tensions on the machine must be carefully watched for tautness or looseness of the fabric. The Nottingham machine is 30 feet wide and the frame may be divided to make eight or ten curtains at the same time. Each fabric is controlled by the jacquard head motion for motif and accuracy.

Machine-made laces are divided into

1) Oriental lace, which is a fine net, made with a heavily embroidered edge;
2) Princess lace, which is made of machine braid on a machine-made net and put together by hand; and
3) Shadow laces, which have a fine-mesh ground in which shadowlike patterns of finer mesh are seen.

There are irregularities in handmade laces, since the patterns do not repeat in perfect order. Insert a pin into threads of the pattern of machine-made-lace, and observe that it is possible to slide the threads back and forth. This is not possible in handmade lace. Lace may be made from linen, cotton, and silk; also from nylon and other synthetics. If you study fibers and yarns, you'll be able to distinguish one from the other.

Nonwoven fabrics

The fabrics you have studied this far have differed in many respects. There were heavy rugs and wispy laces. There was stiff duck and elastic hosiery. All these fabrics hand one thing common: every one of them was composed of yarns. You'll have to consider still another group of textiles: those fabrics that are changed directly from loose fibers into a fabric, without spinning the fibers into yarn. For want of a better term, textile technologists call them the nonwoven textiles. You must understand that his term refers only to fabrics made directly from the fibers, not to knit goods and other fabrics made from yarns. The nonwoven textiles can be subdivided into two classes: Felt is made from wool and similar fibers.

The physical structure of these fibers can cause them to interlock tightly under certain conditions. Felt has been used for many purposes since ancient times. Their construction is based on the fact that certain synthetic fibers melt when heated. Just below the melting point, the fibers become sticky or tacky. You can therefore fuse, or bond, the fibers together by a suitable heat treatment.The felt industry uses wool fibers, also fur fibers.

Let's first look at the manufacturer of wool felt. Suppose you spread wool fibers in a nice, even layer, somewhat like batting. Then you add a thick solution of soap and warm water, or a similar substance. Finally you stamp around on the layer of squashy wool with your feet or you beat it with a wooden mallet. During this time the soapy water, has opened the scales on the wool, and so they will act like tiny barbs. Every time you press the fibers down, they move a little, but the barbs don't allow the fibers to return to their original position after you remove the pressure. Eventually, the fibers becomes so mattered together that you have a compact piece of felt instead of a layer of loose fibers. In modern industry, machines are used to make felt. The wool is spread into even layers by carding. Fulling mills are used to felt the wool. Finishing processes are used to improve the felt fabrics. But the basic principle of felting is identical in all processes.

Wool felt is used for a wide variety of purposes. Fine wool felt can be made so thin that it can be used for kisses' skirts. Since there are no yarns that can ravel, such skirts are very easy to make. The felting power of wool is so great that it holds the fibers together even when re-used wool, waste cotton, and other low-priced fibers are mixed with it in inexpensive felts. Such felts are used for carpet cushions, and in industrial shocks absorbers. An interesting variation of felt making is the production of felt from fur fibers for use in hats.

The prolific rabbit produces most of the fur fibers for this purpose, but beaver, nutria, and other furs can be used too. The tiny barbs on these fur fibers are tightly closed, and must be opened by means of chemicals. This process is called carroting. In former days mercuric nitrate, a poisonous chemical which affected the brain of the worker, was used to open the barbs. Hence the saying "as mad as a hatter." Today harmless chemicals are used for carroting, and the hatters are just as sane as other skilled craftsmen. Practically all felt made from fur, and much wool felt too, is used by the hat industry.

The felt bodies for hats are made in plants called back shops. Their functions are parallel to those of the clothing industry, which readies the product for the consumer. About six million hat bodies are produced every year in the United States. In some hats a hard finish is desired, especially in the brim. This is achieved by putting shellac solution into the felt, a process that really combines felting with bonding of the fibers. In some instances the different techniques of making textiles are intermingled. For instance, you can take woven woollen fabrics and then felt them in a fulling mill until the fibers are matter together. The result is a woven felt which combines the strength of woven fabrics with the cohesion of felt.

Bonded fabrics

Manufacture of bonded fabrics has not yet reached proportions that allow a full evaluation of their possibilities. In properties and appearance the bonded fabrics occupy a place between paper and textiles. Most of the bonded fabrics manufactured today are prepared by producing a web of fibers on a card. The web can be held together by applying adhesive, that is, suitable plastic or glue, in narrow stripes or other suitable patterns.

Another method is autogenous bonding, where the fiber itself is treated to become tacky and to stick together. Some fibers such as rayon, can be made tacky by treatment with acid. Bonding is then followed by compressing the web, washing, and drying.

Other fibers, such as acetate, can be bonded by simply applying heat and pressure. If you take a piece of acetate fabric and carefully apply a very hot iron, you'll notice that the fibers become tacky and stick together.

Many bonded fabrics can be laundered and dry cleaned. However, the fabrics are relatively inexpensive, and their major use seems to be in the production of disposable items. Bonded fabric are used in disposable napkins and tablecloths, shoepolishing cloths and dustcloths filters, bandages, and decorative ribbons for wrapping gifts. As further technical advances are made, the uses for bonded fabrics may expand.

Automatic weaving machine

Use of high performance textile structural composites is becoming increasingly popular in many engineering applications. Examples include aerospace and aircraft structural components, deep submergence vessels, sports equipment, textile machinery and automotive parts. The rate of growth of composite use is expected to continue to increase rapidly with new developments in fibre and matrix materials and manufacturing technologies. Fibre reinforced composites basically consist of two fundamental components; the reinforcing fibres and the surrounding matrix.

Technologies for the manufacture of the reinforcing fibrous preforms include a number of conventional textile processes as well as several speciality techniques developed mainly for the composites industry. Laminating several layers of a woven fabric, cross-laying of tapes of continuous filaments or filament winding the fibres into the required shape were most common in the late seventies and early eighties. However, because of failure by delamination of the these materials, several systems of producing three-dimensional integral shapes have been developed over the last decade.

The new textile systems include 3-D braiding, 3-D weaving and 3-D knitting. Other systems were developed especially for bodies of revolution or for the manufacture of billets which have to be machined to the required shapes after consolidation. Recently stitching multiple layers of multiaxial warp knitted 2-D fabric into 3-D shapes has improved the availability of structures with several fibre orientations as well as enhanced damage tolerance. Considerable development work is taking place in industry, research institutes and universities to automate 3-D braiding machinery using the 2-step and 4-step processes.

Developments in 3-D weaving of net shapes have not been given sufficient attention by the industry. 'This lack of activity was the driving force behind the effort which will be described in this paper. Composites made with 3-D integral structures woven or braided into net shapes offer considerable advantages over laminated composites.

The properties which made composite materials so attractive include their high specific strength, high specific modulus and low thermal expansion coefficient among others. However, the high cost of advanced composites has limited their use mostly to space and military applications, where the performance of these materials has been unmatched by metals.

3-D weaving processes

Three-dimensional fabrics not only have three- dimensional shape, but also have yarns in three or more directions. Multi-layer woven fabrics have been used for a long time in industrial applications, particularly in belting and webbing. Multi-layer fabrics are composed of several series of warp and weft yarns which form distinct layers, one about the other. Binding the layers together can be achieved by many ways, either by interlacing warp ends in the structure with the weft of adjacent layers (referred to as angle interlock), or by having ends interlace between the face and back layers (warp interlock).

The binding yarns may also interlace with the weft vertically up and down between layers producing an orthogonal weave. This system usually involves insetting the weft one pick at a time, which requires moving the fabric up and down, during beat-up, to achieve the desired thickness. The loom can be adapted to weave three- dimensional shapes by the proper arrangement of the warp.

However, it is very difficult to maintain all yarns in the structure straight. Only straight yarns contribute their full• strength to that direction. An integrated 3-D structure is produced by the process invented by Fukuta, et.al. This method comprises three steps: 1) inserting a number of doubled weft yarns (Y direction, across the width) between layers of warp yarns (X direction, axial), 2) inserting vertical Z yarns between the rows of the axial warp yarns perpendicularly to the weft and warp, directions, and 3) packing the yarns together using a reed. The structure produced is 3-D orthogonal.

The density of the structure is limited by the need have sufficient distance between the yarns to accommodate the means of inserting the weft and Z yarns. The patent described the production of structures with rectangular cross section only and did not describe the formation of 3-D net shapes. King invented a different method of forming three-dimensional structure.

In this method, the Z axis yarns, which are rigid rods made of a self-supporting material, are vertically oriented and positioned passing through holes in the upper frame and resting in mating recesses in the upper surface of the lower frame. The X and Y axes filament feed units are essentially identical. They insert the X and Y filaments by advancing parallel, equally spaced needles alternately. The X and Y yarns are doubled and are inserted leaving a loop at the far outside edge of the Z axis filaments.

The selvage (fabric edge) is formed by pins which hold the X and Y axes yarn loops during insertion. The pins may be removed as the filament layers buildu . After sufficient layers have been formed, it is suggested (but not necessary) to compress. The fabric along the Z axis by lowering the upper frame. Again, this method is used to produce only structures with rectangular cross sections. The patent also describes a different method to produce cylindrical shapes.

Mohamed et al. described an automated, computer controlled machine designed to weave 3-D orthogonal structures according to the method described above. Warp yarns taken from bobbins on a creel are separated into layers to allow for weft insertion. In this case there are more than one layer, and thus more than one shed. These warp sheds are fixed open. Multiple weft yarns are inserted through the sheds by needles. The Z yarns are fed into the machine parallel with warp yarns and separated into two layers controlled by harness. When the top Z yarn layer is moved to the bottom and the bottom Z yarn layer is moved to the top a vertical component of yarn is added.

The weaving process can be described as follows: several needles containing doubled weft yarns are inserted horizontally through the sheds in one motion. The weft yarns can be inserted simultaneously or alternately and from one or both sides according the cross-sectional shape. The weft yarn loops are temporarily held on the opposite side by a vertical selvage needle. The insertion needles are then withdrawn to their original position leaving behind a set of doubled weft yarns.

The selvage needles are lowered and the formed structure is then "taken-up", that is, moved a distance corresponding to the required spacing of the weft yarns. The reed is then moved back and the entire cycle is repeated. This process lends itself to continuous production of long structures. The yarn supply is from bobbins on a creel behind the machine. The tensioning of the warp and Z yarns is achieved by weights applied to the yarns individually. The layers of warp yarns are drawn through the reed in a formation similar to the shape being produced. Weft yarn tension is controlled both passively and actively and varies throughout the weaving cycle. All the motions are pneumatically actuated, with the exception of the take-up action. This simplified the design of the machine and eliminates the need for drive motor which could have a high risk of being shorted when weaving carbon fibres.

Double acting air cylinders controlled by solenoids are used for weft insertion, reed, harness and the selvage needle movements. The reed movement is controlled to be linear and perpendicular to the insertion direction. The linear motion is necessary to ensure the vertical placement of the Z yarns. A step motor is used to turn a threaded rod causing the linear motion effecting fabric take-up. A microprocessor using a simple programme, written in BASIC controls the timing of all the movements and the amount of take-up. To control the neatness of the edges, the selvage yarns are knitted through the weft loops.

The control system of the 3-D automatic weaving machine consists of a microcomputer, a control board ' which is connected to the computer with an interface card, solenoid air valves, a step motor, and pneumatic cylinders. Any microcomputer should be able to accomplish the control job, because of the availability, an IBM compatible 386/16 personal computer is used for the machine- An AC5 parallel interface card is used for digital input and output. This caM enables the PC to communicate with OPTO 22's PB24 mounting rack, which can accommodate up to 24 single channel 1/0 modules.

One channel is used for checking on/off status of the control switch to cause the machine to run or to pause. Two channels are used for the operation of the step motor. The rest of the channels are for controlling the solenoid air valves. The control programmes are written in BASIC language and are stored in either a floppy disc or a hard disc. Depending on the dimensions and the cross-section of the preform to be woven, an appropriate programme can be loaded to run the machine. The parameters and the programmes themselves can be modified to meet different weaving requirements. The machine speed could be controlled by changing the corresponding parameters in the programmes. Control of the pick density is by means of the number of steps made by the take-up motor.

Seven
Braiding Processes

Braiding consists of the interlacing of several yarn to form a structure. Obviously, most weaving processes would be encompassed by so general a definition and no clear, accepted distinction between braiding and weaving appears to exist. Products having components that are reasonably termed the "warp" and the "weft" are often referred to as woven structures. Others are usually considered braids or knits. Sometimes the classification is based more on the machine than on the process and depends on whether the machines are composed of loom-like or of braider-like elements.

Materials produced on conventional looms are readily classified as woven products and materials produced by braiders are referred to a braids. Some definitions have been offered that make distinctions based on the method and/or direction of yarn insertion. However, the distinction blurs when the process evolves into a 3-dimensional weaving process. The semantic dilemma is further revealed by examining a generalized interweaving process.

For instance, the general, ideal process could be thought of as a procedure in which the interwoven structure can be produced by the successive exchange of positions of any of many individual yarns arranged in a spatial array. Such a procedure is embodied in the AYPEX process, which consists of a series of elementary position changes and has been shown to be capable of yielding any yarn structure.

Although the AYPEX process will be discussed more fully later in these notes, it will be instructive to examine it briefly here. Interweaving is accomplished by the successive elementary exchanges of positions of adjacent yarns, hence the name Adjacent Yarn Package EXchange. Other braiding (or weaving) processes can be viewed as a less general procedure in which restrictions are placed upon the possible interchanges that can occur and upon the geometric form of the spatial array.

A conventional braider, for example, executes a subset of the possible interchanges and this subset is fixed by the mechanical construction of the machine. Conventional weaving consists of a subset of exchanges. The shedding operation in weaving is the repeated, simultaneous interchanging of complete rows of yarns. Weft insertion is likewise an exchange of position.

A machine capable of executing all of the elemental interchanges would satisfy the definition of a braider that was offered and would be capable of duplicating any of the weaving processes. Loom-like machines are not capable of approaching the general braiding process. However, a machine capable of implementing the general braiding process would Rely be an inefficient weaver.

In fact it would be an inefficient alternative to produce any materials for which more specifically optimal machines could be dedicated. This is because the flexibility to produce all possible interchanges would result in much redundant capability when applied to the production of a particular material. This complexity can be reduced, however, if the goal is to produce materials having a limited range of variation.

Row and column shifting processes

Several braiders have been developed that involve the sequential shifting of rows and columns of yarns. Some of these processes accommodate both a rectangular array of rows and columns and a circular arrangement having radial and circumferential rows. All suffer from one principal

Bluck braider

A basic Bluck braider consists of individual yarn carriers arrayed in a rectangular pattern. Elements 27 and 31 are cams arranged and driven so that the rows and columns in the carrier array can be moved back and forth. The timing of these moves is such that adjacent rows are driven in opposite directions followed by a similar shift of adjacent columns.

The cumulative effect of these motions results in the individual carriers being driven about in the array causing interlacing to occur. While the weaving process yields a structure that is useful for certain applications, the interlacing pattern is fixed by the mechanical characteristics of the machine and the array of yarn carriers. Large scale machines would also be quite complex. Bluck offered other mechanical schemes for accomplishing the interweaving process. However, they too were limited to one pattern and would yield complex machines.

Florentine approach

Another non-conventional braiding process of the tow and column type was suggested by Robert Florentine. It is similar to that of Bluck and can be understood. The circular elements depicted represent yarn bobbins arrayed in a rectangular pattern. The items arranged around the array of bobbins are actuators, possibly hydraulic or pneumatic cylinders, that are used to shift the rows or columns in directions parallel to the rows or columns.

By controlling the sequence of column and row shifts, an interlacing pattern is produced that yields a braided structure. The limitation cited earlier is immediately apparent. The destination and path followed by an individual yarn is very difficult to control independently of the paths and destinations of other yarns even though the actuators can be individually controlled.

Position exchange processes

Some processes which shift individual yarns from position to position afford individual and independent control of yarns and would therefore permit general control of the braid pattern. These processes all require very complex mechanisms if complete generality is to be obtained and therefore have not proved to be practical alternatives.

Fukata process

Fukata process results in a braided structure consisting of a series of yarns woven about another series in a perpendicular orientation.

The braiding yarns are transported from point to point by mechanisms located at each point in the array and that move yarn bobbins individually. The Fukata process requires very complicated machines to accomplish all of the bobbing transfers required. Further, unless the transfer mechanisms are individually controlled, there would be no flexibility in defining the interlacing pattern.

APEX process

APEX process was mentioned earlier in the discussion of braiding, The process involves the exchanging of positions of individual yarns in an array. Richard Weller, the originator of the process, has shown that by implementing a combination of several elemental exchanges it is possible to move any individual yarn from any position in the array to any other position. Full implementation of the process would require individually controlled exchange mechanisms at each point in the braid array and would result in mechanically complicated machines requiring complex control systems.

Farley braider

Gary Farley at the NASA Langley Research Centre has proposed a process that would afford completely general control of the braid pattern. It consists of individually powered and controlled tractor units to transport yarn bobbins about the braiding surface. The braiding surface consists of an array of turntables, each capable of indexing 90 degrees.

Translation is accomplished by linear tractor moves with the translation direction being controlled by the turntables. The braid pattern is obtained by coordinating tractor moves and turntable rotations. While the process has a number of attractive features, it, like several of the other processes, would yield a complex machine when implemented on a practical scale. This process lends itself to mechatronic applications and this aspect of it will be discussed further in later sections.

2-Step braider

Ronald McConnell and Peter Popper proposed a process that has now become known as the 2-Step process.

Researchers at North Carolina State University have achieved significant success with the process. In it a large number of braiding yarns are passed diagonally through an array of axial yarns. The "2-step" terminology derives from the two diagonal directions followed by the braiding yarns. The process permits flexible control of the cross-section geometry of the braided structure and is best applied to materials of uniform cross section consisting of many axial, non-braiding yarns.

Ideal process

An ideal braider must satisfy a two-fold, fundamental requirement--it must possess only the mechanical complexity needed to control the braiding pattern, yet be capable of producing generally variable patterns. As suggested by the descriptions above, most 3-D braiding schemes either achieve simplicity by limiting flexibility or seek flexibility at the expense of complexity. The traditional mechanical braiders, the Florentine Magnaweave scheme, and the two-step braider, described above produce braid patterns that are intrinsic to the process.

On the other hand, methods such as the AYPEX and the Farley procedures possess the necessary flexibility but suffer from complexity that becomes overwhelming when the process is scaled up to produce large braided sections with full flexibility.

An examination of the ideal process as considered above yields the following specific attributes that would be embodied in a machine designed to implement the process:

1. A completely general braiding capability, permitting any particular yarn to be moved from any position on the braiding surface to any other position by any prescribed path, must be attained.
2. The mechanical construction and control requirements must be practically feasible, even in machines of large size.
3. A large number of non-braiding, axial yarn, must be accommodated if needed.
4. The braiding action must require a minimum of actively and independently controlled devices.
5. Actively controlled actions should be uncomplicated mechanically.

Concerning item 4, it can be concluded that the minimum number of active yarn transport devices should be no greater than, the number of braiding yarns, and that one transport device must be sufficient to drive a yarn completely through a braiding cycle.

Shuttle plate braider

A braiding scheme, referred to here as the shuttle plate process, that approaches the ideal in several respects was developed. This braider consists of a braiding surface formed by an array of stationary square sections, each separated from its neighbours by a gap. A flat plate beneath this surface is caused to reciprocate in two perpendicular directions, first in one direction and then in the other. This movement is made possible by openings in the plate that clear short columns supporting the surface segments.

Yarns are interwoven as they are moved about the surface by shuttles. These shuttles are caused to engage the reciprocating plate as needed to yield the desired movements. In the first prototype version, both power and control signals were transmitted to the shuttles through electrical contact with the braiding surface. The shuttle plate is the prime mover that supplies the mechanical energy needed to shift all shuttles.

The shuttles themselves are very simple devices that employ only a single moving part. This part is a solenoid-actuated plunger that engages the shuttle plate on command. Each shuttle is assigned a unique identity and is controlled independently by directing control commands to particular addresses. The entire process is controlled by a host computer.

Each shuttle is individually and independently controlled. The number of actively controlled devices is equal to the number of braiding yarns (the number of shuttles) plus the shuttle plate—one device more than (lie theoretical minimum. Should the shuttle plate be made a completely passive prime mover, then the number of actively controlled devices would equal the minimum possible.

For each shuttle the controlled action requires a simple on/off command to actuate a solenoid. Such simplicity is in stark contrast to other methods that require control of actuators, direction control devices, and the like at each surface location that could be occupied by a yarn end. For example, Bluck's braider and the *AYPEX* process, as originally proposed, require an x-y grid of actuators, all independently controlled and quite complicated in their function.

A 100 x 100 braiding grid would require ten thousand such actuators, even when only a few hundred or perhaps a few dozen yarns are being controlled. With the shuttle plate approach, the size of the braiding grid has no effect on the number of controlled devices.

It is possible to make the shuttle plate itself a completely passive device by driving it alternately in one direction then the other at a constant frequency. However, the braiding process can be sped up by independently driving the plate in the two axes in a controlled fashion to eliminate wasted moves when possible. Such control adds one element to the number of controlled devices and promises substantial speed increases for certain braid patterns.

In the case of shuttle plate braider, there is a sort of synergistic relationship between the electronic and mechanical elements, perhaps the essence of mechatronics. Not only are the elements of both types dependent on the other, the integration of the two helps reduce the complexity of both. First, by directly controlling each shuttie the number of controlled devices in reduced to the minimum. Second, by requiring only an on/off type mechanical operations the electronic control requirements are reduced to a minimum.

Obviously, there remains the need to transmit data to the shuttles and to monitor the operation of all components to detect errors, malfunctions and the like. However, this communication is easily implemented using established technology. It is also held to a minimum by holding the number of controlled devices to a minimum and keeping the controlled actions simple.

Farley braider

The Farley braider would consist of a large array of independently controlled rotating turntables. Such independent control of the turntables is desirable but would require an immense number of actively controlled devices when implemented on a practical scale. Consequently, in the prototype, and likely in a practical implementation, the turntables operate in unison and are actuated by a single actively controlled prime mover. The switching action of the turntable array is controlled by a computer with each rotation occurring after a complete set of tractor moves along a given axis.

For example, with the turntables set in the X-axis, the tractors are moved as necessary in the X-direction (+ or -). After each tractor reaches -its current destination, the turntables are switched to the Y-axis. The next set of moves of the tractors, all in the Y-direction, then take place. The turntables are then returned to the X-axis orientation, and another set of tractor moves occurs. The switching back and forth of the turntables continues in this alternating manner until the entire braiding programme has been executed.

Each of the tractors incorporates an electronic control circuit and a small d.c. motor and gear train. Power is conveyed to the tractors through contact with electrically isolated conductors incorporated into the turntables. Control signals are transmitted by frequency modulated optical signals via emitter-detector pairs mounted in the turntables and in the tractors.

Directional start signals are transmitted to turntable locations occupied by the tractors. Stop signals are erected at the destinations of the tractors. The tractors, once set in motion, continue in motion until they encounter the stop signals. When all tractors have completed moving, the turntables are commanded to rotate a quarter-turn to align to the opposite coordinate axis. In the current prototype, this rotation is accomplished via solenoid controlled valves and pneumatic cylinders.

The rotation completed, the next set of move signals is sent to the tractors and the moves are accomplished as before. Then the turntables are commanded to rotate a quarter-turn, in the opposite direction, back to the original axis orientation. At this time the next tractor move occurs. The sequence continues, alternating between tractor moves and turntable rotations, until the desired braid is completed. The embodiment of this scheme in the test hardware consists of a 5 x 5 array, with three tractors. This has proved of sufficient size to test the concepts involved and to allow valid conclusions to be reached.

Expansion of the array and the use of additional tractors would be required to scale up the machine to production size. Also, since the tractors are motor-driven and the necessary electrical power is provided through the segmented surface, there is likely to be a practical limit to the number of tractors which can be operated simultaneously with safety.

The two braiders discussed accomplish truly generalized braiding, both in theory and as reduced to practice, in that they are capable of moving any yarn from any endpoint to any other endpoint by any practical path specified by the programmer. The real significance of this accomplishment is that desired braids which have not been achievable in the past can be made.

Comparing the two braiders: against each other, as opposed to comparing against other braiding techniques, the following advantages and disadvantages can be cited. The shuttle plate braider is a very simple design from a mechanical viewpoint, and its control requirements are as simple as they can be made since all that is required are simple on/off commands. Further, all the power needed to move the shuttles is derived from the shuttle plate, and thus little power is needed for the shuttles themselves.

The modified Farley braider does not have this simplicity, but it does have the advantage of speed for braiding patterns which require numerous long length moves of the yarn carriers. In addition, while at any given time all the yarn carriers of the modified Farley braider must move along a given axis, some can be moving in the forward direction while others are moving in the reverse direction. Of course, this speed advantage diminishes as the average move length of a yarn carrier becomes shorter in complex patterns. For the Farley braider there is a concern regarding the timing and synchronization of moves between yarn carriers, especially as the number of carriers increases. This concern could force the use of more complicated devices, such as stepper motors, and proximity detectors to avoid collisions between the tractors.

The shuttle plate braider does not have this timing difficult since all shuttle moves are automatically synchronized by the driving plate. Although both braiders transmit power to the yarn carriers via the braiding surface, the power requirement is significantly different. The shuttle plate braider requires electrical power to engage the solenoid in each shuttle.

As currently implemented, this power is held continually to maintain engagement., Activation of several solenoids at the same time would require high currents on the surface.

However, there are numerous ways to overcome this difficulty in a scaled up version of the shuttle plate braider. These include such options as using mechanical latching and momentary currents to engage the latch.

For the Farley braider, the motors must be powered continually. Thus the power, of necessity, must increase as the number of moving yarn carriers increases. There is no simple solution to this dilemma. The shuttle plate braider scales up readily since the control problem remains the same no matter the size of the braider. The inherently more difficult control of long moves and the timing difficulties discussed above make it more difficult to scale up the Farley.

The Farley braider might more easily be implemented on an upwardly curved surface. Use of such a surface would reduce the size of the braiding surface needed to control braid angles. However, such an approach would complicate the design significantly. For example, the turntables of such an arrangement would have to be of unequal size or rotate through unequal angles, depending upon location on the braiding surface. Finally, set-up and operation of the shuttle plate braider is much easier and more reliable, as demonstrated in operation to date. Either braider could be applied to special or short-run production items, since such situations could not justify the development of special, dedicated machines.

Fixed delivery cone winding

Typically the yarn is delivered by a pair of 'pinch-rollers' and therefore any variation of the take-up rate at which the yarn is wound onto the package results in tension variation. When winding cylindrical packages ('cheeses') tension variations can be kept quite small, but for economic reasons it is sometimes desirable to wind directly onto conical packages to avoid an extra winding operation. The package is surface driven approximately half way along its length in such a way that the average take-up rate is slightly higher than the delivery rate, to provide a small positive winding tension.

However, as the traverse guide spreads the yarn across the package (at a large helix angle) the take-up rate varies. At the small end of the cone the take-up will be lower than the supply rate, while at the large end it will be higher. Unless some form of compensator is included in the system the yarn may go completely slack at the small end and/or break at the large end. Even if a package can be wound excessive tension variation will cause a higher frequency of end-breaks during winding, may prevent even dye absorption if the yarn is to be package dyed, and can cause problems in over-end unwinding of the package.

The task of implementing a mechanically driven positive compensator is not as straightforward as might at first be assumed. Although winding a helical path onto a conical surface might be expected to require a compensator motion described by a simple, and hence easily generated, geometric function, in practice this is not the situation. The compensator motion required is made more complicated because of practical requirements of the traverse guide movement.

In order to ensure a positive drive to the surface of the yarn package, the winding helix angle is reduced in that part of the package which contacts the drive tyre. This makes the package slightly firmer at that point and prevents the tyre from sinking-in. The practical requirement to keep stresses in the traverse-cam track and follower down to acceptable levels at the reversal points of guide motion also dictates that the winding path is not a simple helix. The actual velocity at which the yarn is wound onto the package therefore varies in a complex way, which shows the variation in winding velocity during one complete traverse guide cam cycle.

Unfortunately the difficulties of designing a mechanical positively driven compensator are greatly compounded because the compensation required changes as the package builds. The ratio of the diameters of the small and large ends of the package is not constant for differing package sizes. This means that different, progressively smaller amounts of compensation are required as the package builds up. Despite these difficulties, mechanical positive compensator mechanisms have been built and operated successfully at moderate delivery speeds.

Designs employing cams are expensive and difficult to lubricate successfully for use at high speeds in the textile machinery environment. Designs based on linkages, which contain only rotating joints, have also been investigated. Although free from lubrication problems and potentially inexpensive if mass-produced, these designs give only approximate compensation and are difficult to optimise. They are also inflexible in that small changes in machine design which affect the yarn path require complete linkage re-design. This is a potentially costly problem since tooling costs for mass-producing the low-inertia links required for high-speed operation would be substantial.

Further problems arise with yarn threading since it is difficult to arrange for the drive to be disengaged for 'parking' the compensator in a convenient threading position, an increasingly important consideration now that robotic devices are commonly used for piecing.

Mechatronic compensators

Mechatronic approaches to tension compensation can avoid many of the problems inherent in the mechanical types. Two different mechatronic approaches are evident: open and closed loop systems.

A closed-loop mechatronic tension compensation system in which yarn tension is monitored and compensator position adjusted accordingly would seem ideal. In practice, the difficulty and expense of measuring yarn tension make this approach unattractive at present. The development of a reliable, low-cost yarn tension sensor is a promising area for further work.

The open-loop compensation system, in which yarn is taken-in and let-out cyclically according to pre-defined information, in a similar manner to a mechanical positive compensator, has some advantages. It does not require a tension sensor and the compensation motion can be produced by an inexpensive stepping motor which is simple to control and, having no brushes, has a long service life expectancy. A large amount of positional data is required for the compensator/motor position at each stage of the winding process, but this can be pre-calculated 'off-line' so that the computational requirements of the control system are quite modest.

As in the passive mechanical compensator a disc with two bollards is used to take-up and let-out yarn, since this is probably the simplest arrangement possible compatible with a rotational direct drive. The position of this disc is controlled by a small stepping motor (Nippon Pulse Motor PQ40-200C; a style of motor commonly used for computer floppy-disc head positioning and therefore available very economically as a high volume mass-produced component).

The motor is a four phase hybrid vernier design, giving 400 steps per revolution driven in half step mode, and is driven by a bipolar-chopper type drive circuit employing RIFA PBL3717 integrated circuits. The use of a relatively sophisticated drive circuit of this type rather than a simpler RL drive is desirable since it provides better motor performance (higher torque at high stepping rates) and consumes less power, potentially easing power supply and distribution requirements for a 144 spindle spinning machine quite significantly. A number of sensors are required to provide the information needed to control motor/compensator position.

Since at switch-on the motor could be in any position, a 'top-dead-centre' reference is required for initialisation. This is implemented by means of a reflective opto-switch (infra red LED and photo- transistor) mounted behind the bollard disc. The back of the bollard disc is coloured half black and half white so that the opto-switch can sense the transition in order to provide a datum position. The position of the traverse guide also requires a datum so that the compensation cycle can be started in phase with the cam. This is achieved by mounting a small metal target on the traverse guide and sensing its presence at the end of traverse using an inductive proximity detector.

Only one such detector should be required for the whole spinning machine, although if traverse cams are run out of phase with one another to minimise machine vibration, as is commonly the case, care needs to be taken in interpreting this datum information appropriately at each compensator. The timing information required to allow the compensator to keep in step with the traverse cam movement is provided by an optical encoder mounted on the camshaft.

A high resolution two-track incremental optical encoder was used on the prototype for reasons of availability but a single track 'optical tachometer' disc of modest resolution is all that is required. As the camshaft rotates this device provides the 'timing' pulses which are needed to determine when the compensator's stepping motor should be stepped to its next position. The process leading to the design and optimisation of the bollard disc was as follows. In order to minimise the task of the stepping motor attention was first given to optimising the yarn path by calculating the profile of an appropriately curved yarn guide bar which nominally removes the path-length variations caused by the varying position of the traverse guide.

The next step was to derive the relationship between the amount of yarn stored by the bollard disc and its angle of rotation and bollard spacing. A computer programme was written to evaluate the yarn storage characteristics for any particular set of bollard disc and guide spacing parameters. This enabled the amount of yarn in the compensator to be computed at each angular step position of the motor. Analysis of the CAD data for the traverse cam, in conjunction with the geometric data for the empty cone and yarn path allowed the maximum required amount of yarn length compensation to be determined. This enabled a limit to be set on the minimum bollard spacing.

The maximum bollard spacing is limited by the 400 step/rev resolution of economically obtainable motors, which limits the smallest discrete increment of compensation which can be applied. An appropriate bollard spacing having been provisionally chosen, the bollard and disc inertia was estimated. The motor torque and stepping rate requirements were then ascertained approximately, using the simplifying assumption that the compensation function would be sinusoidal, to establish that a suitable motor was available.

A further computer programme was then written to take the traverse-cam CAD data and the yarn storage characteristics of the bollard compensator and work out the angular positions of the traverse cam at which the stepping motor needs to be stepped by one half-step to give the required compensation. This angular information was then processed into an appropriate form to be used as a look-up table for control of the mechatronic compensator.

The look-up table entries are 8-bit values representing the number of traverse cam shaft angular-encoder pulses to be counted before making the next motor step. Information is also placed in the table to indicate direction reversal and cycle repeat points. An 8031 single chip microprocessor is used to implement the control algorithm. One of the 8031's inbuilt counters (counter 1) is used to determine when the stepping motor should be stepped. The counter is pre-loaded with the current value from the look-up table and counts (encoder pulses) up from this value until it reaches its terminal count.

At this point the counter is re-loaded with the next sequential count value from the look-up table and the motor is stepped once in the current direction of rotation. If the new look-up table entry is a 'flag' value, it is not used as a count but taken to signify that the motor direction should be reversed for succeeding steps.

In this case the table is accessed once more to obtain the count information. A different flag value is used to mark the end of the table to alert the algorithm to re-commence at the beginning. Returning to the problem of determining, and applying differing amounts of compensation for, the varying states of package build, the system performs these tasks as follows. Differing degrees of compensation appropriate to different package sizes are applied by working from a set of look-up tables designed for different cone sizes. The look-up table most appropriate to the current stage of package build is used until it is sensed that a switch to the next table is required.

A number of ways of determining the package size to provide the control algorithm with the necessary information to select the appropriate look-up table were considered. The most obvious was to monitor the angle of the package arm. This approach was rejected, however, for a number of reasons. The angle of rotation of the package arm between maximum and minimum cone size conditions is relatively small. Measuring angular rotation by a directly digital approach would, therefore, require a high resolution absolute encoder, which would be prohibitively expensive.

The digital information from the encoder would also be in parallel form and would thus require multiple connections to the controller, entailing further complexity and expense. Use of an analogue sensing technique, such as a potentiometer, could reduce the cost of the sensor but this approach was also rejected as it would require an A-D converter, again increasing expense and complexity quite considerably. The solution adopted was to infer the cone size by measuring its period of rotation. This can be done with very little hardware.

A Hall-effect sensor is employed to monitor the presence of target sectors on the cone hub (which is a permanent part of the machine). The output from this sensor gates clock pulses into one of the 803 l's inbuilt counters (counter 2). The software can then deduce the rotational speed of the cone by reading (and then re-setting) the count during the inactive period when the Hall-effect sensor output is low.

In normal operation the processor's main task is to continually re-estimate the cone size as follows:

— Look for negative transition on cone rotation sensor i/p.
— Clear counter 2
— Look for high level on sensor
— Wait for low level again
— Read counter
— Calculate cone size and set address of correct look-up, table into RAM (for interrupt routine)

This 'main' routine is regularly interrupted whenever counter 1 reaches its terminal count, indicating that a motor step is due. The interrupt routine performs the following main steps:

- Step the motor one step
- Consult lookup table and get counts to next step (also set direction if changed)
- Load counter 1
- Check end break detector
- Return from interrupt (to size routine)

The system is further complicated in practice by the need to take account of the anti-patterning mechanism built into the winding hardware. This prevents turns of yarn in successive layers from being built up exactly on top of one another and forming ridges on the package. It functions by cyclically varying the speed at which the traverse cam is driven by a small amount. This has a second-order effect on the tension compensation requirements which can be allowed for by providing further lookup table information.

Optimising system performance

One significant obstacle to developing an 'all-digital' system, such as the one described here, lies in the difficulties in 'tuning' the system. Since there are no analogue sensors or actuators in the system it is very difficult to monitor its performance (which must, of necessity, be done in real-time) and hence modify the lookup tables to optimise them to take into account dynamic effects (the lookup table information generated from geometric considerations is all based on static analysis).

Using an Intel IPDS 8051 in-circuit, emulator, the algorithm was checked for basic performance using a single lookup table designed for initial winding onto an empty cone (the worst case condition from the compensation point of view). This single lookup table could be fitted into the on-board memory of the 8051 (and hence the emulator).

Once the basic operation of the programme had been established the emulator was replaced by an 8031 CPU and the programme placed into external EPROM. This configuration having been verified operational, the EPROM was replaced by an EPROM emulator (a 'Softy-3' EPROM programmer used in its emulation mode). This allowed the contents of the memory to be easily altered by downloading data from an IBM PC compatible computer, thereby allowing easy alteration of the contents of the lookup tables (which were initially generated by software on the PC).

Having established a mechanism for 'tuning' the lookup tables without having to re-programme the EPROM's, their contents were refined by fitting (analogue) tension monitoring equipment into the yarn path and recording residual tension variation along with appropriate machine timing indications (from the digital sensors) on a digital storage oscilloscope. Painstaking manual data reduction allowed usefully improved performance to be obtained by adjusting the lookup tables.

It is quite difficult to see how this difficult development stage could have been improved. Incorporating some kind of analogue feedback (eg a potentiometer to monitor bollard disc position) into the development prototype appears attractive. The imposition of additional friction and inertia would, however, have detracted from the performance attainable (the limits of which were being explored) and taken the system one step further from a potential commercial realisation.

The background of mechatronization of textile machines has been improving very rapidly in Japan. Because most weaving factories are located away from city area due to noise pollution and the working conditions are not so good, the textile industry is always suffering from a lack of hands. Therefore, the mechatronization of weaving machine is much desired in order to try to save labour.

Demanding quality of the products is increasing year after year and the inspection of fabrics is getting more strict. In order to pass such strict inspection, fine adjustments of weaving machine are required. Moreover, the trend that new-field products (fabrics) are developed in weaving factories is remarkable. However, traditional full-mechanical weaving machines can not meet such needs. These factors have accelerated the mechatronization of weaving machinery. The weaving machines mechatronized with high performance are mainstream at present in Japan.

Motion of weaving machine

Though we take up Nissan air-jet loom for an example among many kinds of looms, the fundamental structure is common to all of them. In general, the motion of the loom can be divided into five main-motions as follows:

(1) Shedding motion

(2) Filling motion

(3) Beating motion

(4) Let-off motion

(5) Take-up motion

(1) through (3) are periodic motions synchronizing with the rotation of the main-shaft of the loom. Since one woof is inserted into the warp every one rotation of the main-shaft, the productivity of the loom is usually represented by revolutions of it. Weaving motion starts with the shedding motion. The warps adjacent to each other are pulled up or pushed down respectively due to the vertical motion of the heddles (Shedding motion).

At the same time, the reed swings backward and a space through which the woof passes is taken. Then, the woof of the same length as the reed width, which has been pooled in advance, is inserted into the space between the warp with an air-jet stream (Filling motion).

After the insertion has completed, the reed returns forward and thrusts the woof into the cloth-point (Beating motion). (4) is the motion in which the warp wound on the yarn beam (spool) is unrolled keeping its tension constant. (5) is the motion in which the cloth just woven is wound on the cloth-roller at a constant velocity.

In traditional full-mechanical weaving machine, all the motion including the main motions mentioned above were generated by the mechanical coupling with the rotation of the main-shaft by means of gears, cams and links. That limited the movements and caused complicated transmission mechanisms and difficulty in fine adjustment of the movements.

To overcome these limitations, the newest machines are mechatronized to separate some main motions from the rotational motion of the main-shaft, that is, they are composed of several independent devices. Each device has a microprocessor (microproeessors) to control the actuators and sensors to generate exact motions instructed by the operator.

In the mechanical system, the rotation of the main-shaft is transmitted to a continuous speed-change gear whose output shaft rotates the yarn-beam using the reduction gears. The change of the warp tension is converted into the displacement of the backrest roller. The displacement is transmitted to the lever of the speed-change gear through the spring and the links. The warp tension is set by varying the weight hung on the lever A. The speed-change gear is required that the rotational speed change ratio of the input to the output is more than five times which is the same as the ratio of the radius of the yarn beam which is almost empty to that which is fully rolled up. The speed-change gear which is capable of changing the speed with such a wide range is very expensive. In addition, the displacement of the lever of the change gear induces the displacement of the backrest roller, which sometimes causes a serious problem, uneven quality of the fabric.

The combined vector of the warp tension applied to the backrest roller varies as the radius of the yarn beam changes. To resolve the problem, complicated mechanisms to compensate the change of the combined vector is required. On the other hand, the mechatronized let-off device is driven with AC servomotors using vector control. The warp tension is detected with a force sensor as the force applied to the backrest roller. The strain gauges attached on the sensor-body convert the force into an electrical signal, which is used as a feedback signal by the controller.

The microprocessor mainly performs the following processes:

1) Extraction of the real value of the warp tension from the signal of the force sensor.
2) Computation of the manipulated variable.
3) Compensation for the sensitivity of the force sensor due to the change of the combined force vector.
4) Input of the warp tension value instructed by the operator.

The mechatronization of the let-off system brought the following results.

1) Controllability, especially responsibility and steady state error, were improved and the fluctuation of the warp tension was very reduced.
2) The structure of the machine was simplified because mechanical transmission gears used for driving the peripheral devices were removed.
3) Remote operation comes to be possible.

In filling motion system, the woof is usually supplied in the form of a yarn package. It is impossible to insert the woof supplied from the package directly into the warp or the woof will snap before completing the insertion because the resistance force generated by unwind-motion of the woof is too large. Therefore, to keep the woof from snapping, the woof is rewound on a measurement drum. When the reed swings backward and a space through which the woof will passes is taken, FDU (Feeder Driving Unit) unhooks; the woof to enable the woof to leave the dram for the space. At the same time, TCU (Timing Control Unit) opens the woof-gripper and the main air-valve.

The woof is carried with the air-jet stream through the main-nozzle and inserted into the space between the warp. In the case that the machine has a long reed space, the air-stream jetted from the main-nozzle can not arrive at the end of the reed due to reduction. To strengthen the jet-stream, several sub-nozzles are used with the main-nozzle. FDU counts the turning numbers of the woof which has just left the drum in order to measure the length of the woof which should be inserted into the warp.

As soon as the number reaches a value FCU quickly returns the woof-stopper to prevent the woof from overrun. FLU detects the woof arrived at the end of the reed and outputs a signal meaning success in the insertion. After receiving the signal, TCU closes the woof-gripper and shuts all the air valves. In this time, the reed has already been swinging forward. When the woof is thrust into the cloth-point, TCU operates the cutter to cut the woof. The correct setting these timings is very important to make the woof insertion successfully.

The timings depend on fabrics, that is, they have to be changed according to the kinds of fabrics. It is because the flying velocity of the woof varies according to the kind of the woof, the diameter of the woof, weight and so on. In the case of the full-mechanical machine, it was very difficult to adjust the timings precisely because the timings were adjusted by changing the phases of pairs of cams, so that the setting of the timing had depended on the experience of the operator. As the result, it had taken a long time to find a good condition to operate the machine steadily. Mechatronization of the filling motion system enables the operator to set the timings easily, quickly and precisely by means of key-input with the operation panel or down-loading the timing data using a LAN system.

False twist texturing

The first jet texturing process to be commercialised was Taslan and this was followed shortly afterwards by the Du Pont BCF process using jets driven by steam or hot air. The Du Pont BCF process was very successful for deniers of 1000 upwards and so has had a very large impact in the upholstery and carpet markets. Below 1000 denier the Du Pont process was not usable due to the production of twist knots in fine dpf fibres.

This drawback was overcome in the "Fibre M" process by the work of Foster, Murenbeeld, Ferrier and Berry. Out of the "Fibre M" development came a process using feedback control. The "Fibre M" process was developed as a very high speed process (up to 6,500 m/min) for textile deniers. The process was non-isothermal in that the temperature changed from time to time within a position and was different from position to position. The guiding principle was to keep the heat flux into the yarn constant and so produce yarn of constant bulk and constant dyeability.

False twisting processes have however, resolutely stayed isothermal in nature. In order to achieve as perfect an isothermal character as possible, heaters have been made as massive as possible so that stray draughts from open doors etc. will have as minimal effect as possible on the temperature of the heater and hopefully on the temperature of the yarn. At the same time in order to achieve higher speeds and hence better economics, the pin spindle has been replaced with the disc or belt spindle.

Current machines have heaters that are 2.5m in length and if the heater is not angled, machine heights of over 6m have been necessary. Such heights mean special and costly buildings and of course the machines themselves become very expensive. On taking stock one finds that with the advent of fine dpf fibres, commercial speeds for processing 150 denier polyester have recently declined to the region of 650-700 m/min. The problem of surging has not been overcome.

The new work described here discussed how to utilise concepts of feedback control in false twist texturing.

Hot fluid heaters. The first experiments showed that superheated steam or hot compressed air could in fact be used to successfully heat tightly twisted yarn. On cooling the yarn was heat set and was indistinguishable from yarn made on a conventional long contact heater. Having established that a heater only 4" long could replace a 2.5m contact heater, the next step was to determine what form of feedback control should be used. The need is to measure the bulk of the textured threadline on the run.

Use of yarn reservoirs. Several possibilities suggest themselves. We could use the "Fibre M" approach utilising a yarn reservoir and experiments showed that this route has possibilities. However, making a yarn reservoir purely for measurement of bulk has drawbacks both operationally and economically.

Effect of tension barrier in second zone. If we deliberately insert a tension *barrier* into the second zone of the false twisting process then it can be shown that

$$\frac{V_a}{V_1} = 1 - Fe^{-\mu\theta} - C_{max}\,[1 - e^{-\mu\theta}]$$

Where V_a = Yarn speed in the feed zone.

V_1 = Yarn speed at the intermediate feed roller

F = Overfeed

C_{max} = Maximum value of the crimp contraction

μ = Coefficient of friction between yarn and guide

θ = Angle of wrap round the tension guide

All the variables except V_a and C_{max} are constant machine parameters and therefore V_a can be used as an indicator of the value of $C_{max.}$ If V_a is kept constant then C_{max} will be constant. When there is no effective guide present, i.e. when $\mu = \theta = 0$ then the above equation reduces to

$$\frac{V_a}{V_1} = 1 - F$$

So that the yarn speed in the feed zone becomes independent of the crimp contraction. In other words it is vital to have a tension barrier in the thread line. From this analysis we can see that by measuring the yarn velocity of the textured thread line, we can measure the bulk of the yarn in the threadline. If we can measure the bulk of the textured yarn we can create a feed back loop to keep it constant.

Direct yarn velocity measurement. Direct yarn velocity measurement has been achieved by putting a freely revolving roller in the threadline, and the signal developed has been coupled into a feedback loop to a supplemental heater in the superheated steam or hot air supply line. By increasing or decreasing the temperature of the heater we can keep the bulk of the dyeability of the textured yarn constant.

Alternative methods of signal generation. Similar analysis allows one to use tension measurements or yarn temperature measurements for generation of a feed back control signal. Other methods of measuring the yarn bulk such as capacitance, direct laser measurement etc. could also be used for generating feedback control signals in addition to the methods described.

Alternative feedback control routes: The feedback singal can of course be used to control other machine parameters such as

— the twister spindle
— the input roll
— the output roll
— the intermediate roll
— combinations of the above
— pressure of heating fluid
— specific heat of heating fluid

Because of the shorter heater the machine is only 2m in height, the threadline is short and much higher processing speeds are possible. Yarn quality is improved and machines built incorporating non-isothermal feed back control have the following advantages:

— machine only 2m high, no special building costs,
— lower capital cost of machines (50%),
— shorter threadline, reduced or no surging,
— higher speed (3-4x),
— better quality control within package and package to package,
— flexibility of production, machine can be stopped and started
— permits 3 shift working (as opposed to 4 shift)

— permits 4 day 2 shift working

It would appear that a new dimension to false twist texturing technology i.e. constant bulk non isothermal false twist texturing, is opening up and the heart of it is feed back control, that is mechatronics.

It is believed desirable to have a yarn temperature of 200°C or higher, and as can be seen this very small jet achieves this goal quite comfortably. Table 1 shows the relationship of tenacity, elongation and crimp contraction for 167 dtex draw-textured polyester as steam pressure is increased from 70 to 130 psi. Tenacity and elongation are unaffected, while the crimp contraction of the yarn is substantially increased.

Table 1: Effect of pressure

POY Polyester (300 f 30 ® 167f 30)

Textured at 600 m/min speed and 220o C temperature

Pressure psi.	tenacity cN/tex	Elongation %	Bulk K%
70	35.5	20.2	31.5
85	34.6	19.0	33.7
100	35.4	18.7	33.0
115	35.2	19.3	40.2
130	35.1	18.9	39.1

Table shows the relationship of tenacity, elongation and crimp contraction for 167 dtex draw-textured polyester as the jet temperature is increased from 200°C to 250°C.

Eight
Designing Mechatronics

While there is a lot of high level software available to support mechanical design, electrical and electronic design and software design, there is little available to support the interdisciplinary design philosophy of mechatronics. Mechatronics opens up to the design engineer an enormous spectrum of choices and frees him to use his creativity in ways hitherto unfeasible. It is perhaps this very creativity which stands in the way of software support.

In exactly the same way that attempts to emulate human intelligence have so far failed almost entirely so that the so-called all remains locked in a 'blocks-world', so it appears likely that attempts to mechanise human creativity are also doomed to failure and that artificial design is likely to remain capable only of routine selections of options from previously prepared lists. There is, nevertheless, good reason to seek to put together software which will perhaps take the tedium out of the mechatronics design process if, by nothing else, by allowing easy transfer of data from one analysis package to another.

This, at least, is the rationale behind Fujitsu's "Integrated System to Support Computer Analysis in Preliminary Aerospace Design". This type of design demands programmes for modelling, simulation, dynamic analysis and optimisation which use huge databases.

Inefficiency in the design process is caused by:

— Awkward data transfer from programme to programme due by the fact that each programme has hitherto been the province of a different 'department'.

— Design data being generated and used by each group separately.

Fujitsu software uses knowledge bases to allow convenient cross-reference between different programmes. The technology library contains a large number of technology programmes each of which can be plugged in or unplugged to suit an application. It is claimed that any unfamiliar engineer can execute programmes, manage data and interface with other registered programmes easily.

The system is implemented in the LISP language. The Hitachi company is also working towards integrated software for design support. The industrial interests of Hitachi cover such a wide spread that it is very easy for a company engineer to gain the sort of multidisciplinary experience needed for mechatronics design work. However, it is also necessary to try to gather data from this wide effort together in a useable form. Hitachi have evolved a system known as HIDESS. Mechatronics is seen as a subset of Analysis and Simulation, no doubt because Hitachi, in common with many Japanese companies, sees mechatronics as synonymous with Advanced Robotics.

In the UK a special Engineering Design Centre (EDC) with the theme of mechatronics Design has been set up at the University of Lancaster. This has a major aim to develop software to support mechatronics, but little has yet emerged. In Denmark, the Engineering Design Institute at Lyngby has done a great deal of work on Design methodologies. Buur, in particular, has made an in-depth study of Japanese design and manufacturing methods, and has evolved a classification of design which explains much of the Japanese success. For instance, he shows how the Japanese i introduce new products much faster than we do in the West. This is necessary to keep up with the competition from other companies.

It is ironic that while JIT manufacture was originated in Japan with Toyota, it cannot now be applied in many companies because the very high rate of introduction of new products means that there is not enough time to get the manufacturing lines working in an error free manner before they have to be modified for the new models. The Canon company of Japan accept that true JIT is impossible for this reason.

Japan has developed the mechatronics approach to product design to a very high degree. Many would argue that it is precisely because of this that Japan now enjoys its predominant," position in the global marketplace for high technology consumer products like cameras, videos, music synthesizers and motorcycles. Buur has conducted an in-depth study of Japanese design and manufacture and has analysed the situation in order to provide some guidelines for other manufacturers. The Yokogawa Company of Tokyo, Japan is heavily involved in the mechatronics approach to motion control - in its case by developing an electric motor/controller combination capable of out-performing existing products by a long way.

DYNASERV Direct Drive Servo Actuator has developed mechatronics and the route of this product from conception to marketable form reveals much of Yokogawa's mechatronics approach to product development. The seeds for the DYNASERV range came from the research interests of some staff in robotics.

A number of direct drive robots have been designed worldwide to take advantage in terms of speed and precession to be obtained by the elimination of transmission elements such as gears and cables. This required a new type of motor—

one which could rotate slowly but, produce a high torque and with the capability of being precisely controlled in both position and speed. Such an actuator, together with an integrated controller, would find a large market not only in robotics but also in machine tools and automation generally.

Having had the idea, the staff members then put the proposal to the Yokogawa management, whose procedure then is to consult with a large number of academic researchers and also industrial R&D workers. This high profile research evaluation team meets in several brainstorming sessions under the auspices of the Yokogawa Technology Board. This team decides whether the idea should be supported and taken forward, or dropped.

If the evaluation team manage to convince the Technology Board that the potential profit is high and that the product fits the Yokogawa profile, then the next part of the sequence is, initiated. Within the Research and Development Department a small interdisciplinary team of researchers is set up. This consists of a project manager, a mechanical designer, an electronics engineer, a software specialist, a manufacturing specialist, any other specialists whose knowledge is deemed useful and, crucially, a young engineer recently recruited to the Yokogawa staff. A typical team will have between 10 and 20 members. This team meets regularly in brainstorming and evaluation sessions and eventually there emerges a product in prototype form yet possessing features of manufacturability which puts it close to the final form.

Yokogawa see this team formation and operation as the key to their mechatronics design success. In the case of the DYNASERV actuator/controller sets the result is a motor which has enormously reduced torque ripple (achieved partly by careful electromagnetic design and partly by feedforward of the expected ripple profile) and, via the application of real-time adaptive control techniques, the ability to self-tune to handle inertia variations of 10:1. The eventual aim, very near to achievement, is to be able to handle up to 1000:1 inertia variations found in automatic indexing tables. The next Yokogawa product will be the MOTIONACE Universal Motion Control System. This will be modular with integral libraries for inverse kinematics, joint transformations, transmission mechanism characteristics and, eventually, full dynamics capability.

The design process can be regarded from many different points of view: planning, organization, creativity, design tools, task assignment etc. When proposing methods and procedures to aid the designer, we must be very distinct about the viewpoint we take, and about the scope within which the methods are valid. A suitable framework for describing design has been suggested by Andreasen and Hein. It distinguishes three levels of resolution:

1. Problem solving, based on the human way of thinking.
2. Product synthesis, based on the characteristics of technical systems.
3. Product development, based on the company organization.

The term 'problem solving' for the activity carried out by humans, when finding and deciding on a solution to a complex problem. By complex we mean,open-type' problems which have many possible solutions, as opposed to 'closed-type' problems with only one or two solutions that can be found by some calculation method. The solution achieved through the problem solving process may be material (e.g. products) or non-material (e.g. services, schedules). To suggest a method for solving problems, one must study how a designer as a human thinks: creativity, decision making etc. Evaluating a number of ideas will always yield a better result than considering only one, intuitively found solution. In order to limit the field of possible solutions, the problem should be defined in advance, and criteria should be determined for the evaluation of alternatives.

Problem solving may be regarded as an elementary activity to be applied to every sub-problem and in every iteration cycle of the design work. Naturally the number of necessary alternatives and the care taken in evaluation must be determined by the priority of the problem and the degree of innovation. In each phase of general problem solving, a number of design methods and tools may be applied. For instance methods for creative and systematic idea generation (brainstorming, morphological methods, hierarchical methods), methods for evaluation (point scale methods, pair-wise comparison), and CAD tools for specification of geometry and structure. The main purpose of these methods is to encourage the designer's imagination, and to prevent 'human blocks' due to preoccupations and limited knowledge.

There isn't anything particularly 'mechatronic' about the general problem solving process. This activity is based on the human way of thinking, and therefore almost independent of technologies. We will however find that creativity and qualified decision making are important preconditions for mechatronic design, and that both these activities will be severely limited, if the designers involved do not have a wide, interdisciplinary knowledge of mechanics, electronics and information technology.

In product synthesis level, we concentrate on the characteristics of the technical artefaet to be designed: it's purpose, functions, organs, interfaces, parts structure, total form, etc. Synthesis is the activity of combining separate elements (or problem solutions) into a complex whole. To synthesize a product means to combine a multitude of decisions on every single one of those characteristics of the system. Methods for product synthesis must be based on a general theory of technical systems and in particular of mechatronic systems.

The theory proposed by Hubka and Amdreasen constitutes such a foundation. It states that the designers' activities at any one point can be located in one of the four domains: process, function, organ and parts domain. Each domain covers a subset of the characteristics of the technical system. Once the design is completed, the characteristics of all four domains have been established. The human designer has the capability of freely jumping back and forth between domains in his mind in an iterative sequence. He may for instance think of the abstract function of 'supporting a rotating shaft' and simultaneously consider the very concrete properties of a ball bearing. Similarly in electronics design, he may think of the function of 'converting analog to digital signals' and simultaneously consider price and specifications of a particular SMD-type component. This makes the suggestion of a detailed design phase plan on the level of product synthesis unrealistic.

The knowledge of domains in product synthesis, however, permits us to develop design methods specifically for one domain or for the transition from one domain to another. Using a catalogue of electronic components for example, is a method for proceeding from an abstract description of function to a physical realization. Since product synthesis is based on characteristics of the technical system, methods at this level are specific to mechatronics, even though some of them will resemble, methods from machine design, electronics design or software design.

The product development level reflects the total activity of a company. In fact, the goal of product development is not the product itself, but rather the successful i;' business it creates for the company. Therefore it is insufficient to concentrate only on product design, we must also consider market research and the establishment of production and sales. On this level, we can explain the restrictions laid upon the product design by the customers and competitors (the product must be saleable) and by production (the product must be produceable).

For many years, companies have considered product development as a fixed sequence of activities, each performed by a different department: market research by marketing, product design by engineering, production preparation by manufacturing, and sales by the sales department. With increasing international competition and pressure to reduce product leadtimes, this routine is no longer viable. Activities must be performed in parallel to ensure that sufficient attention is paid to market needs and manufacturing technologies during design. In the sequential strategy, too much information is lost at every transition from one department to another, resulting in numerous changes in product specifications along the way.

Catch-phrases for the new strategy are 'Integrated Product Development', 'Simultaneous Engineering' or 'Concurrent Engineering'. The starting point of the process of 'Integrated Product Development' is a rather undefined situation of 'need' to be examined. The process is then divided into 5,phases to be completed in sequence by the joint forces of marketing, product design and production. Amount of work to be completed in each phase depends on the nature of the product: is it a totally new product type, a revised model, or production rationalisation?

Special attention should be paid to the transition points between phases, as these are indicators of the progress and direction of the total project. Working methods may be attached to each phase of the product development process, e.g. specification methods to the 'investigation of need' phase and design review methods to the transition points. The interdisciplinary nature of the mechatronics technology may just add to the complexity of the engineering design activities, if mechanics, electronics and information technology are handled in separate departments. Mechatronics possibly requires even closer links between design and manufacturing than the pure mechanics or electronics do separately.

All three levels recommend a series of activities to be completed, but the underlying theories are different, and in particular the result of each process is different: a solved problem on the first level, a mechatronics system on the second, and successful business on the third. Also the course of the design process on each level is very different: problem solving is performed again and again during the project, product synthesis is completed once, but with numerous iteration cycles, and the phases of product development are performed once in straight sequence. To work systematically with design, the designer must choose methods suitable for each task, since not all methods are applicable in all situations. It is very difficult to give general guidelines as to which methods apply in which situation. The three-level approach is a framework, which helps subdividing the designers' toolbox.

Design concept of mechatronic system

Design concept of a mechatronic system is characterized by: the structure of those organs, which realise the most important functions of the system; the structure of those interface organs, which define the border of the system, man/machine, systems and environmental interfaces and the borders between electronic and mechanical subsystems; the activity structure of the organs, including the software instructions for programmable organs and the expected behaviour of the operator; and the basic mechanical structure and lay-out of organs, industrial design, production methods etc. When comparing design ideas at an early stage in a development project, we must make certain that they are comparatively complete, i.e. that all of the four aspects mentioned above have been considered to some level.

Because of the complexity of mechatronics, we need to be careful in describing the design concepts on the same level of completeness, before comparison is made to find the best concept. Mechatronics, is just another way of making machines work faster and production cheaper. This, however, is only one side of the medal, and presumably not even the most important one. The other side is: we all know that machinery is part of our daily life, that technical systems do coexist with biological systems. This coexistence will come to a cooperation, and it is the cooperation with biological or to some extent "unstructured" systems where the use of mechatronics will be of eminent necessity.

In such cases there is little chance of circumventing the use of "intelligent" machinery as it is still done nowadays in the industrial world, for example by redesigning a product in such a way that it can be handled, packaged or assembled more easily. Therefore we will have to come up with machinery with some kind of intelligence. But inevitably this intelligence will hardly ever be enough. There will always be the need to deal with exceptions, i.e. situations which have not been foreseen. And the best exception handler we can think of is the human being. We want to have a machine that can work autonomously up to a certain level of complexity, and in critical situations or for high level intervention there should be means of interaction with the operator. And this interaction requires adequate means, not just a warning light, a sound, or a simple emergency shut down.

Subsequently three robotic projects of the ETH will be presented where this man/machine interaction has been realized under various intentions and constraints: a pingpong playing robot, a cooperating robot, and a polite, mobile robot. The pingpong playing robot was initiated by research on fast gripping and touching with a robot. For that project we needed a robot capable of fast and controlled motions. And additionally the control of the robot should react very quickly to signals of external sensors, in order to actually perform this controlled touching at all. Such a robot was not yet available on the market. Therefore we built the robot ourselves, mainly by partitioning the task into student projects and integrating them into our educational activities.

In order to make the tasks attractive to the students, they were asked to design the robot in such a way that is could play pingpong against a partner. It took nearly three years, 25 student projects and some dedicated work of our tutoring assistants until the machine worked. The students came from mechanical and electrical engineering, and from computer science. The difficulties arise, at various levels. At first the information processing is more complex than in usual robot tasks—it must be faster and in real time. The sensors have to pick up the spatial motion of the ball fast enough and, above all, we have to generate a goal oriented spatial motion of the robot.

For this purpose we need a sophisticated control of mechanical energies with corresponding requirements for the mechanical construction and for the drives /FBN 88/. Therefore the playing of PingPong with a robot is of interest as a study project in other places, too, as in the US at the AT&T Bell Labs, or in Japan at the Toshiba Company, where it is considered as a benchmark test for advanced motion control.

In the meantime a contest between pingpong playing robots has been set up, initiated by Prof. Billingsley from the Portsmouth Polytechnic in England. Contests have taken place several times already. In August 1988, during the

Congress EUROMICRO in Zurich, we were lucky enough to win against three other teams from England, Sweden and Finland. The rules of the game, of course, are a subset of the conventional ones. The table is smaller (2m × 0.5m), at the beginning the white ball is released from a caging mechanism in the middle of the table, the ball has to pass through a frame at the end of the table, and it may hit the table only once after crossing the net. This restriction of rules is intended to decrease the size and with it the costs for the mechanical construction of the robot.

A basic design concept of a universally usable industrial robot allows main degrees of freedom, i.e. a rotation about the vertical, an up and down motion of the arm, and a horizontal motion of the carriage which is carrying the hand with the paddle. The rotation about the vertical is not even necessary for playing according to the simplified rules. The driving system consists of brushless dc-servomotors with a nominal power of 1 M, which can be overloaded for a short period of time for generating four times the nominal torque.

In future such controllable drives probably will be more and more used instead of mechanical gears in various textile machinery for generating controlled motions in a versatile and easily programmable way. For the robot under consideration, in order to keep the movable masses low, the drives of arm and carriage do not participate in the translational motions. The forces are transmitted by cables and pulleys. The arm and the carriage are a special lightweight construction consisting of aluminum and carbon fibers, they move on rollers on especially developed guideways. This mechanical construction allows extremely high accelerations of the hand of up to 25g. The hand is the only mechanical element which has been designed for pingpong playing only. Its three additional degrees of freedom allow an orientation in space and a controlled hitting with the paddle. It is driven by bowden cables, an element used in bicycle brakes as well, and activated by drives fixed in the workspace.

The motion of the ball is picked up by two CCD-cameras at a rate of 50 half-frames/s. The single gray images are transformed into binary images, and from that the spatial position of the ball is determined with an accuracy of one millimeter or less. The complicated task of calibration is done with photogrammetric means /BFW 89, FBW 90/, and it runs nearly automatically. The velocity vector is derived from sequences of such images. The difficulties associated with vision, mainly concerning the correct exposure time and the illumination of the scene, were considerable but not of a basic nature. Even the fast information processing could be handled.

Three microprocessors of the Motorola 68000 family were connected to a multiprocessor system on a VME-bus. They were responsible for the three tasks of image processing, playing strategy, and drive control. Programming was done in the high level language MODULA 2. Thus with this configuration it became possible to position the paddle in its working range of 0.3 × 0.3m within 1 time interval of 0.1s, and to return the ball about 3 to 4 times against an other robot or against a willing human partner. This may look like a nice result for the beginning, but of course the question comes up as to potential improvements, especially taking into account any human performance.

The mechanical and electronic hardware components of the robot are, with respect to velocity and response time, more than sufficient for that task. Deficiencies, however, appear to be primarily in the available software, the intelligence of recognizing and acting. One of the next, more easily realizable steps will therefore be to improve the model for the trajectory of the pingpong ball on which the playing strategy is based. For the future use of advanced robots in industry, it will not be sufficient to just provide more sensors, as is often assumed nowadays. It will be essential to have much more sophisticated software which right now we can see only in somewhat vague terms /ISH 89/.

Thus this project of the pingpong playing robot goes beyond the actual technical requirements. It gives some incentive for interdisciplinary problem definitions, and that is one of the reasons why we look for and support contacts in these directions. For example, recently a group on *Neuro-Informa tics* has been founded jointly at the University of Zurich and the ETH (Swiss Federal Institute of Technology), a collaboration of natural and medical scientists with engineers, connecting biological and technical aspects of information processing. Cooperating robot with tactile and vision sensors will have to work in an only partially structured environment, performing industrial tasks like assembling, complex sorting, inspecting or repairing in a rather autonomous way.

Unavoidably there will be exceptions where the supervising operator, without endangering himself or herself, should be able to take actions within the working range of the working robot. Therefore the robot has to be able to really cooperate with its operator. As a benchmark and as an application in the area of service tasks, we would like to use the robot for removing dishes from a tray in a cafeteria and to put them into a dishwasher. The problems to be solved for that task require a close multidisciplinary cooperation across departmental borders. This is a challenge for the organisation of the project, quite typical for most problems in mechatronics. At the ETH we already have an interdisciplinary group since 1985, which is responsible for research and teaching in mechatronics, and we have split up the project into specific tasks according to the expertise of the members of this group:

— 3D visual object identification and high speed data processing

— intelligent robot gripper
— selfcalibration of the robot
— interactive cooperation between human operator and robot

Even a mechanically simple gripper can be made intelligent and versatile using task specific sensors and appropriate software /SHV 91/. The kinematics of the gripper are simple and therefore less expensive: three stiff and straight fingers can move. Independently for gripping objects of various shapes and sizes, the objects can even be soft and flexible. The most important sensors for grasping are the strain gauges and the fibre optics in the fingers. For each finger four strain gauge bridges are measuring the finger forces and their contact points.

From these signals further information about the object, e.g. stiffness and slippage, can be derived. A special small sized fibre-optic range-finder is mounted in the axis of the finger and measures the distance from the finger tip to an object in front of the finger. A six-component force-torque sensor mounted between the gripper and the robot measures the object weight and can also stop the robot in the event of unexpected contact with the environment.

Two ultrasonic range-finders prevent collisions between the robot and the environment during robot motion. The grasping data for known objects are derived from the vision information and the object specification stored in a data base. In the case where the object is unknown or not recognizable, the vision system still provides a set of points describing the contour of the object. Based on these points a neural network computes three suitable finger locations for a force stable grasping. The combination of the two methods guarantees a high success rate of grasping. The question of robot safety becomes increasingly important as future robots will be required to share their working area with humans.

A failure of the robot's hardware or software can result in an unexpected robot motion which may be dangerous for the operator or user. For the cooperating robot two additional safety systems using accelerometers and a camera to supervise the robot were implemented.

The first safety system is based on three perpendicular accelerometers mounted on the robot wrist. An emergency stop is initiated if the difference between measured and expected accelerations exceeds a certain limit. The resulting runaway protection can be easily applied to any existing (industrial) robot or any other motion controlled machine.

A second safety system uses a camera to supervise the robot's workspace, The system checks, whether the desired position of the robot corresponds to its real position. Furthermore, it provides the location of the human operator. This information allows to temporarily stop the robot or to change its path thus avoiding to interfere with the human.

The vision algorithms were implemented on a data flow machin and permit a real time detection of moving objects. One of the major results of this study and directly applicable to industrial problems was the ability to perform handling tasks in a certain unstructured 3D environment. It was demonstrated in a test setup for the perception and control for sorting simple 3D objects. The sorting of objects is a substantial task in industry and has a large potential market. The system uses a range-image sensor for object recognition and fibre-optical short-range sensors, mounted in the fingertips of the parallel-jaw gripper, to guide the robot right before contact.

The rang-image sensor is based on illuminating the scene with structured light and using triangulation. Lines of light are projected onto the scene and observed by a camera. The deformations of the lines reflect the shape of the scene and can be used to compute the depth of the object at the illuminated points by triangulation. From several hundred lines projected over the entire scene a complete range image can be computed. This is achieved by projecting a set of light patterns representing different bits of a binary code. By producing *n* patterns we are able to identify 2^n different lines. The patterns are generated with a very fast LCD shutter combined with a strong stroboscope thus reducing the influence of the ambient light.

The data are used by a simple "realtime" vision algorithm to segment the 3D image into a set of planes. The robot is guided by the vision system towards the approaching face of the target parcel. The vision system itself, however, is not able to guarantee collision-free grasping of a parcel. To correct these shortcomings the optical sensors in the fingertips are used. If one of the fingertips is obstructed by an adjacent parcel before the grasp position is reached, the robot stops and closes its gripper to grasp the parcel. This "grasp- and top reflex" provides a high robustness of the grasping process and effectively corrects errors or inaccuracies of the vision information.

When a situation occurs where several parcels with equal height are lying so close together that no free space is available for the gripper finger or when the vision system cannot make a suggestion for a gripping approach for any other reason, the robot changes the configuration of the pile by pushing some parcels aside and offer's the vision system a new chance.

Design models

This section deals with methods for generating and describing mechatronic design concepts. We will limit the discussion to the functional interaction of mechanics, electronics and software since methods needed for the spatial arrangement of subsystems are usually of a different kind. When speaking about the 'function' of a product or system, we are normally not very precise about whether we think of what the system does or how it does it.

In order to design systematically we need to be more explicit about the terms we use. Otherwise we cannot describe abstractly what we want before we start looking for detailed technical solutions. In particular three terms need to be defined more closely:

— Transformation, functions,
— Purpose functions, and
— States of the system.

We may regard the mechatronic system as a structure of transformation functions, which processes one of the following type of transformation operands: material, energy or information. cThe transformation function concept is well suited for describing the purpose of both mechanical, electronic, and software systems. It is worth noticing, however, that electronics can transform information only. We can visualise the transformation functional structure in a diagram of black-boxes. The diagram shows what happens to a transformation operand, not how the mechatronic system makes it happen. Therefore the diagram is independent of technical realisations, so it can be used for creating alternative designs on a high level of abstraction. Typical ways of creating alternatives are:

— to relocate the systems border
— to subdivide one transformation into subfunctions
— to integrate subfunctions
— to change the sequence of subfunctions
— to establish parallel branches of transformations
— to insert transformers or conductors
— to relocate information inputs or change information carriers.

Transform information, either as their main purpose (e.g. a telefax) or when controlling material or energy processes (e.g. an electronic sewing machine, an intelligent motor). Note that information can only exist in mechatronic systems, if attached to either material (e.g. a photocopy, a blood sample) or to energy. (e.g. an electric signal, a sound signal). When information is coded on an energy form, we will use die term signal. Generally, mechatronic systems handle two kinds of information:

1. Process information, which is transformed by the mechatronic system regardless of its semantic value, and
2. Control information, which the mechatronic system applies to control internal functions.

It is comparatively easy to distinguish between process and control information, but if one regards the flow of information on several hierarchical levels, the distinction is not so clear any longer. An electronic feed-back loop in a robot, for instance, carries control information, since its purpose is to control the movements of the robot.

If we focus on the sensor and the signal processing circuit of the feed-back loop however, the same information is of process type. From the point of view of sensor and circuit the semantic value of the processed information has no influence on their function. In mechatronic systems, process and control information appears alternately in a hierarchical structure: Control signals need signal processing and signal processing systems often need control on a lower level.

The ability of a mechatronic system to create necessary effectsis its *purpose function.* It is very common for machine designers to think in terms of such functions. For instance, "I need something which creates rotation", the designer might say. Here rotation is a required effect, and create rotation is the purpose function of a subsystem (a motor). We can regard the mechatronic system as a structure of purpose functions.

Typical examples of purpose functions are: 'measure level', 'allow for manual adjustment', 'store value', 'compare to reference' and 'support shaft'. The structure of purpose functions contains all those effects necessary for the mechatronic system to fulfil its purpose.

An important point in methodical design is that functions can be sub-divided into secondary functions on a lower level. For mechatronic systems a basic principle states that to realise any function in the system, one or more of the following secondary functions will be required:

- Power function to provide energy supply
- Control function to govern the state of the system
- Interface function to convert inputs and outputs
- Protection function to prevent undesired interaction with the environment
- Communication function to interact with other systems
- Structural function to provide mechanical support.

The transformation function of an electric motor is to transform electric power (input) into mechanical rotation (output). It is a transformation of energy. The purpose function of the motor is to 'create rotation'. A particular transformation can only be accomplished if on a lower level there is a set of effects (purpose functions) available. For the electric motor 'accept electric power', 'create rotating magnetic field', etc. We can say there is a kind of causal relationship between transformation and purpose functions. When expressing the complex of secondary functions in transformation terms, we can derive a general black-box model of mechatronic system. This shows the main transformation function and all the secondary functions of the complex. Secondary functions are placed on the systems border to indicate that they may be shared with connecting systems. Between two systems of a signal processing line, for instance, there will only be one interface function.

The structural function has not been included in this model, since it cannot readily be expressed in transformation terminology. This systems model is recursive. It can be applied to describe mechatronics on all levels components, modules, products and systems. The main advantage of the model is that it explains the relations between primary and secondary functions. It can hardly be used as a design tool, because the relations between several blocks will quickly become too complex to allow easy sketching on paper. All mechatronic systems function in a number of *states,* two being the smallest number (on and off). For a photocopier, there will typically be five states on the coursest level: off, warming up, ready, copying and error. The system functions in a different way in each state. The point at which the system changes from one state to another is decided by logical conditions internally in the system or interactions between the operator and system.

The photocopier changes for instance from the warming up to the ready state, when a heating element reaches a required temperature, and the transition from ready to copying occurs when the user pushes a button. The state-transition structure is a must for developing control software for mechatronic systems. Naturally the state-transition description of a mechatronic system must somehow relate to the transformation and purpose functional structures. Since the system operates in a different way for each state, the functional structures must change according to states. In fact we need to describe a different transformation functional structure for every single state of the system. In a video recorder transformations occurring in the record and in the play states are completely different. In the former, an electronic video signal is transformed to a magnetic pattern on the videotape. In the latter state, the reverse process happens.

To make a precise description of the transformation functions and the logic behaviour of the mechatronic system, we must ensure that the transformation functional structure for each state is stable or continuous, i.e. that it cannot suddenly change to a different output. A simple example may illustrate the point. Let us assume that we want to design an intelligent system for room lighting: the system should automatically switch on the light when people are present in the room, and the lighting level should be adjusted according to the level of ambient daylight. If we try to describe the transformation function of the system without thinking about logic states, then the output will be 'light now and then at varying level'. Instead we can decompose the transformation functional structure into two separate structures, one for each of the two states room empty and room occupied.

We must add a state-transition diagram, which shows how the system will change from one state to the other. Now let's have a look at the relations between the purpose functional structure and the logic behaviour of the mechatronic system. We can regard the purpose functional structure as a table contents of all the effects necessary to make the system work. The only some of the functions will be active in each state of the system. We are now leaving the solution independent domain of functional description and turning attention to actual physical solutions.

For this, we need to describe the term organ: an organ is a set of parts, which exploit physical, chemical or biological phenomena to create a required function. An electric motor for instance is an organ, which exploits the electromagnetic effect to create rotation. The word 'organ' was chosen to underline the analogy with organs of the human body which are typically entities that realise one particular function. We can understand mechatronic system as a structure of organs, each of which realises one or more functions. This comes very close to the way most designers think, when suggesting solutions.

For instance, "We could use a motor with suitable gearing and an angular encoder..." suggests a structure of three organs: motor, gear reducer and angular encoder to provide the required function. Electronic components, e.g. a transistor or a potentiometer, can also be regarded as organs for as long as the designer is thinking about its functionality and not about its precise type or dimensions. A microprocessor cannot be considered as an organ without the intended software—only with software does it fulfil a particular function, 'and software in itself cannot be an organ.

Let us look at the relations between functions and organs. Organs are the physical artefacts, which realise functions, but a direct mapping between functions and organs is seldom possible. This is because an organ can sometimes cover more than one function. For each required function we can usually choose between several alternative organs which provide the same effects. This is what makes design so difficult and interesting: one must choose the most appropriate solution for each function. There is a cause/effect relationship between functions and organs.

Those organs which cause a particular function on one level, will require the realisation of a set of subfunctions on the next lower level. Each subfunction can again be realised by organs. A function/means tree is a design tool which maps the hierarchical pattern of functions and alternative solutions of the mechatronic system. At the top of the tree the means that realise the (purpose) functions are transformation structures; further down they become organs.

The complex of secondary functions will be of help, when trying to formulate which subfunctions a particular choice of organ will require on the next level, Often it will not be possible to make the choice between alternative organs, until one has examined the consequences of each choice a couple of level down the tree. One type of organ, which requires particular attention in mechatronics design, is the interface organ, that defines the borders between the system and its environment and between subsystems internally.

The interface is primarily made up of organs which send and receive information, but occasionally there will also be a condition of energy input, e.g. levers, crank handles. Since information must be tied to either energy or material, it is comparatively easy to systematise those organs, from which the designer can choose. The systems interface defines the relationships between the neighbouring systems.

Mechatronic systems can exchange material, energy and information. The interface between a photocopier and a sorter, for instance, handles paper. Mechanical interface organs are typically couplings, while electric interface organs are types of connectors. For electronic communication interfaces, the organs must often be supplemented with a communication protocol and a common set of characters. The environmental interface typically covers casings, cooling structures, ventilators etc. They exchange material, energy and information with the environment of the system.

The electro-mechanical interface defines the border between.mechanical and electronic subsystems. The interface organs can only be of the type sensors and actuators. The description of an organic structure is only complete, when information about the logic behaviour of all organs and their relations is added. From software engineering we can adopt some tools for modelling the activity structure of the mechatronic system.

The four different aspects of logic behaviour are:

— *States and transitions,* i.e. the states of the organ, permissible state transitions and conditions for changing from one state to another.

— *Sequential procedure,* i.e. the activities. (operations) and how they follow one by one in sequence.

— *Hierarchical pattern,* i.e. the activities (operations) and how they relate to each other on superior and subordinate levels.
— *Timing,* i.e. constraints in time on the performance of activities.

The activity structure must typically contain information about the software instructions which control how organs work, and the expected behaviour of the operator of the system.

Automated garment manufacture

There are three important aspects of the garment manufacturing industry which require immediate attention:

— Cost of assembling a garment is estimated to represent between 20% and 30% of the total manufacturing cost. This can be reduced by taking the assembly abroad, where the labour costs are less, but a report on the attitudes of United Kingdom consumers towards clothing made in different countries indicates that goods made in Britain are thought to be of a higher standard than those made elsewhere. The cheap labour factor will also become less important as wage rates rise in other countries.
— Consumer is looking for quality in the goods bought and is becoming more critical and selective when purchasing. It is therefore necessary for the industry in general to set and maintain standards as with the use of the wool symbol.
— The garment manufacturing industry must be able to respond quickly to incoming orders, design, material and size changes.

Advanced equipment being introduced into factories is being used to de-skill operations or carry out some of the simplest tasks by hard automation. A major advance has been made through the use of computers in the design and cutting stages in order to reduce the amount of wasted material. Sewing machines have also been upgraded by the addition of digital displays and pneumatic actuators to alter settings. Thereby allowing the operator to concentrate on manipulating the material. Some hard automated systems have also been introduced, for example auto-sergers for the hemming of skirts.

These machines perform automatic edge following during sewing, but are primarily limited to use on dimensionally stable woven fabrics. The only way to improve the production rate and to reduce labour costs in the long term is to automate the handling and manipulation of fabrics. This involves developing techniques to orientate, pick, place, and fold fabric panels in a cheap and reliable way, whilst being able to cope with size, colour and style changes. The major problem when automating garment manufacture is the flexibility of fabric.There are six basic areas for automation.

1. Ply separation
2. Transportation
3. Ply/sub-assembly position and orientation
4. Pick and place
5. Joining
6. Manipulation

The range of fabrics in common use for garment manufacture range between heavy denims and single knit Jersey.The properties of the fabric depend both on the yarn being used and the construction technique, for example, knitted or woven. There has been a relatively large amount of research into the properties of woven fabrics as used in shirt and suit manufacture. This work, for example Kawabata, has produced a whole range of tests for woven fabrics, primarily to predict the quality of garment which will be produced for a given material. This objective measurement is very important when producing a suit, but not as critical for underwear.

The most important of the properties measured are Friction, Bending Length, Shear and Buckling. The emphasis has been on properties important to the feel or 'handle' of the garment. As will be seen there are many properties important to handling which are not covered by these 'traditional' tests.Relatively little work has been carried out on knitted materials where problems such as curling of the edges can be extremely important in the design of automated handling equipment.

Production of garments starts atthe laying up and cutting of the fabric into panels. Although single ply cutters are commercially available, this task is usually carried out by laying up multiple plies and then cutting the fabric into stacks. The stacks are then removed and transferred to the sewing machinists who have to take off panels one at a time, or sometimes in twos. The starting point for many automation projects has been the removal of this single panel off a stack, and many techniques have been developed. The separation means has to grip the top most ply and restrain the plies beneath during the removal process.

There are two main problems. The first is that during the cutting operation the stacks are compressed resulting in cohesion between the two plies. The second is the intertwining of fibres (linting) along the edge caused by the action of the cutting blades. There is, however, no single technique which can cope with the whole range of fabric types. A range of different techniques are therefore required so that the appropriate one can be chosen for the specified fabric. A number of different techniques ranging from pins to freezing systems.

Three destacking techniques have been developed at the University of Hull. i) the sensory air jet gripper ii) electroadhesion; iii) Glue.

The sensory air jet gripper uses air blown onto the top of the stack to vibrate the top panel. A key feature in this technique is the creation of bubbles of air under the top most ply and their propagation towards the stack edge, thereby breaking any linting which may have occurred. The vibration causes the topmost ply to flip over the lower finger. Simple infra-red sensors are used to detect the number of plies between the jaws. Further infra-red sensors along the finger allow alignment of the fingers with a straight edge prior to clamping and removal of the panel. Once the edge has been located, the jaws of the gripper are closed and the panel peeled off.

Sensors are also required to position the finger relative to the top and edge of the stack to ensure that the panels are consistently destacked. This technique works best with porous lightweight fabrics such as knitted cottons, which also have low bending stiffness. If a dielectric is polarised, by means of a charged metal surface, any other dialectic it comes into contact with which is electrically polarisable will experience a force of astriction. This is a high shear, but low cohesive force and is a surface only effect which allows fabric panels to be destacked.

Electroadhesion is not suitable for 'fluffy' fabrics, but works well on most woven fabrics. Which generally have a relatively high radius of bending thereby allowing rollers of a minimum of 25mm diameter to be utilised.

Glue based grippers have been available for many years, although they have always been prone to dust building up on the surface, reducing their effectiveness. The most common method of improving their reliability has been to use a 'typewriter' style cassette to increment the adhesive area used after each pick. This becomes expensive, as the cassettes are disposable items. An alternative is the use of water washable adhesives. Monkman used several including MAGNATAC™ as the basis of his grippers.

The adhesive gives a much stronger general purpose grip then electroadhesion, allowing more vigorous destacking methods to be employed. Unfortunately, the releasing of the panel is not as easy. One method presently employed is to push an adhesive covered plunger through an aluminium tube to pick up the panel. The panel is then released by placing the tube onto the working surface to hold the fabric, while the plunger is removed. An alternative method is the use of rollers.

Fabric prehension is given by the front roller which is coated with adhesive. Movement of the gripper over the fabric ensures enough fabric is wrapped around the front roller to secure it. These may be mounted on robots or on a single platform similar to that used by Koudis for gusset construction. It is essential that two rollers per gripper are utilised—one coated and the other plain—otherwise it is virtually impossible to maintain positional integrity of the fabric after the first roller has become free.

The adhesive gripper works on a large variety of materials, and is only affected by the build up of dust on the surface. Periodic wiping of the surface by water allows continual use.

Various strengths of adhesive are available to suit the nature of fabric. Pins can be pushed through the top panel, and then tensioned to hold it. This technique is dependent on the thickness and the planar stiffness properties of the fabric but, unfortunately, delicate fabrics can be damaged. If two pegs are pushed down onto the top of a piece fabric and then moved together then the fabric will bunch up and be pinched between the two pegs.

The effectiveness of this technique depends on the friction coefficient between pegs and fabric and the bending stiffness of the material. There are many methods of single panel destacking. Each technique relies on different fabric properties, so care must be taken to define the range of fabrics to be used before selecting a particular method. The reliability of all of the techniques can be improved by the addition of sensors.

In typical garment assembly factories garments are moved from operator to operator using bundles or on moving hanger systems which are ideal for the operators but cause problems for automation. Operators can cope well with the 'handkerchief problem' described in the introduction, simple automated systems cannot unless special hangers are used. The alternative, removal of panels and subassemblies from stacks can be automated but remains a highly sensor. Picking up large panels dependent task, and should be kept to a minimum.

Conventional monorail hangers, such as the Gerber Mover™, allow fabric panels to be hung in totally random ways, usually from one point. Work is now in progress at the University of Hull and Leicester Polytechnic on the CIMTEX project to interface automated systems to such systems. To aid the automated removal, the panels are held along one edge, thereby giving a more consistent position.Removal is achieved with a robot which locates and grasps this held edge.

Conveyors are also used to transport fabric between work cells.Some operations can be performed while the conveyor is moving, for example, sewing of a straight seam, and others while the .conveyor is stationary, such as the addition of other panels. Problems can occur when placing panels onto moving conveyors. If the panel is moved onto the conveyor in the direction of travel, there are two basic methods which can be used, depending on the speed of the conveyor.

The 'furl-on' method is used if the conveyor is faster than the manipulator. The panel can be fed onto the conveyor by the manipulator and held stationary.The free end of the panel will then be pulled along by the conveyor due to friction, until the panel has been pulled out and can then be released. If, however, the çonveyor is the slower, then the handling device can be used to pull the panel over the conveyor.

Once the panel is completely on the conveyor, it can be released. Both of these methods are dependent on the bending and frictional properties of the fabric. These can be related to the minimum height the panels can be held above the conveyor, as well as the relative speeds of the conveyor and manipulator. The shape of the fabric panel used can influence the effectiveness of the system as non-symmetrical shapes will skew due to uneven forces across the panel. Removing fabric panels from conveyors is a less trivial task compared to removing rigid components as care must be taken to ensure that the panels are not creased, distorted or damaged.

If the conveyors can be stopped during the cycle, then the surface is effectively a stationary flat surface. If the panel has to be removed from a continually movingconveyor, then alternative methods can be implemented. One such method is the use of a 'scoop'. A scoop is effectively a low friction plate, onto which the fabric panel is dropped or pushed. There are two basic types of scoop: lower scoop and upper scoop. The lower scoop is held at the end of the conveyor, allowing the fabric panel to drop onto it. The lower scoop is ideal for removing fabric panels with high bending stiffness, such as woven shirt collars. It has the additional merit of accurately locating the leading edge of the fabric panel against the end of the scoop. With lower bending stiffness fabrics, the lower scoop has to be placed at a very sharp angle in order to catch the panel. Thereby causing the panel to deform. The upper scoop consists of a plate on top of the conveyor. As the panel moves along the conveyor, it runs into the plate. If a free running roller is placed just before the upper scoop, it ensures that the fabric momentum is sufficient to push it completely onto the scoop. This technique works even for low bending stiffness such as single and double knitted cottons. Again the type of scoop used is dependent on the frictional and bending properties of the fabric. Simple optical sensing can be used to detect the presence of a panel on the scoop.

The accuracy of location of a panel varies with the operation to be performed but normally +/lmm will suffice. There are two fundamental ways of locating objects. The first is to observe an large area in which the panel is placed on to observe a number of smaller areas whose feature such as edges or corners are expected. The panel's position and orientation relative to an origin can then be calculated.

Camera systems can be used to passively locate panels, as well as identify them. This can be achieved using a area scan camera or a line scan camera if the component is introduced on a moving conveyor.The use of cameras is described by Gilbert. The main problems with cameras are that they rely on the colour, and texture of both the fabric and its background, as well as the lighting conditions. Two examples of active systems used at the University of Hull are air and vibrating tables. The air table relies on a laminar airflow across a flat surface to lift the panel off the surface. The system implemented uses an industrial fan mounted inside a box with aluminium gauze as the work top covered with a layer of fabric. The angle of the gauze to the horizontal is then altered to move the panel. The air flow is crucial to the operation and is dependent on the fabric's air permeability. If the air flow is too low, then the piece will not float, and if too great, the panel 'balloons' causing the edges to fold back on themselves.

If any part of the panel moves off the air top, then it sticks irreparably and removal from the table while the air is on is very difficult. The vibration table is easier to implement. A standard industrial linear vibrator is bolted to a desk and an A4 by 10mm sized aluminium sheet attached to its top. The top is then covered in acetate to create a low friction surface. When the table is switched on, the fabric moves in the required direction and speeds of up to 30mm/s can be achieved. The speed of movement appears to be related to the coefficient of friction between the fabric and the acetate, and research is underway at the University of Hull to establish this relationship. Again a barrier is used to locate the edge of the fabric panel. A second direction of travel is also obtained by altering the angle of the top to the horizontal. This means that the panel moves down the slope under gravity, and hence align itself against the barrier. Once the panel is successfully moving on the surface, alignment can be achieved by allowing it to run against a barrier. It can then be moved along the barrier by altering the angle of the table top, or by the addition of air jets. A simple reflective sensor is used to record the position of the corner, given that the edge is against the barrier, and the vibrations are then stopped.

These systems rely on the physical properties of the fabric. In the case of the air table, the air permeability of the fabric is predominant, although panels with low stiffness tend to be more susceptible to ballooning.The vibrating table is very sensitive to changes in the frictional characteristics of the fabric, and so the selection of the surface is of the utmost importance. There is considerable mechatronic difference in the two basic philosophies given above. The camera systems are complex sensors and are dependent on the visual properties.

Movement of fabric can be simply classified as 2D and 3D, where 2D operations involve the movement of the fabric in a plane, and 3D movements take the fabric out of the plane.

Various gripping technologies have been developed. In simple 2D grippers, pins, glue electroadhesion, vacuum or even simple friction have been used to move fabric panels across planar surfaces. An example of this is the Hull University friction gripper which moves knitted underwear panels from a stainless steel upper scoop to a vibratory orientation table. The biggest problem to be encountered here is that the surface of the vibrator is not horizontal and so compliance is built into the gripper in the form of a foam damper.

The gripper surface is constructed out of perspex and coated with the brush side of Velcro™. By ensuring that the gripper is always in contact with the panels, it can be used to move them over the surface, assuming that the coefficient of friction between the gripping surface and the fabric is suitable. Care has to be taken as high friction surfaces can also exert high cohesive forces, which can lift the fabric panel off the surface, when the gripper is removed.

Again many of these fundamental technologies can be used to move fabric panels through space. Some novel ideas have been introduced, for example, freezing, where a moist gripper surface is placed on to the fabric and then frozen. The relevant fabric properties here are probably absorption and thermal conductivity. A cycle time of 3 seconds has been claimed for this technique. One of the simplest technologies used at Hull University is mechanical clamping. There are two main types:

1. *Clamping grippers*: In the first type, fabric is sandwiched between two parallel clamps or jaws. Getting the fabric between the jaws prior to clamping may be achieved in a number of ways, for example, insetting part of the gripper into the work surface, or allowing the fabric to be pushed over a knife edge and between the jaws. An example of this can be seen in the Pegasus RMC-200 Cuff maker.

2. *Pinch grippers*: The second technique utilises two 'pegs' which are placed onto the fabric, distanced *d* apart. When the pegs are brought together a loop of fabric is formed between the pegs and the fabric can be secured. This requires the coefficient of friction between the pegs and the fabric to be greater than the coefficient of friction between the fabric and the surface.The initial distance between the pegs, *d*, appears to be dependent on the bending and friction properties of the fabric. Research is underway to find the exact relationship.

Fusing and sewing are the two basic joining methods employed in factories today. Fusing involves the placing together of fabric panels which have been coated in glue. They are then transferred to a fusing press which melts the glue and presses the panels together. This technology is used primarily in the manufacture of woven garments, for example, shirt collars and suits. The transportation of the panels through the press is achieved by its own internal conveyor belts, so guidance of the panels through the process is not necessary. All of the sewing machine manufacturers have invested a lot of resources into the development of sewing aids for the operator. These include automatic cutters, ply sensors, computer controlled motors and edge following devices. These are helping to implement automated sewing. The accuracy of placement of panels prior to sewing is dependent on the type of seam being sewn.

Overlocking sewing machines have built-in fabric trimmers which trim the edge of the fabric as it is sewn. This allows a placement tolerance of 2mm to be acceptable, whereas chain stitch machines which do not trim require an accuracy of 0.2mm. The automated transportation of fabric panels through a sewing head is primarily dependent on the number of plies to be sewn, and the seam to be sewn. Most commercial systems for sewing simple straight line seams use conveyor belts with an additional top belt feed. These clamp the fabric and guide it past the head with a velocity matched to that of the sewing mechanism. Alternatives used at the University of Hull include the use of jigs. A jig comprises of a simple plate attached to a linear actuator which has both position and velocity control. A clamp is used on the jig to secure the fabric plies to be sewn to ensure that the do not move during the sewing operation.

This is ideal for simple straight line sewing, but can also be modified for some curved seam operations.In the case of the elastication of underwear legs, the legs can be straightened using flexible curves which are placed onto the curved assembly and then straightened. Variation in the size of garment produced requires the curves to be adjustable. Sensing also needs to be added to ensure that the straightening has been successful. This is similar to the action an operator performs on the garment on an incremental basis. This is only possible because of the low stiffness of knitted fabrics, and the concave nature of the seam. When sewing more complex seams, edge following devices, such as the Zyppy device can be used to good effect. At first sight commercial sewing systems are readily adaptable to automation. Sensors are available to stop and start the machine, thread cutters remove the excess thread, motors are easily computer controlled, and speed information is accessible from the tachometers. Three examples of complex manipulation which have been automated at the University of Hull are now given.

i) *Completing the assembly of briefs*: Once a gusset formation has been completed with its legs elasticated, the last three operations are to close one side seam, elasticate the waist, and finally to close the other side seam. This sequence is performed in the factory by three operators, who rebundle the garments after each operation. This is not feasible in an automated system due to the complex nature of the shapes formed in these final processes. It would be expensive to emulate this and accuracy problems would arise. It was, therefore, decided to make a gripper which would hold the key points of the assembly throughout these last stages. This was achieved by a multi-axis gripper. Simple pinch grippersare used to hold the key points, as relatively high forces are imposed on the fabric during the manipulations. The gripper is used to pick up the flat completed gusset assembly, fold it over and present thefirst side seam to elasticator. It can not be opened greater than 90°, otherwise the garment would be stretched. Once the first part of the waistband has been sewn, the garment is rotated through 90° to allow the waistband to be completed. Finally, the gripper is closed, and the final side seam presented for sewing. This form of manipulation is only possible due to the extensibility of the fabric, and hence works very well with knitted fabrics. The general principle of holding all the key points to be operated on during the sequence can, however, be applied to many complex manipulation problems and reduces the need for sensors between tasks.

ii) *Folding of leisure tops*: Leisure tops are usually produced in the UK by constructing the front and back panels, joining them at the shoulders and adding the neck. Raglan, curved or straight sleeves are then added. The next stage is to fold the garment in half ready to sew the side seams. Thekey points to align are at the cuffs, arm pits, and waistband.A gripper to perform this folding operation of the type described above would be very large, and so an alternative solution was sought. The system used at the University of Hull folds a garment approximately into two with a metal plate between the two halves. Stepper motor driven conveyors both above and below the plate provide independently controlled movement of each half. The conveyors can then be moved to align the key points. A bank of optical sensors is used to feedback positional information to the conveyors to give accurate alignment as the garment is removed. This system has been implemented and has been found to work with a wide variety of fabrics, from denim to knitted cotton.

iii) *Addition of cuffs*: The problem of adding tubular cuffs has been aided by the development of the Pegasus RSC cuff attacher. This uses a spiral to stretch the cuff to the size of the sleeve and pull it under the foot while sewing. Thus, the automation problem is reduced to loading the cuffs and the sleeves on to the machine. Each sleeve or cuff is fed in as a flat tube which is opened out, ready to load onto the machine. Pins are used in the gripper to maximise the retaining gripping force whilst the sleeve/ cuff is pulled onto the sewing machine. The expertise required of the operator has been reduced by the addition of fabric independent devices to sewing machines. This has led to the development of 'one operator-two machines' systems, where the skill of the operator has been transferred from the act of sewing to the loading of the machine. It is becoming increasingly clear that the next stage is to link multiple sewing machines together. Such linking of these systems is difficult due to the fabric dependency of the handling devices. When designing an automated handling system, it is therefore necessary to define the range of fabrics to be used. From this a list of relevant handling techniques and technologies can be derived. Once the these have been short listed, the sensors to be used and where they are required can be outlined. This information can then be fed back into the technology consideration and the process repeated as necessary. The handling methods given above by no means form a complete list, but they represent some of the wide variety of techniques which have been developed.

Nine

Textile Industry in India

The Indian Textile industry is in the process of responding to the changes in the Global economy, and have exploited their strengths in order to build up an international present in stages. Today, India is the second largest producer of Textiles in the World, next to China. However, considering that the Indian textile industry is one of the largest and oldest, and the availability of inexpensive skilled workers and technicians along with the availability of cotton in the country, it has been doing well in the recent past.

In the world Textile market countries like Japan, South Korea are becoming high cost economics. Therefore, it is expected that India could move into the positions occupied by these countries due to its strengths mentioned above. Indian Textile Industry can do much better with the Government policy backing the strategy of the Indian Textile Industry.

In order to contribute substantially for the growth of the Indian Textile Industry, it is necessary that Indian exploits its strengths i.e. availability of inexpensive skilled workers, availability of raw cotton, both short and long staple.

The recent liberalisation of the Indian Government has helped in giving a boost, but it is not good enough to keep the Indian Textile Industry competitive in the world market. Beeause of its fundamental strengths there are a number of opportunities that are likely to be available to the Indian Textile Industry, which need to be exploited to its fullest extent.

India's textile industry has a pivotal role to play in the national economy, and given proper encouragement, drastic steps and bold innovations of policy, through disciplinary measures by the Government and industry to take advantage of the global opportunities by increasing the exports of textiles from India by implementation several suggestions mentioned below into meaningful policies. In order to exploit the World market and become a major player, the following measures need to be taken by the Government:

1) A ban bn the exports of cotton, with a mechanism to ensure reasonable prices to the farmers, to be worked out.
2) Duty free imports of capital goods with export commitment on the same level as EOU's should be made available to the Indian Textile Exporting Community.
3) Interest rate on preshipment packing credit to be brought to the levels ruling in the international markets such as 10%.
4) Removal of SSI regulation on garment industry.
5) To bring in the ginning industry under the purview of the Textile Ministry, instead of Agriculture Ministry as it is today.

In above measures are implemented in the opinion of the Indian Textile Industry the following projections can be achieved:

The International Cotton Yarn trade besides being of considerable magnitude has already been registering improved growth in the recent years. Over a period of 9 years from 1981-90 it has gone up from 7,07,650 MT to 15,60,000 MT. In short the global exports of cotton yarn in the last 10 years have doubled over at the moderate growth rate 8% per annum.

Exports of cotton yarn from India can be expected to cross 25,00,000 MT by end of 1997. 32,00,000 MT in the year 2000. The major importing countries of cotton yarn were Hong Kong, Japan, Gèrmany, Benelus and U.K. in the 1980's.

India's share in the global exports of cotton yarn used to be very insignificant. Until the second half of 1980 the country was faced with unstable and deficient domestic cotton situation, which hardly left room for contemplating cotton yarn exports in a big way. Another reason was that the spinning industry had not equipped itself fully to overcome the technological barriers for producing yarn to the quality specification of the sophisticated International Markets.

Fortunately, over the years these handicaps have been gradually overcome. In the case of yarn quality, considerable improvement has been made in its upgradation so much so that the quality of yarn produced by quit a number of mills is comparable to some of the best in the world, and has found acceptance even in the sophisticated world markets. It is worth noting that India's share in the world trade of cotton yarn till the year 1987 was very negligible at around 1%.

During 1987 the exports of cotton yarn reached a peak and amounted to 86 million kgs with a global share of 5.9% There was a setback in the following year, but lost ground was retrieved and 101 million kgs exported in 1991. Even then our share in the world exports of cotton yarn was a measure 7-8%.

The statistics available on cotton yarn exports revealed the directional pattern of increased exports of cotton yarn from India to Non Quota countries. This strength of increased exports to Non Quota countries is likely to continue in the coming years.

It is significant to note that the Far Eastern countries have been emerging as major importers of cotton yarn. Raw cotton constituted 65% of the cost of production of cotton yarn. Therefore, the factor affecting the availability of cotton have direct and substantial effect on the supply and prices of yarn.

The Textile Policy and the Government has recognised the need to make available raw cotton to the Mills in adequate quantity at reasonable prices, but the releases of raw cotton for exports have resulted in flaring up of cotton prices. The area under cotton cultivation in the country is not likely to expand in the coming years due to the continuing food requirements of a growing population. In view of this, the need of the hour is to emphasize increase in productivity of cotton to achieve price stability of yarn and retain competitiveness.

The country has indeed vast potential for further stepping up of exports of cotton yarn. With regard to the competition from other countries,the real threat to India is from its two closest Neighbors viz., Pakistan and China. These countries are infact emerging as 'Cotton Powers'. With a tremendous growth in cotton production and the huge investments these countries are making in the spinning industry, they are bound to strengthen their challenge.

One advantage that India has over Pakistan and China is the wide range of varieties available in India from short to extra long staple types. In fact India is a leading producer of extra long staple types in the world. The time has come to change the approach and to include in the planning process specific targets for exports of yarn and taking special efforts to achieve the targeted figure. For instance, 250 million kgs would be a feasible target for exports in 5 years from now which would fetch a tidy sum of Rs. 3750 crores in Foreign Exchange.

In man-made textiles export there has been an erratic growth in the last 5 years and therefore, past performance is not a suitable guide to work out the suitable rate of growth for the future. The reason for such erratic exports include Government policy, expansion of production base, etc. Considering the past performance of the existing Government Policies and perspective for future, the growth rate of 20% seems to be a reasonably attainable target.

The following factors would help in attaining the growth rate of 20% of exports from India :

1) Large scale increase in production of fibre, yarn and fabrics have shown sufficient export surplus.
2) Developed countries have shut down many production lines due to exorbitant costs.
3) Developed countries are withdrawing from low and medium line items as it is uneconomical.
4) The trend of shifting to readymade garments than those tailor-made leading to a quick change of garments and fashions, in turn resulting in higher per capita income of fabrics.
5) With the rise in the standard of living, the consumer is paying more attention to household textiles.
6) Production of industrial fabrics being imported from developing countries.

Considering the above factors India's exporting Companies may be able to achieve the above target provided the Indian Companies meet the export target and has competitive prices.

Inclusion of Synthetic Fibre and Yarn in the list of sensitive items has led to the following disadvantages :

a) Exporters of Synthetic Textiles are denied the facility of granting of Value Based Advance Licence under Duty Exemption Scheme.
b) Any facility sought to be given to promote Exports trade if granted for Synthetic Textiles is given with a restriction.

c) The tendency of the authorities to look at any proposal of Synthetic Textile with prejudice.

d) In order to exploit the export potential of Synthetic Textiles, Synthetic Fibre and Yarn be removed from the List of Sensitive items.

e) The Government to grant Value-based Advance Licence Facility to Synthetic Textile industry by stipulating realistic value addition norms.

f) As against the existing EPCG Scheme for unregistered Export Oriented Units granted of duty free imports of capital goods should be made available.

g) For effective utilisation of Advance Intermediate Licence Scheme, the Excise rules should be simplified and aligned with the existing EXIM Policy. The industry should also be exempted from levy of excise duty of multi staged raw material.

h) Government should make a very powerful infrastructure and information backup on World trade for exporters to have access without difficulty.

Readymade Garment Exports at Rs. 6282 crores in 1991-92 is the second highest product category in India's Export basket, after Gems and Jewellery. In a huge and growing market world wide, there is scope for significant growth, inspite of Quota restrictions in the West for this category of exports under the Multi Fibre Agreement.

The major competitors in this segment of the market are developed countries, Asian tigers like Korea, Taiwan, Hong Kong, and Singapore, developing countries like Indonesia. Thailand and Malaysia and Poor Countries like Bangladesh and Myanmar and last but not the least China. Developed countries are in the process of phasing out due to higher cost considerations.

Therefore, the major readymade garment manufacturers would be from developing countries and fast growing Asian countries. To increase the garment exports the following need to be implemented:

1) In order to bring in quality into Garment exports, it is essential that the SSI restrictions of Garments industry are removed. While there are no SSI restrictions for exports, it is necessary to attract foreign investors into projects that include local marketing and exports.
2) Joint Venture with majority Foreign shareholding as well as Technical Collaborations should be allowed under simplified automatic approval procedures. For this purpose Garments should be included in Annexure III of the New Industrial Policy. Unfortunately, as the Readymade garments are in SSI Sector, equity participation of the Foreign Partner is limited to the extent of 24%.
3) Labour laws and their interpretation need to be liberalised to allow entrepreneurs to get over their fear of employing large number of workers under one roof.
4) A research, development and training institute focused on post garment processing like washing, dyeing, etc. would fill a very major gap.
5) Indian Government need to negotiate higher Quotas from USA/EEC in line with its sizes and capabilities. This is possible if we can offer access to our selected markets in return.
6) Streamlining Internal Quota Administration and freezing minimum export prices is crucial for the future of the Readymade Garments Exports industry.

We recommend the following changes on Quota system:

1) It is suggested that only one Quota type to be introduced entirely based on past production, which should be freely transferable.

2) It is recommended that there should be only one period, and this should be January-December. Further, all quotas to be released by 10th January of every year, and not delayed to February-March.
3) In the area of shipping documents it is recommended that we do away with the system of AEPC endorsement and instead have a passbook of each Quota category issued at the beginning of every year with the total entitlement.

Exports of Cotton Textiles in 1991-92 increased by 55.8% in terms of Indian Rupees and 12.5% in terms of US Dollars as against the previous year. Exports increased as much as 17% as against the target of Rs. 4618 crores or US $ 1670 million set for the current year, exports during the year April-September 1992 accounted for 49% of the target.

It is expected that the exports would touch a level of US $3318 million by the end of 1996-97 with an annual growth rate of 20%. It should be possible to increase our export performance by the end of the five year period commencing from 1992-93 provided certain measures are taken up with real earnestness:

1) The quality of cotton supplied to the Textile Mills should be improved considerably by modernising the Ginning factories.
2) In order to keep up with the International Tech-nology in Spinning and Weaving Sector it is essential to allow duty free imports of machinery.
3) The cost of financing such duty free imports should be reduced to match the international interest rates of 11.5% as was prevalent earlier when the IDBI was operating Soft Loan Scheme for the modernisation purpose.
4) The benefit of import of items included in the Negative list currently granted to exporters of ACU countries, deemed exports, Export/Trading/Star Trading houses should be extended to other exporters also.

5) In order to encourage value added items, processed fabrics and made-up items, the exporters should be allowed to import dyes and chemicals which are in the negative list allowed to the extent of 5%.
6) The interest rate of pre and post shipment credit, which is currently at 13.5% should be brought in line with the international average rate of around 6%.

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