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AN HISTORICAL INTRODUCTION TO WEAVING

The Ancient History of Weaving

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

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

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

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

The Early English Woolen Industry

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

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

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

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

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

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

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

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

The Industrial Revolution

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

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

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

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

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

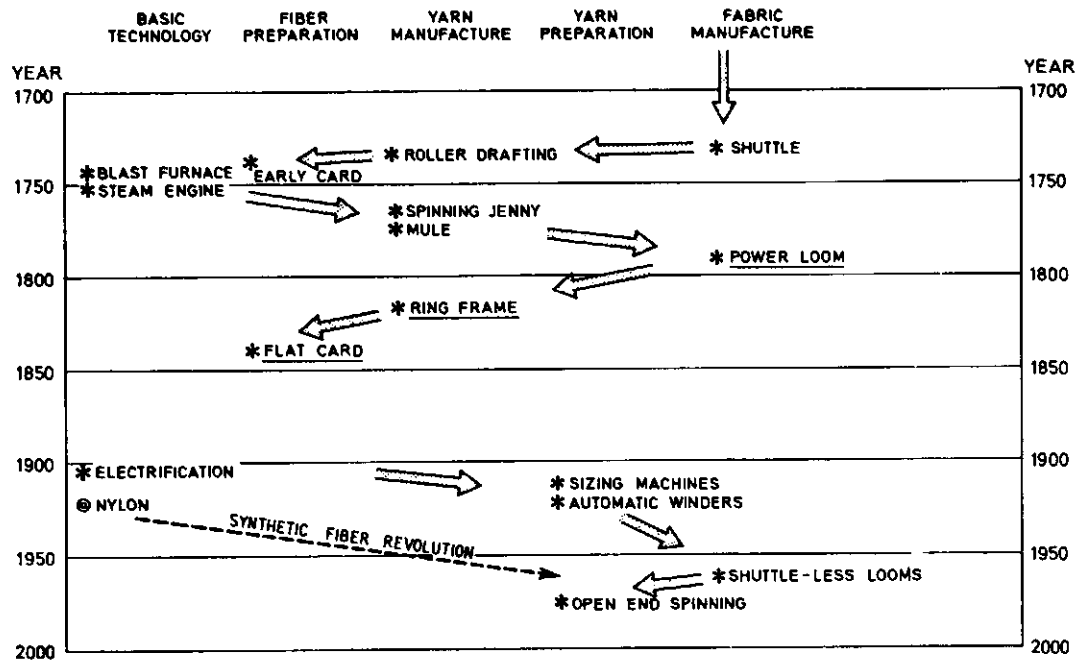

Fig. 1.1. Development of the textile processes

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

Economic and Social Effects of the Industrial Revolution

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

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

No wonder Blake wrote

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

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

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

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

The Cotton Industry

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

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

* Sey was a fabric.

Manchester Exchange was opened in 1729 and John Dyer says:

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

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

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

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

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

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

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

Aitken says:

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

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

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

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

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

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

Man-made Fibers

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

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

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

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

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

Knitting

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

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

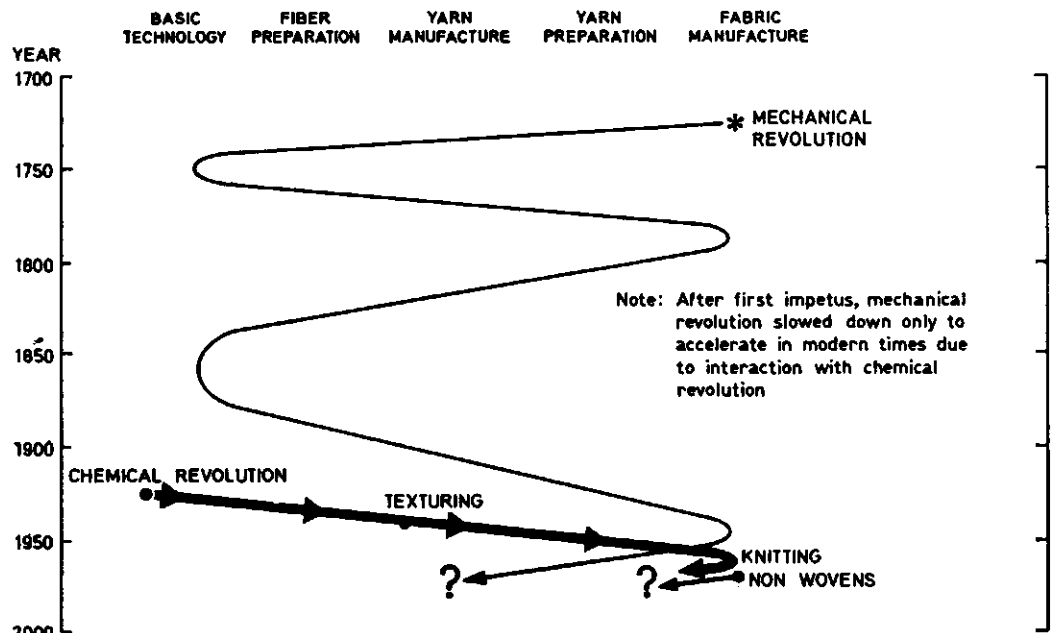

Fig. 1.2. Interaction of the mechanical and chemical technological revolutions

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

"Nonwoven" Materials

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

Summary

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

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

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

Apologies to Lewis Carroll

2

A TECHNICAL INTRODUCTION TO WEAVING

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

The Fabric and the Phases in its Production

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

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

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

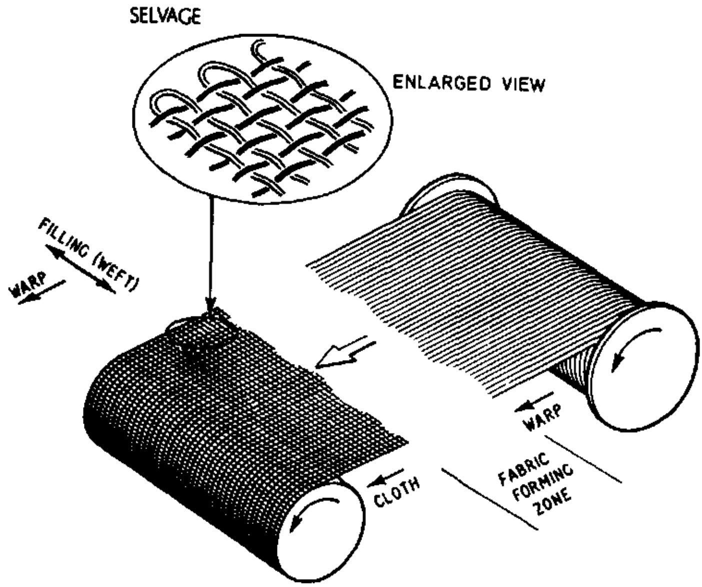

Fig. 2.1. Warp and filling (weft)

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

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

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

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

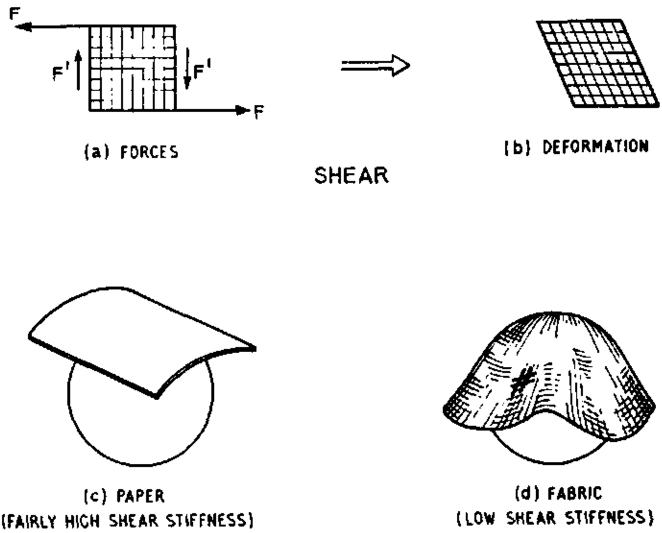

Fig. 2.2. Ability of material to mold, i.e. drape

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

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

Yarn Preparation

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

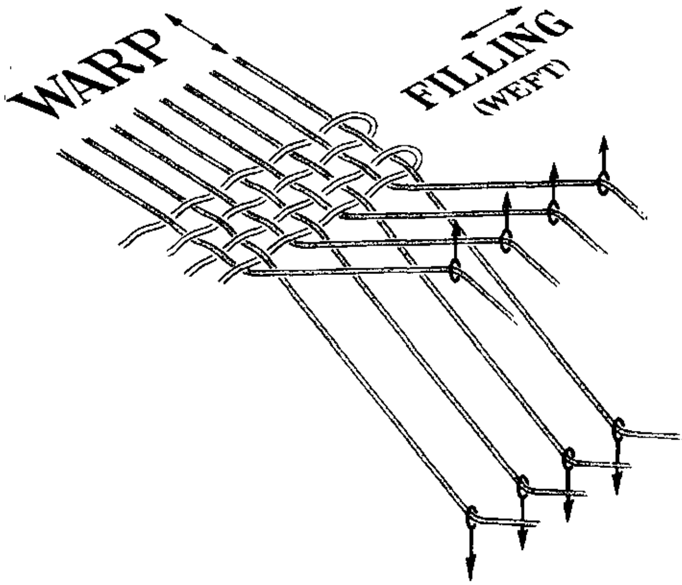

Fig. 2.3. Shedding

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

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

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

Looms

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

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

These will be discussed in detail in subsequent chapters.

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

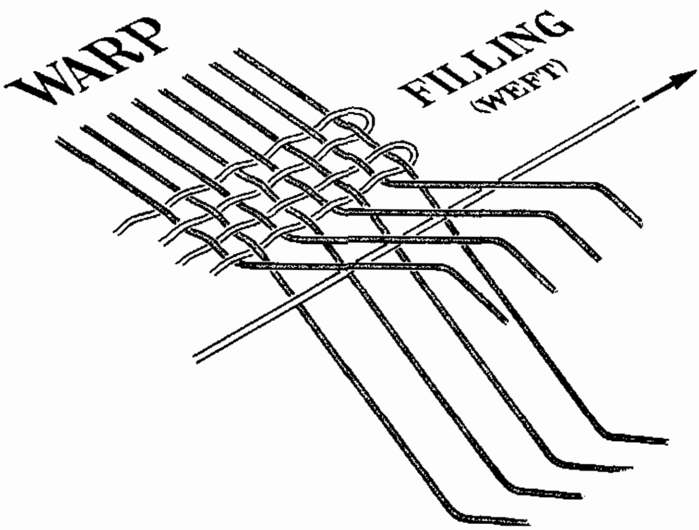

Fig. 2.4. Filling (weft) insertion.

The Development of the Loom

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

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

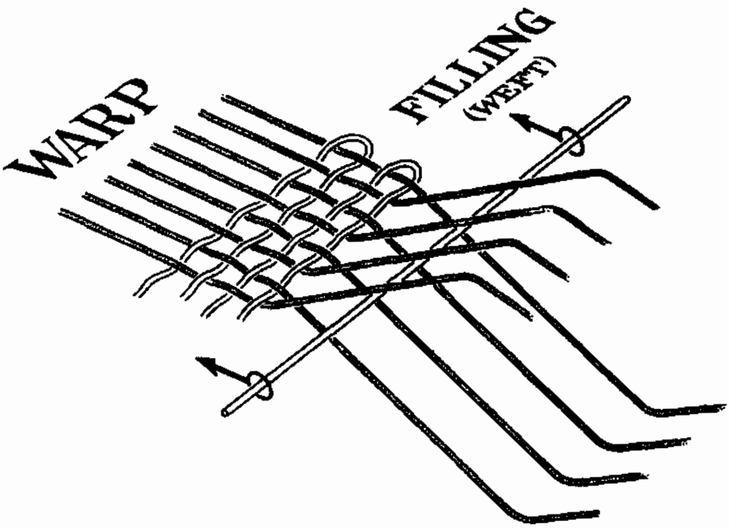

Fig. 2.5. Beat-up.

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

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

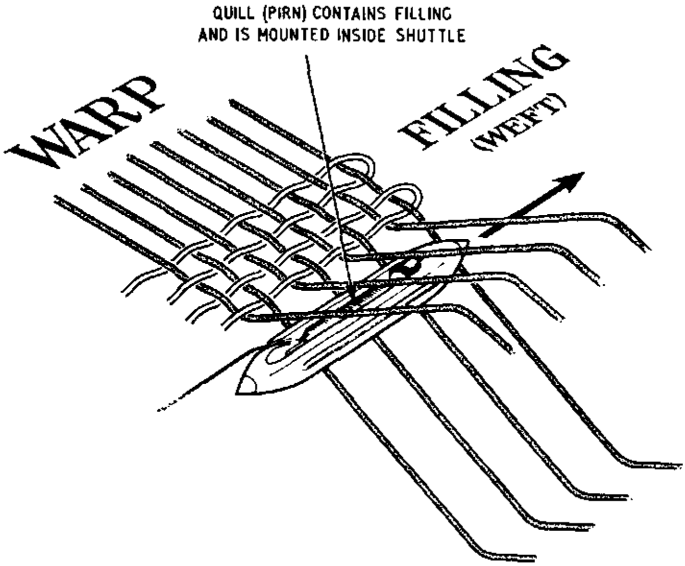

Fig. 2.6. Shuttle passes through warp shed leaving filling (weft) trailing behind.

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

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

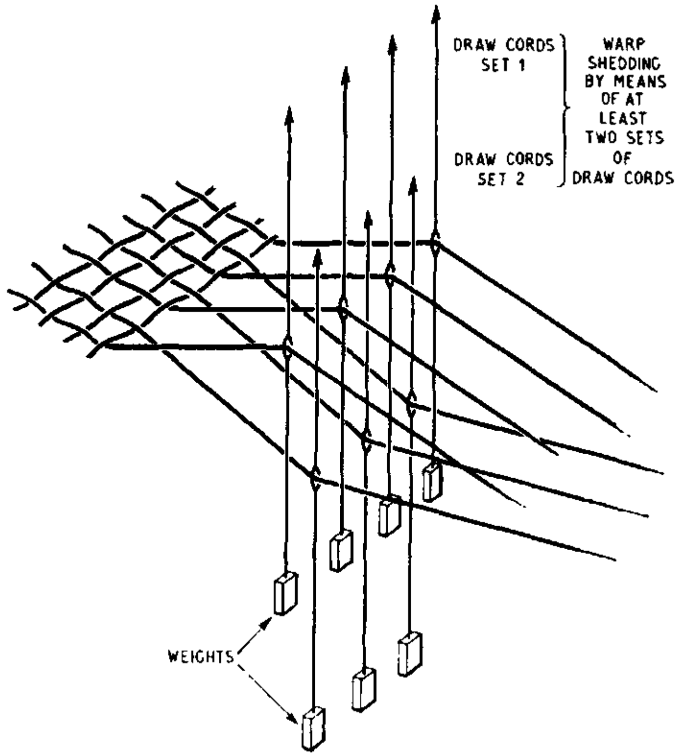

Fig. 2.7. Schematic view of shedding in draw loom.

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

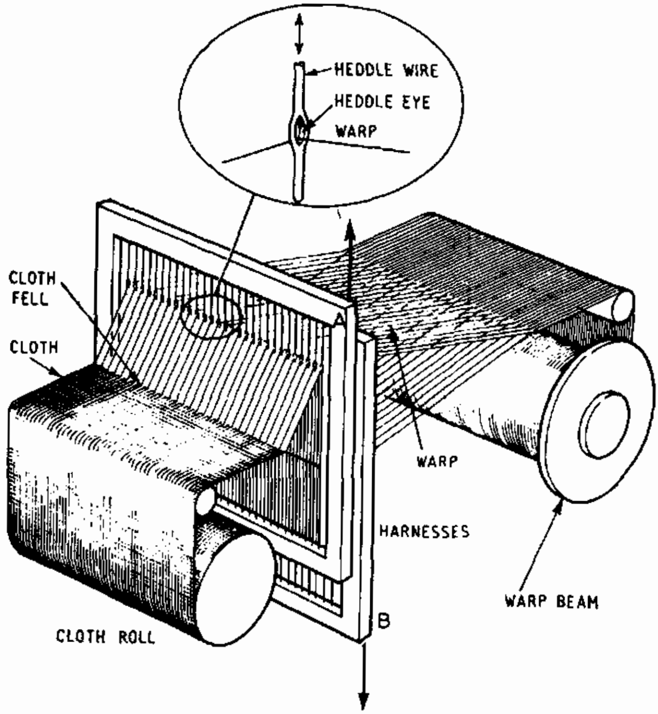

Fig. 2.8. Shedding

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

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

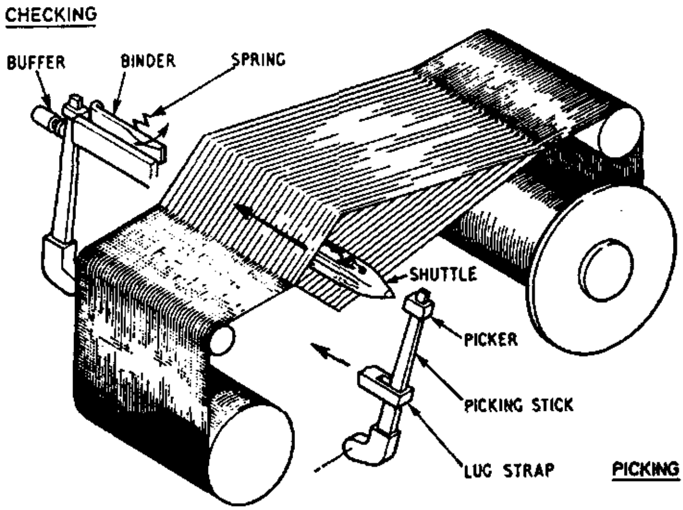

Fig. 2.9. Filling (weft) insertion.

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

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

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

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

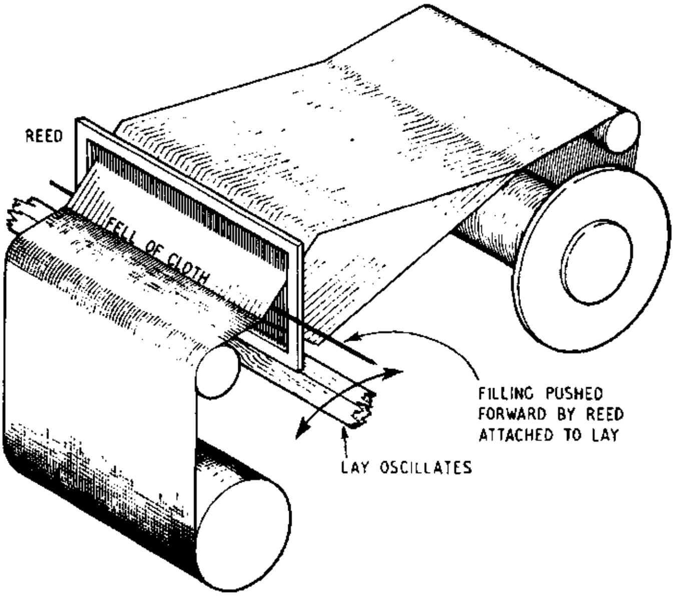

Fig. 2.10. Beat-up

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

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

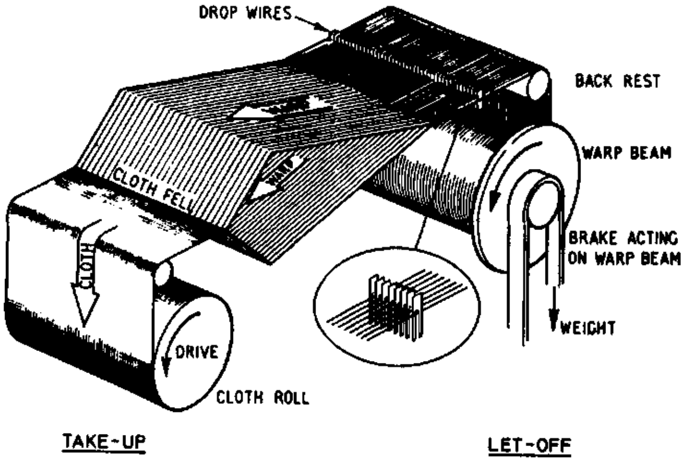

Fig. 2.11. Flow of material through the loom

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

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

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

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

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

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