15

SHUTTLELESS WEAVING SYSTEMS

Key words: *air-jet loom, barré, cutters (weft cutters), effective mass, filling transfer, filling retraction, flexible rapier, fringed, giver, gripper, guides, inertial system, Leno selvage, momentum, rapier, rigid rapier, selvage, selvage motion, shuttleless weaving, slough-off, sonic velocity, staple yarns, taker, toggle, torsion bar, tucked-in selvage, turbulence, water-jet loom.*

Introduction

In a shuttle loom it is necessary to pass a shuttle, which may weigh ½ kg (1 lb), to insert a length of filling which may weigh only a few milligrams. The relatively massive shuttle has to be accelerated rapidly, and it must also be decelerated abruptly; it is difficult to do this without causing shock and noise. The system is intrinsically inefficient from a mechanical point of view, and considerable amounts of energy are dissipated at the binders (swells), picker and checking mechanism generally. The wear life of the picker is strictly limited because of the heavy and repeated impacts that it suffers. In fact, the whole mechanism is subject to great wear and tear, with the consequence that it has to be made rugged and heavy. The shocks arising from picking and checking disrupt the smooth sequence of events in weaving, with the result that there is a certain instability in the loom speed. This affects the maximum permissible running speed of the loom, and it can affect the fabric. Furthermore, the shocks lead to noise and vibration which are extremely difficult to subdue. There is growing concern in many countries regarding the environment in which

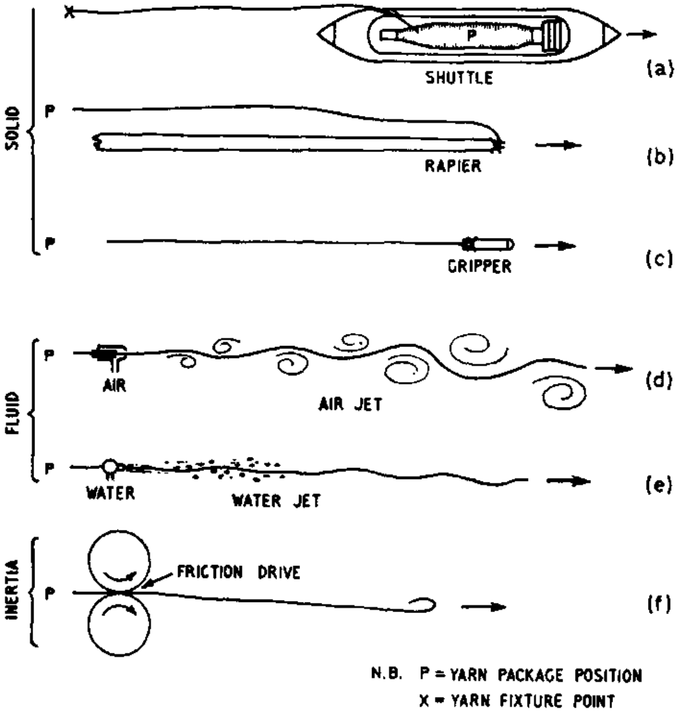


Fig. 15.1. Filling insertion systems

workers are employed, and this is likely to become an increasingly important issue. Little wonder that the shuttleless loom has begun to make its presence felt.

Forms of Shuttleless Weaving

One solution to the problems inherent in the weaving process is to reduce the size of the element used to propel the filling (weft). This element may be a solid or a fluid, and these two categories may be further sub-divided as indicated in Fig. 15.1. In most cases the propulsion element traverses the warp shed in the loom, but it is also possible to apply

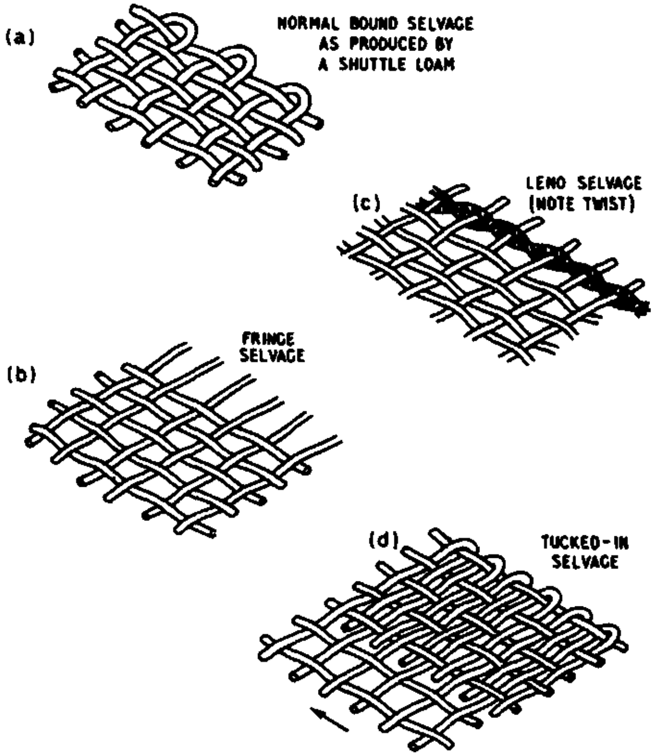


Fig. 15.2. Various forms of selvage

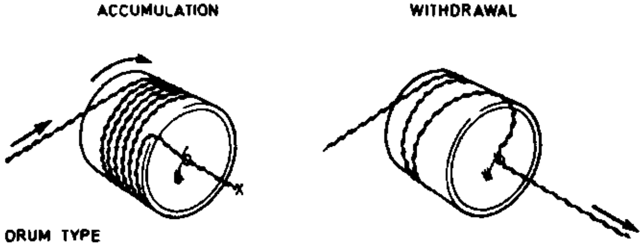
energy to the length of filling before it enters the shed and to allow its inertia to carry it across.

Shuttleless looms of the type which use *projectiles* or *rapiers* now predominate. *Water-jet looms* are also quite widely used, but they are restricted to the weaving of filament yarns because of the effects of water on *staple yarns* which have been sized. However, all the systems have features in common and it is convenient to discuss these common features before considering individual systems.

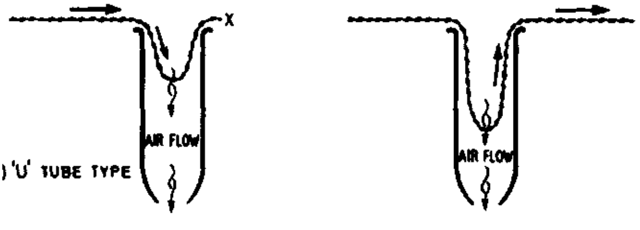
In none of these systems is a quill or pirn carried to and fro to give a normal selvage (see Fig. 15.2(a)). The length of filling is inserted usually from one side, with the result that at least one selvage must be *fringed*, as shown in Fig. 15.2(b). To enable the fabric to withstand subsequent processes, the fringed selvage must be reinforced in some way. It is possible to use adhesives, but the most popular solutions are to use a *Leno selvage* (Fig. 15.2(c)) or a *tucked-in* selvage (Fig. 15.2 (d)). For cut goods, or those to be hemmed, the Leno selvage is usually sufficient, but if a good edge is required on the finished product, as in the case of sheets, the tuck-in motion is preferred. The latter simulates a conventional selvage but there is a concentration of filling ends at the edge and it is usual to alter the fabric structure locally to accommodate the crowding. The tuck-in technique places some restriction on the structures which can be woven but this is rarely an oppressive restriction.

With normal weaving, the quills can arrive at the loom in a different order from that in which they were wound. Bearing in mind that the yarn varies in count as it leaves the spinning machine, there can be a quill to quill variation. If these quills become disordered, there can be sharp changes in count from one to the next, and this shows up in the fabric as barré faults. These stripe-like faults are most noticeable in weaving filament yarns. This difficulty is greatly reduced by weaving from a large package such as used in shuttleless looms; the gradual changes in count within the package are not usually very noticeable and the frequency of change is sharply reduced. With a large package, the amount of fabric produced between changes is measured in meters (yds). (The precise amount depends on loom width, pick density, yarn count and package size). With a normal quill, the amount of fabric is measured in cm. Thus quills may produce narrow barré (which is very noticeable) whereas the large package is only likely to produce one single step change in any normal length of fabric. This also has a repercussion on the level of quality control which must be applied to the filling yarn. Generally, specifications can be relaxed a little with the large packages and this can save money.

Since a quill is no longer used with a shuttleless loom, there is no need to restrict production by using small yarn packages for filling; in fact, a major advantage accrues from using the large package because winding and filling replenishment costs can be reduced. However, unwinding a large package does pose some problems when the withdrawal is intermittent (as it is in most of these looms). At the speeds involved, over-end unwinding is the only practical way of dispensing the yarn and this gives rise to difficulty. Under steady unwinding conditions, a yarn balloon forms which holds the yarn clear of the package as it is withdrawn. Under unsteady conditions, such as apply in the case under discussion, the yarn can be dragged over the surface of the package. This can cause one or more turns of yarn to *slough off* and cause a stoppage; it can also cause the yarn tension to rise suffi-



(a) DRUM TYPE



(b) 'U' TUBE TYPE

Fig. 15.3. Filling yarn storage systems.

ciently to cause a break. Thus it is required to unwind the yarn as steadily as possible and to store excess delivery at certain times against the sudden demand at others. One practical way of achieving this objective is to store sufficient yarn on a smooth cylinder by side winding and then at the point of sudden demand, allow the accumulated yarn to be withdrawn over-end so that it may be removed rapidly without contact against other layers of yarn beneath. The principle is shown in Fig. 15.3(a). Another technique is to use a suction tube to hold a long U-shaped loop of yarn until the sudden demand causes a rise in tension which removes the yarn stored in the U-shaped configuration. The steady supply of yarn to the system allows the U to grow in size until the next demand, and so on (see Fig. 15.3(b)).

In many cases, the filling cannot be located across the width with great accuracy; it is necessary to insert an excess and to cut both ends of each length of filling after insertion to give good register. The *cutters* are usually scissor-like devices but it is possible to use a hot wire cutter when the filling is made of certain fibers. The cut end is tucked in or is left as a fringe. Alternatively, the selvages can be sealed by heat or adhesive, but this tends to give a stiff edge to the fabric.

Some of the methods mentioned lead to the insertion of a filling which has to be straightened prior to beat-up and there are several ways of doing this. Where the contortion of the filling is large, it would be wasteful in material to straighten from the free end and cut off the excess (i.e. to remove the excess yarn at the selvage remote from the filling insertion device). In these cases it is normal to use a *retraction* device which is situated near the insertion device and which pulls out the excess filling and stores it so that it may be used in the next pick. To obtain good straightening, it is necessary to restrain the free end of the newly inserted filling whilst the other end is retracted. It is possible to use an air suction for this purpose or to use a pair of yarns which are twisted so as to entrap the end at the time and place required. In either case the entrapment medium can be used to carry away the ends cut off by the selvage cutters. A third possibility is to use a mechanical clamp which catches the end; this solution is favored where the end is to be tucked in to simulate a normal bound selvage. Sometimes the retraction device is a mechanical finger, which is favored for tuck-in selvages. Suction devices used for retraction are usually combined with the storage system, but care must be taken to prevent the yarn twisting about itself and forming snarls which are likely to cause stoppages and/or fabric faults.

Vincent Inertial System

It is desirable to reduce the linearly moving elements of the filling insertion system to an absolute minimum; ideally, the mass would be reduced to that of the length of filling concerned. The Vincent system aims to do this by causing energy to be imparted to the filling yarn before it enters the warp shed. This is done by introducing the filling to a pair of high-speed rollers which grip the yarn and accelerate it up to speed very rapidly indeed (see Fig. 15.1(f)). The yarn then traverses the warp shed by virtue of its momentum. In its simplest form, the device projects the yarn at constant velocity, but air drag causes the leading end to slow down whilst yarn is still being fed at the higher velocity; this causes the yarn to buckle in an undesirable manner. If, however, the drive rollers are decelerated to match the leading end, this difficulty can be avoided and remarkably straight picks can be generated. The initial acceleration causes a hook to be formed at the leading end because there must be some initial slippage which causes the leading end to be overtaken by following elements of yarn; this is much more difficult to overcome.

Should the length of filling yarn be buckled or have an appreciable hook at the leading end, there is a good chance that the yarn will touch the warp shed. Since the *momentum* of such a light piece of yarn is very low, it needs only the slightest touch to cause it to be stopped or seriously slowed down; if this happens there is nearly always a fault produced in the fabric. Thus a hairy or deformed length of yarn passing through a warp shed (particularly an unclear warp shed) is very likely to cause a fault. This is a defect shared with the *air-jet loom*.

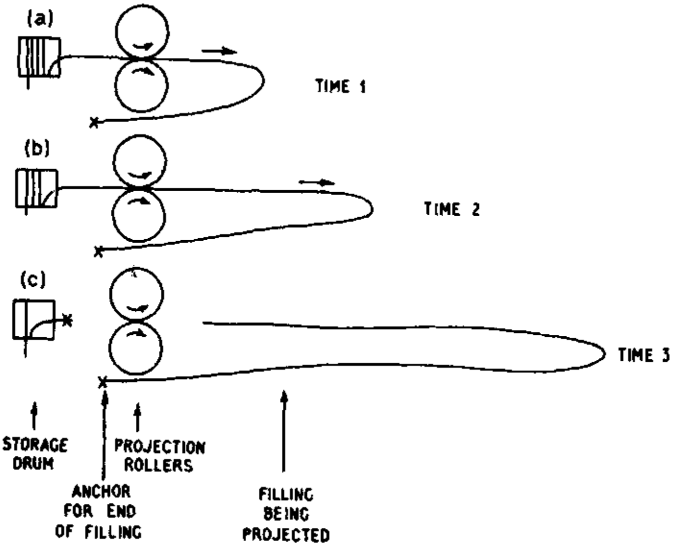


Fig. 15.4. Modified Vincent system

In an interesting development of this technique, the free end is anchored and succeeding elements are projected in the manner shown in Fig. 15.4. The "unrolling" type of motion applied to the yarn tends to straighten it and reduces the potential for faults. At the time of writing, none of these devices has been exploited commercially.

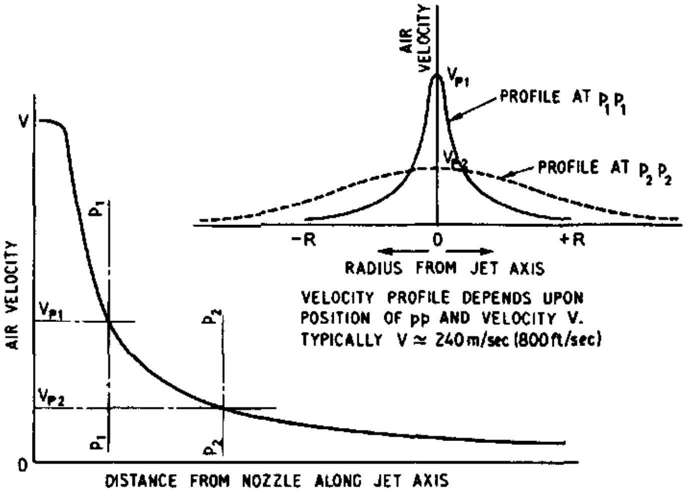


Fig. 15.5. Typical air jet characteristics.

Air-jet Loom

A blast of air would seem to be an effective way of inserting the filling, but to get enough traction on the filling yarn it is necessary to use very high air velocities. These normally exceed *sonic* velocity with the consequence that the looms are noisy and consume considerable amounts of energy. This increases the cost of weaving and tends to make air-jet looms less attractive.

When an air jet is allowed to expand freely, the moving air is contained within an imaginary cone whose axis is coincident with that of the air jet (see Fig. 15.1(d)). The air just emerging from the nozzle is highly energetic and, as it moves away from the nozzle, it entrains some of the surrounding air which tends to slow the mass down. Thus as the moving mass of air moves away, it grows larger and becomes slower. The air velocity component parallel to the jet axis declines sharply with both axial distance and radius, as shown in Fig. 15.5. Friction is low in air, and the original kinetic energy of the air in the nozzle cannot be lost quickly enough. The air stream breaks up into *turbulence*; the excess energy is absorbed by the turbulent eddies and this energy is irrecoverable. This is where the majority of the energy is wasted. Moreover, the eddies cause the filling to become contorted as indicated in Fig. 15.1(d), and it is necessary to have a much larger warp shed than might be supposed, simply because the contorted filling would catch upon the warp. A length of filling traveling on its own has little momentum and can be easily stopped. The problem is increased because the filling moves into a field of declining air velocity and thus behaves as if it is propelled from behind; the front end moves slower than the rear and the yarn buckles. The net result is that usually the warp shed must be larger than that for a shuttle loom. In practice, it is not possible to project a filling more than about 1½ m with a simple air jet of reasonable size and power consumption; therefore, the width of the loom is limited too. Even so, it is possible to run looms of this sort at over 400 p.p.m. which indicates that the bar to increased productivity in a shuttle loom is really the picking and checking system.

One way of improving the performance of an air-jet loom is to use a device to prevent the air-jet from breaking up so quickly. A series of orifices, with slots to permit the removal of the filling at beat-up, can be placed along the filling axis. These act as a sort of porous tube and tend to improve the axial air velocity running over the filling. They also reduce the turbulence so that there is less disturbance to the filling. Such a system permits an increased productivity by allowing a higher loom speed or wider loom or both to be used. The orifices are sometimes called "confusers".

A second way of improving the performance of an air-jet loom is to use a multiplicity of jets across the width of the loom. The auxilliary jets protrude through the warp and yet are arranged in such a way as not to impede the warp shed change or beat-up. The propulsive urge can then be distributed along the width of the loom to maintain the straightness of the filling yarn and to extend the width of the loom. These multi-jet looms can be made in widths that are attractive to the user, and thus the fortunes of the air-jet loom have revived. Unlike the water-jet loom, there is no restriction on the type of yarn that can be woven but, because of the higher speeds used, there is a need for a higher level of quality control of the yarn used. The slashing also has to be carried out with care. Failure to utilise the highest standards of quality control can result in very poor loom efficiencies and loss of production.

Water-jet Loom

A water jet is more coherent than an air jet. It does not break up so easily, and the propulsive zone is elongated, making it much more effective. It is effective in terms of energy requirements, it is quiet and, when the jet does break up, it goes into droplets which create very little turbulence to disturb the filling (see Fig. 15.1(e)).

The droplets spread in such a way as to wet much of the warp; thus a sized warp containing a water soluble adhesive can be adversely affected. Because of this, water jet weaving is usually restricted to filament yarn, but there is some hope that it might become economically feasible to weave staple yarns on these looms.

Two main reasons for the efficiency of the water-jet loom are that there are no varying lateral forces to cause the filling to contort, and the moving element is more massive because it is wet. Thus there is less chance of fault due to contact with the warp.

The range of jet, and thus the width of the loom, depends on the water pressure and the diameter of the jet. Water is virtually incompressible and a simple jerk pump can be used to give adequate pressure without difficulty. A fireman's hose has a tremendous range but the jet is several cm in diameter; large volumes of water and considerable pumping powers have to be used. In weaving, a much more modest jet is used; in fact, it is possible to reduce the diameter of the jet to some 0·1 cm, and the amount of water used per pick is commonly less than 2 c.c. Even with these small jets, it is possible to weave at up to 2 meters in width with small power consumptions. It is also possible to weave at up to 1000 picks/min on narrower looms. Several forms of water-jet loom have now become established. Performance in comparison with other types is shown in Table 15.1.

Projectile Loom (Gripper Shuttle Loom)

A more positive way of inserting the filling without resorting to the heavy shuttle is to use a projectile or gripper shuttle which grips the end of the filling yarn presented to it and, when projected across the warp shed, tows the filling yarn behind it (see Fig. 15.1(c)). This projectile or gripper shuttle will be referred to throughout the rest of this text as a projectile although the alternative names of gripper shuttle and gripper still have some currency. The projectile does not have to carry a yarn package with it and it need only be relatively light in weight; however, it is sufficiently massive to be unaffected by minor obstructions in the warp shed.

Since there is no moving package, there can be no normal selvages and it is usual for the projectile always to travel in the same direction when carrying the yarn rather than to reciprocate as in a normal loom. The projectiles are returned to the starting point by some form of conveyor belt and several projectiles are needed even though only one may be in active use at any one time.

Because the mass of the projectile is much less than that of the conventional shuttle, the forces needed to accelerate it are less and the picking mechanism can be lighter; this in turn reduces the total mass to be accelerated and makes it possible to use new systems. Also, because the mass is low,

Table 15.1

LOOM PERFORMANCE DATA

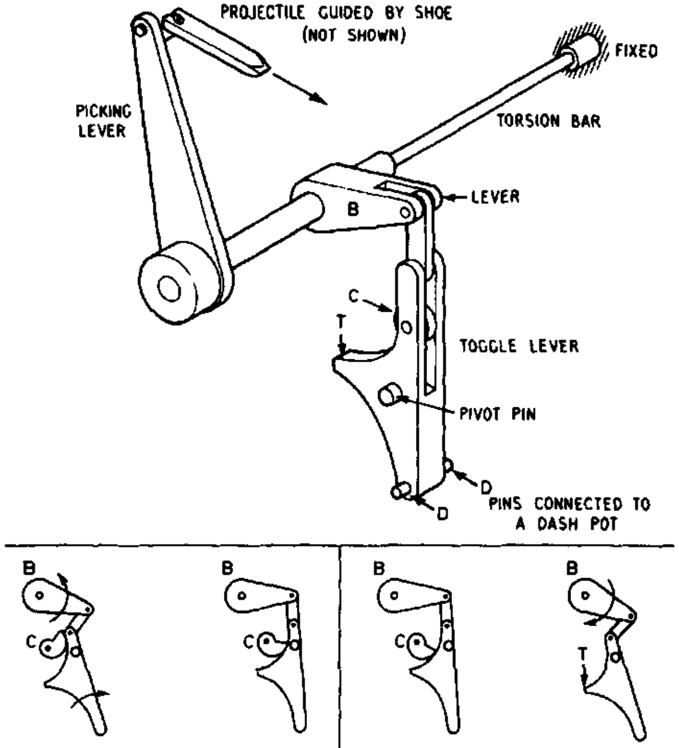
Loom Type	Width Range cm	Speed Range ppm	Maximum Rate of Filling Insertion m/min
Rapier			
Single phase	165 – 360	180 – 325	600
Double phase	2 x 125 – 2 x 205	220 – 300	1100
Projectile	220 – 545	200 – 320	1100
Water-jet			
Single	125 – 210	400 – 700	1100
Double	2 x 165	400 – 600	2000
Air-jet	125 – 330	350 – 600	1300
Multi-phase			
Weft wave	2 x 165 – 4 x 165	280 – 620	2000
Warp wave	2 x 100	3600	3600

the speed can be increased to compensate (at least to the point where shedding and beating give trouble). Thus these looms can be run faster than conventional shuttle looms. Also the acceleration of the projectile can exceed that of a shuttle by a factor of about 7. This affects both the space consumed and the productivity to advantage.

A good picking system needs to store energy which is released as the shuttle is accelerated; the same consideration applies to the propulsion of a projectile. In the most widely used system, a *torsion bar* (instead of the wooden picking stick) is used to store strain energy prior to picking and this energy is released during the acceleration of the projectile by a *toggle* action. The whole unit is very compact and effective (see Fig. 15.6).

Each new projectile is accurately positioned before it is projected across the warp shed and thus the strength of the pick is not dependent on any of the interactions described on p. 224 and 282. The energy expended in picking is roughly one half of that used with a normal shuttle despite the higher velocity of the projectile. In consequence, the picking mechanism is less massive than that used with a conventional shuttle, and it is easier to check the picking lever used with the projectile than it is a normal picking stick. Also it is much easier to check the projectile because of its low mass. Bearing in mind the normal difficulties in checking, it will be realized that this represents a significant advance in design.

The normal projectile is rather short and if it were to meet a substantial obstruction in passing across the loom, it could quite easily be deflected; at worst it could fly out of the loom, which could be very dangerous. Also the collection of the projectile after it has completed its task of carrying the filling is made more difficult if it does not follow an accurate path. For these reasons, a series of *guides* are used to constrain the projectile as it passes across the loom. To make this possible, the guides must protrude through the warp sheets as shown in Fig. 16.1. (p.313).

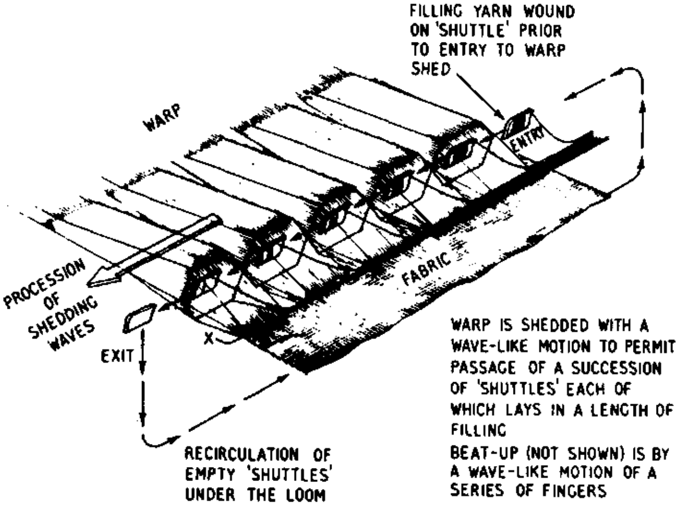


ROTATION OF CAM C CAUSES RELATIVELY SLOW BUILD UP OF STRAIN ENERGY IN TORSION BAR PRIOR TO PICKING

SIMULTANEOUS MOVEMENT OF CAM C TO RELEASE POSITION AND APPLICATION OF FORCE T AT TRIGGER POINT CAUSES SUDDEN RELEASE OF STRAIN ENERGY INTO PICKING MECHANISM

Fig. 15.6. Toggle torsion bar picking mechanism

At first sight it might seem that a very small warp shed could be used because the projectile is so small. However, it is still necessary that there should be a clear shed, and this means that the angles of the warp must be greater than certain minima. As the travel of the lay cannot be reduced below a certain level, the warp shed has to be rather large



FILLING YARN WOUND ON 'SHUTTLE' PRIOR TO ENTRY TO WARP SHED

WARP IS SHEDDED WITH A WAVE-LIKE MOTION TO PERMIT PASSAGE OF A SUCCESSION OF 'SHUTTLES' EACH OF WHICH LAYS IN A LENGTH OF FILLING

BEAT-UP (NOT SHOWN) IS BY A WAVE-LIKE MOTION OF A SERIES OF FINGERS

RECIRCULATION OF EMPTY 'SHUTTLES' UNDER THE LOOM

Fig. 15.7. Loom with simultaneous laying of many fillings

considering the size of the projectile. However, there is some gain and, perhaps more important, there is an improvement in the warp breakage rate which has advantageous economic repercussions.

The use of a small projectile tends to reduce the amount of "shuttle" interference (or its equivalent) as shown in Fig. 16.2. This is because the projectile is shorter and the time needed for it to pass a given point is reduced. Also the projectile is slimmer than a shuttle and the warp can more nearly close on the departing projectile than it can on the fatter shuttle. Thus tighter loom timings are possible and the gain can be taken as either an increase in loom speed or in fabric width.

Of the two alternatives cited, an increase in fabric width is usually preferred and looms of up to 6 meters in width are now made. One reason is that the projectile is only usefully employed when it is carrying filling across the warp shed. When the projectile is at rest or is being accelerated, it is not fulfilling its main task. With a narrow loom, the projectile spends a greater proportion of its time in unproductive dwell or acceleration than it does in a wide loom. Since acceleration has to be limited to what the machine elements can bear, it tends to be the same irrespective of the loom width; also in practice the projectile speeds do not vary much with loom width, and therefore there is an advantage in using wider looms. For example, it has been found worthwhile to weave sheets side by side on a wide loom rather than to use several single width looms. This is despite the fact that a pair of *selvage motions* has to be fitted for each fabric width on the loom.

Over the years, loom widths have tended to increase and this seems to confirm the trend noted above. However, there must be limits to the gains which can be achieved. For one thing, the retardation of the projectile in its passage across the loom has to be taken into account. Also, and perhaps more importantly, the wider the loom, the greater is the chance of a warp break. A single end break causes the whole loom to stop and the wider the loom, the more production is lost due to the stoppage.

Wave Shed or Multi-phase Looms

An interesting design utilises multiple *carriers* as shown in Fig. 15.7. By laying in several fillings at the same time, the productivity of the loom is greatly increased if the loom operates at a reasonable speed. To accommodate the several carriers, it is necessary for the beating and shedding to operate in a wave-like manner so that the opening in which a carrier travels also moves with it. This means that the shedding and beating elements have to move independently at the appropriate times, rather than in a block as they do in a normal loom. There are limits to this system; for example, an end break can cause difficulty because of the progressive entrapment of the multiplicity of filling yarns. Winding yarn onto the carriers at a sufficiently rapid rate could also cause problems unless there is a multiplicity of winding heads or the carriers are pre-wound. The system also limits capability of the loom to produce a range of fabric designs.

Another interesting design utilizes a multiplicity of warp shed openings which move in the direction of the warp. Several picks can be in motion at the same time, one to each warp shed opening. The filling carried in the shed opening is beaten into the fell of the cloth as the 'warp wave' approaches the fell. Once again the multiplicity of filling insertions makes possible a very considerable increase in productivity.

Rapier Loom

The shuttle loom is an imperfect machine in that the shuttle is not fully restrained. Mechanical shocks are generated when the shuttle comes under restraint; high *rates* of acceleration are generated and this limits the level of acceleration that may be accepted. Thus if full control of the filling insertion device is achieved, an advantage accrues simply because shocks are almost eliminated; higher levels of acceleration can be accepted and this implies that the speed of the loom can be increased (subject to other limitations).

At first sight it might appear that a rapier system would involve less effective mass than a shuttle system, but this is not necessarily so. In theory, it is possible to replace the actual system by one in which there is an *effective mass* which is driven along the filling path by a massless drive apparatus, the effective mass being that which would cause the input portion of the system to suffer the same torques or forces as the actual one. In a shuttle loom, the effective mass is about twice the shuttle mass, in a rapier loom it is many times the mass of the rapier. The inertia of the rapier drive is thus far more important than that of the rapier itself, and it is the mass of the drive that largely controls the behavior of the whole picking system. Thus it is the improved mass control that is important, rather than the mass advantage.

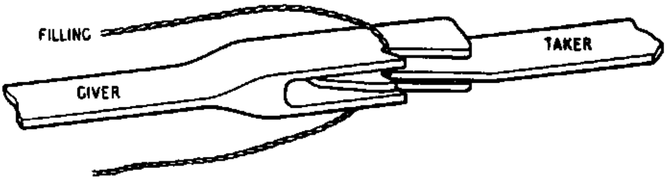


Fig. 15.8. A simplified version of a filling transfer system

One way of controlling the filling insertion device is to use a *rigid rapier* (Fig. 15.1(b)). One end of this carries the filling and the other is connected to a suitable linkage or control mechanism. In some ways it is almost a return to the primitive forms of weaving.

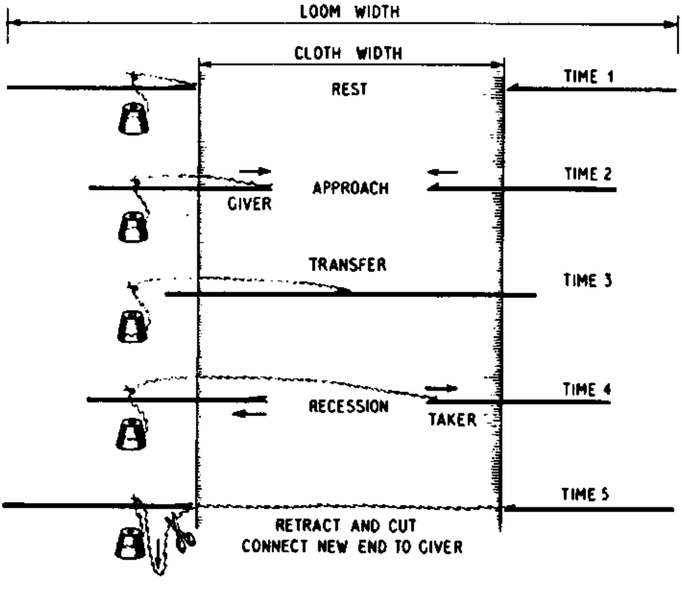


Fig. 15.9. Schematic diagram of a rigid rapier sequence

A disadvantage of this technique lies in the space required for the removal of the rapier to allow the warp shed to be changed. Even if two rapiers are used, one from each side of the fabric, this space requirement remains, and the loom must be at least twice as wide as the fabric being woven. Taking into account the fact that there are always appendages which make any loom wider than the fabric and these are disposed on either side of the loom, it is generally an advantage to use a two rapier system. This requires that the filling be transferred from one to the other in the middle of the warp shed during the filling insertion operation. One rapier (called the *giver*) takes the proffered yarn and carries it to the center of the shed; concurrently, the other rapier (called the *taker*) also travels to the center and the two meet. At this time the yarn is collected by the taker whereupon both rapiers are withdrawn, the giver returning empty and the taker completing the motion of the length of filling yarn. A sketch of a *filling transfer* system is given in Fig. 15.8 and a diagram of a typical system is shown in Fig. 15.9. An alternative system is shown in Fig. 15.10 but in this case it should be noted that the free end of the filling can rotate during the latter part of the filling insertion phase and the yarn can lose twist. This is a problem mainly with twist-lively yarns.

Although it is possible to use some of the excess space needed by rigid rapiers (such as to allow room for large multipackage creels of filling yarn), it is more economical in terms of space to use *flexible rapiers*. The flexible rapier can be coiled as it is withdrawn from the warp shed (Fig. 15.10) and this saves considerable space. However, a long flexible blade tends to buckle when violently accelerated from the rear, and lateral restraints are needed to prevent this. These may take the form of thin guides which can protrude through the warp sheet at intervals along the width of the fabric or of guides attached to the rapier drum (see Fig. 16.1). If the distance apart of the guides is too great, the rapier will buckle; if the distance is too small, the warp will be affected

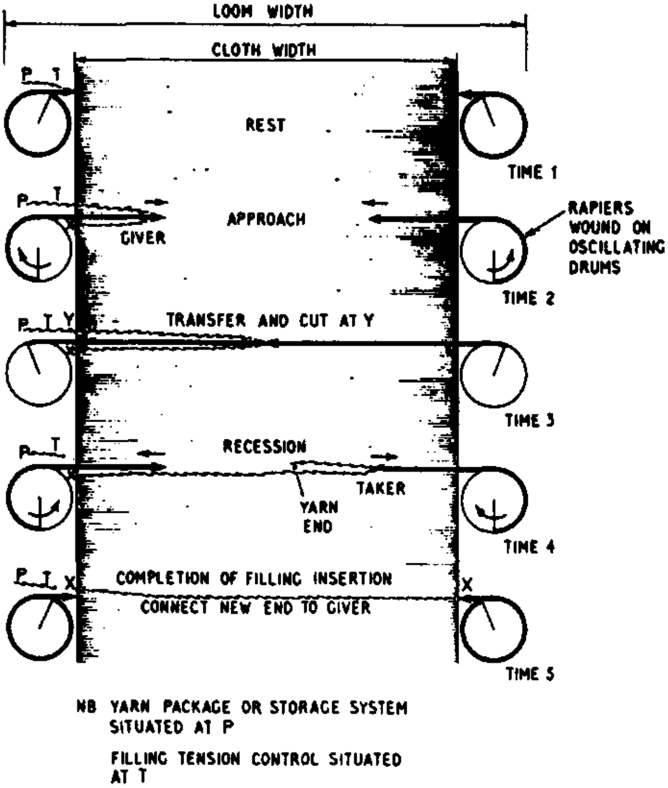


Fig. 15.10. Schematic diagram of a flexible rapier sequence

because of the space taken up by the guides. The rapiers cannot be made too stiff or they could not be coiled properly; on the other hand they cannot be made too flexible or they would buckle easily or need too close a spacing of the guides. It is important to get as good a compromise from the competing factors as possible since this affects the life of the components, and thence the cost of weaving. Of course, it is possible to limit the speed since this will reduce the buckling loads for a given system, but this can only be done at the

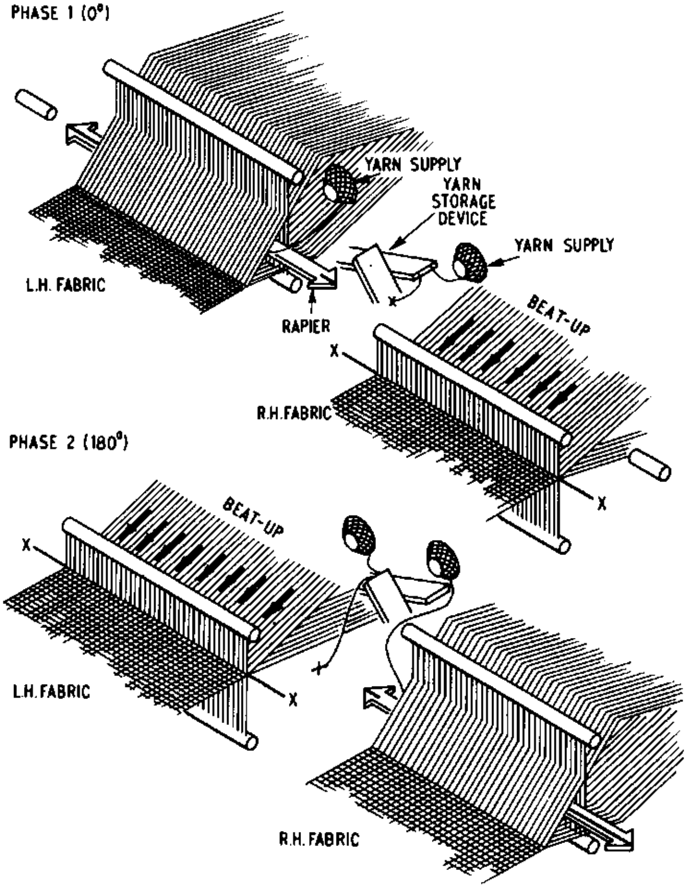


Fig. 15.11. Double-fabric rapier loom.

expense of production. In this context, it is relevant to point out that the use of two rapiers rather than one reduces the accelerations needed (which in turn reduces the buckling forces at a given loom speed). Thus the two rapier system is almost universal in modern looms of this type.

Another development to overcome the space requirement of rigid-rapier looms is the use of telescopic rapiers. This system also eliminates the need for the guides that are necessary with most flexible-rapier looms. In a recent development, a loom was introduced using a single rapier with symmetrical rapier heads at each end. This inserts filling in two warp sheds on either side of the central drive as shown in Fig. 15.11. The two sides of the loom operate with a phase difference of 180°. It is worth noting that rapier looms saw considerable development in the seventies and have reached fairly high levels of width and speed.

An advantage shared by all shuttleless looms is that it is easier to change the filling from one color (or type) to another for the purposes of producing decorative designs than it is in the shuttle loom. Instead of the whole shuttle having to be changed, it is only necessary to proffer a different yarn end to the appropriate rapier. This is quicker and easier; furthermore, it is possible to have a whole array of ends awaiting selection and thus more complex patterns can be woven. Practical limits arise because of creel size and complexity; nevertheless the new systems give the designer a much wider scope and this is important at a time when fashion plays such a large part in determining whether or not the fabric can be sold.

16

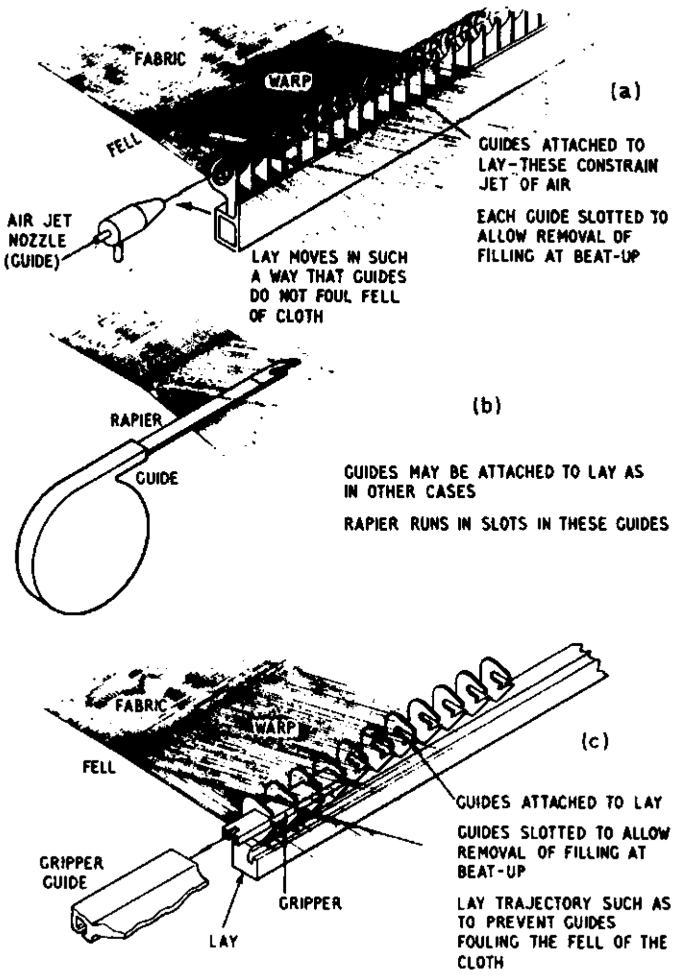
MORE ON SHUTTLELESS LOOMS

Key words: *air-jet loom, beating action, buckling length, buckling load, capital intensive system, coiling drum, down time, effective lay mass, flexible rapier loom, gripper loom, idle time, interest, labor intensive system, lay dwell, negative beat-up, overhead, positive beat-up, productivity, quality control, rigid rapier loom, shedding diagram, speed of filling insertion, transport efficiency, winding pattern.*

Guidance of the Shuttle or Carrier

Apart from the obvious gains which arise from successfully dispensing with the shuttle, there are other potential gains as well.

At first sight, there seems to be little reason why the picking mechanism of a normal loom has to be mounted on the lay. Careful reflexion will reveal that the forward motion of the lay tends to cause the shuttle to be kept in contact with the reed and gravity acts to keep it in contact with the raceboard; the raceboard and reed thus act as constraints which guide the shuttle. Attempts have been made to introduce conventional picking mechanisms which do not oscillate with the reed, but shuttle guidance has created problems. As the shuttle or its equivalent is reduced in size (or is eliminated), so the problems become easier to deal with. It becomes possible to use guides to control the carrier used to insert the filling, and the need to place the picking mechanism on the lay is correspondingly reduced. The carrier used to insert the filling might be air, water, gripper, rapier or shuttle.



GUIDES ATTACHED TO LAY-THESE CONSTRAIN JET OF AIR

EACH GUIDE SLOTTED TO ALLOW REMOVAL OF FILLING AT BEAT-UP

LAY MOVES IN SUCH A WAY THAT GUIDES DO NOT FOUL FELL OF CLOTH

GUIDES MAY BE ATTACHED TO LAY AS IN OTHER CASES

RAPIER RUNS IN SLOTS IN THESE GUIDES

GUIDES ATTACHED TO LAY

GUIDES SLOTTED TO ALLOW REMOVAL OF FILLING AT BEAT-UP

LAY TRAJECTORY SUCH AS TO PREVENT GUIDES FOULING THE FELL OF THE CLOTH

Fig. 16.1. Guidance of filling carriers

It is interesting to observe similarities in a variety of systems. The *air-jet loom* sometimes uses guides as indicated in Fig. 16.1(a), the *rigid rapier loom* is controlled by an appropriate linkage, the *flexible rapier loom* uses guides as indicated in Fig. 16.1(b) and the *gripper loom* uses guides as indicated in Fig. 16.1(c); sometimes, the flexible rapier loom also uses guides similar to those mentioned in the latter reference. In each case, the filling insertion system is not connected to the lay and the object is to control the movement of the carrier. Arrangements have to be made to remove any guides protruding through the warp whilst beat-up takes place and the simplest way of doing this is to arrange the trajectory of the lay to be such that the guides leave the warp without fouling the fell of the cloth as the lay moves forward to the beat-up position.

Lay Motion

Having removed the picking mechanism from the lay and thus considerably reduced the oscillating mass, it is possible to think of increasing the operating speed or increasing the *dwell* of the *lay* to give wider fabrics, or both. The operating speed for a given width is controlled by the *speed of insertion* of the filling and the latter cannot be brought beyond a certain level. Thus, there is every incentive to consider the production of wider fabrics. In the past, air- and water-jet looms have been limited in width and the gains have been taken in terms of speed. Modern developments have permitted some of the gains to be taken in terms of width. Developments in wide shuttleless looms have occurred.

Consider a very wide loom with non-mechanical synchronization. It is possible to contemplate a loom in which the arrival of the shuttle at a shuttle box triggers the beat-up motion and the shedding at appropriate intervals and one of these actions triggers the next pick and so on. In such a case, the *shedding diagram* would be elongated and it would be possible to allow the shuttle to travel for extended times to give very wide fabrics. The filling transport system is only directly useful when it is actually transporting filling through the warp shed. In one sense, the times needed to decelerate the system, replenish it and accelerate it back to speed are waste. Thus, one might think of the efficiency of the system being typified by the ratio t_d/t_s (Fig. 16.2). If a large carrier is used (such as a shuttle), the useful transit time is less than when a small carrier (such as a gripper or rapier) is used with the same shedding. In other words, it is possible to get a wider fabric and a greater *transport efficiency* by using a small carrier. Obviously, to get the best advantage out of this characteristic, it is necessary to redesign the lay drive so that the beat-up motion is completed in time t_b. A simple crank system will no longer suffice and it becomes necessary to seek alternatives. One well-established alternative is to use cams which can be designed to give almost any reasonable dwell period required, and the beat-up motion can be confined to a small angular movement of the crankshaft. It is also possible to arrange for the carrier to be projected across a stationary lay which helps with the guidance problem. The timing diagram of a Sulzer loom illustrates these points well (see Fig. 16.3).

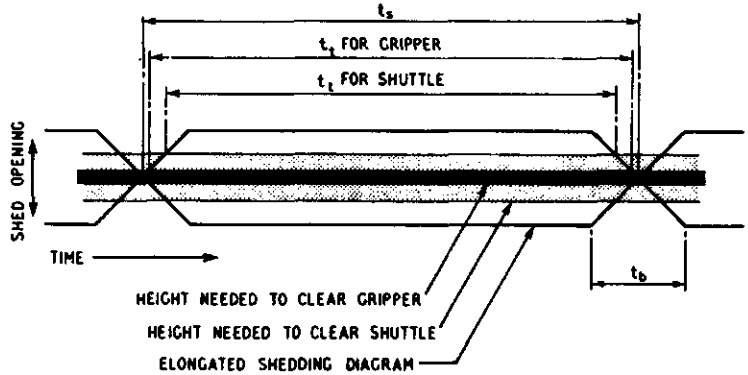


Fig. 16.2. Shedding diagram for a wide loom

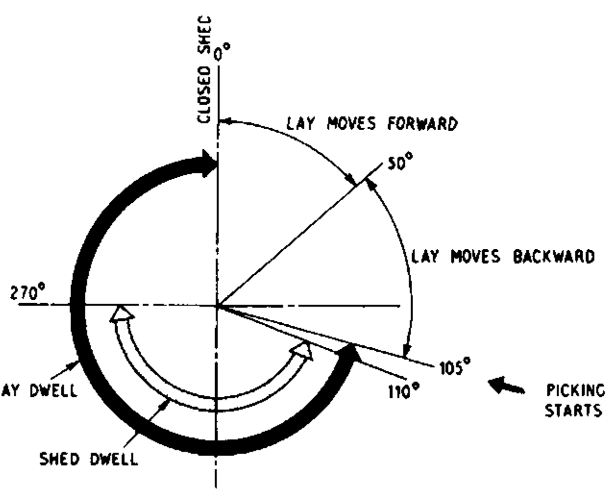
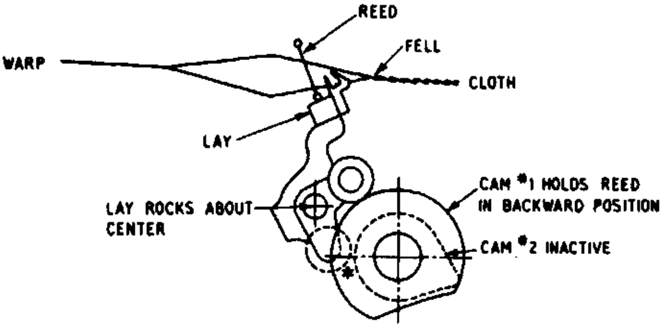
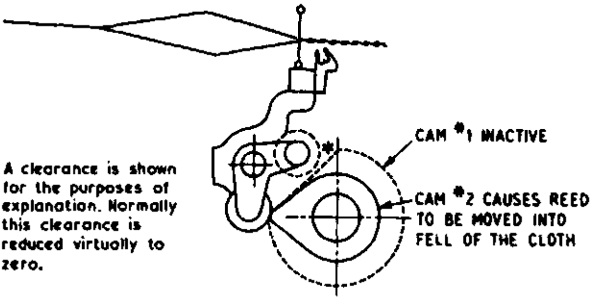


Fig. 16.3 Timing diagram for a 5.5 m (213 inch) Sulzer loom

To minimize forces, the lay motion during the acceleration and deceleration phases should be approximately parabolic in much the same way as is required for picking; also, slight modifications to the cam profiles are needed to reduce shock levels. The similarities between the two cases are so close that further discussion is superfluous for the present purpose. If the lay has an appreciable mass, it would be unwise to allow it to be retarded by the *beating action* itself; normally a *positive* control is needed. One means of doing this is to employ another cam to act to decelerate the lay. A neat way of disposing the opposing cams (conjugate cams) to give the controlled motion required is shown in Fig. 16.4. By dispensing with the shuttle boxes and other impedimenta, the lay mass can be reduced substantially. In one operational design, the *effective lay mass* is less than 30 per cent of an equivalent shuttle loom and consequently the accelerations involved can be increased to compensate without causing mechanical difficulty. The acceleration is a function of the cam design and loom speed; in practice,



SYSTEM IN DWELL



* NB A clearance is shown for the purposes of explanation. Normally this clearance is reduced virtually to zero.

SYSTEM AT BEAT-UP

Fig. 16.4 Lay driven by conjugate cams as in Sulzer looms.

it is possible to take some of the gain in terms of an increase in speed.

If the lay is very light in weight, it is possible to allow the beating action to retard it; this is known as *negative beat-up*. In such a case the beat-up is force controlled rather than position controlled, with the consequence that the pick density might vary from zone to zone in the fabric. This can give difficulties with let-off and take-up mechanisms.

In the case of the cam driven lay, the amplitude and speed of lay movement affect the forces involved. Since the limiting factor is the force involved, the amplitude must be kept as low as possible so as to permit high speeds. Obviously the amplitude has to be large enough to permit a filling insertion device to pass through the shed; it follows, therefore, that the smaller the filling insertion device, the better. Hence by careful design, it is possible to obtain significant gains in speed and width, both of which tend to increase production and reduce cost.

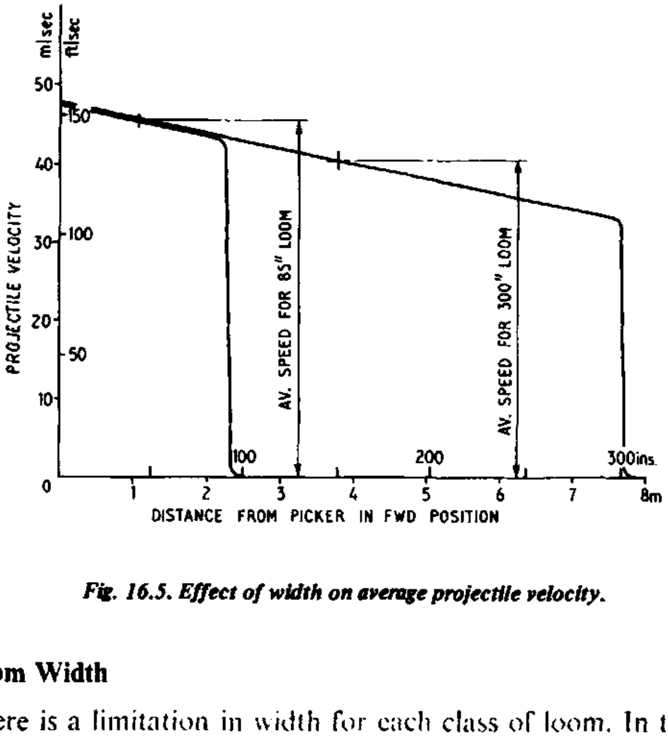


Fig. 16.5. Effect of width on average projectile velocity.

Loom Width

There is a limitation in width for each class of loom. In the case of jet looms, the width is controlled by the jet characteristics. In the case of rapier looms, space and/or rapier characteristics control the width. In all cases end breakage rates limit the widths that can be used in practice.

With projectile or shuttle looms, one controlling factor is the decline in speed of the projectile or shuttle as it passes

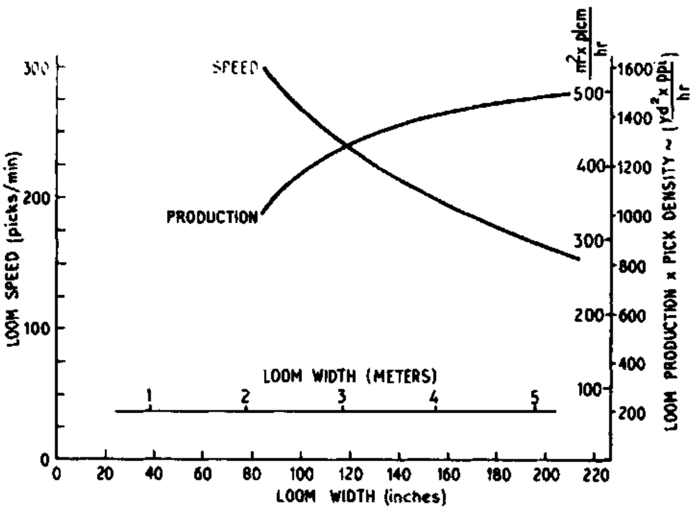


Fig. 16.6. Speed and productivity of a Sulzer loom as a function of width

across the shed. Figure 16.5. shows typical velocity characteristics of a projectile. The accuracy of projecting the shuttle affects this characteristic. If, for example, a projectile were badly projected through a set of guides as shown in Fig. 16.1(c), the projectile would rub heavily against the guide surfaces and would be retarded correspondingly. Hence an accurate picking device is required. Also, even if the picking mechanism is worked to give the maximum initial projectile velocity, the average speed will decline as the loom is made wider and the projectile transit time becomes longer. Thus the loom speed has to be reduced as the width of the loom is increased. The extent of this depends in part upon the design and accuracy of the system. For example, if a single guide is set out of position, it will deflect the projectile and cause an extra retardation which in turn will lower the average speed. This point is illustrated by Fig. 16.6, which shows a graph relating loom speed and width for a Sulzer loom. It is commercially possible to weave some fabrics whose total width exceeds 8 m (300 in); furthermore these fabrics can be woven at speeds higher than with many shuttle looms of a fraction of that width. Figure 16.6 also shows how the productivity of a series of looms increases with width; however, this assumes 100 per cent loom efficiency and, as will be described later, this drops with width if all other factors are kept constant. Nevertheless, the reason for the urge to use ever wider looms can be quite easily seen.

With a rapier loom, the maximum width is set by the rapier characteristics. A very wide loom with a rigid rapier system would require excessive space, and space costs money, but 2 m width models are available. A flexible rapier reduces the need for extra space but it does not eliminate it. The rapier has to be coiled and the diameter of the coils on each side of the loom are extra to the fabric width. Attempts to use more than one wrap on the *coiling drums* have not yet proved to be successful; hence very wide looms normally require rather large diameter coiling drums. Furthermore, the *buckling length* of a rapier depends on the thinness of the blade and upon the unsupported length of blade that has to be accelerated; thus there is a connection between the loom width and the design of the rapier unless intermediate guides are used.

Consider the case of a simple rapier loom without intermediate guides. The *buckling load* of a strut can be stated as $EI\pi^2/\ell^2$ (the so-called Euler equation) and a rapier being accelerated from one end acts as a strut. E is the modulus of elasticity for the material of the blade, I is the second moment of area of the cross section of the rapier blade, and ℓ is the unsupported length of rapier being accelerated. For the purposes of explanation, let the problem be simplified by assuming that the mass of rapier being accelerated does not change as the rapier is extended, and let this mass $= M$.

If the acceleration of the rapier is α, then when

$$M\alpha > \frac{EI\pi^2}{\ell^2} \qquad (16{\cdot}1)$$

the rapier will buckle.

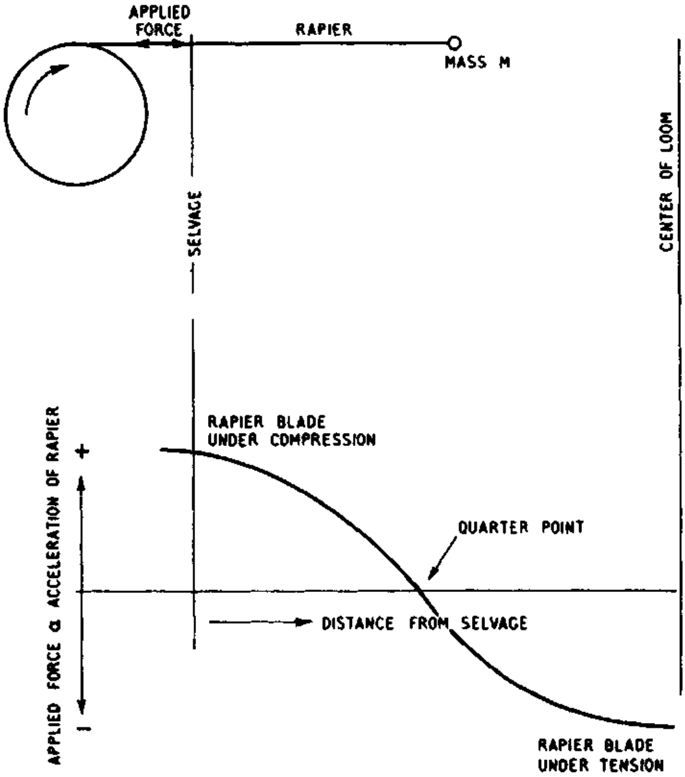


Fig. 16.7. Acceleration characteristic of a rapier

This can be rewritten in the form,

$$\frac{M\alpha}{EI}\left(\frac{\ell}{\pi}\right)^2 > 1 \qquad (16.2)$$

The acceleration characteristic of a normal rapier is similar to that shown in Fig. 16.7, from which it can be seen that as the rapier tip passes the quarter point on its way to the center, the rapier is under tension and will not buckle.

It is during the approach to the quarter position that the rapier is under compression along its length and is likely to buckle. For a given rapier (M/EI) is a constant and therefore $(\alpha\, \ell^2)$ must not exceed some value which is set by the rapier design. This result is based on an approximation, but it still remains true that, for a given rapier operating at a given acceleration, the length has to be limited if buckling is to be avoided; this means that the loom width must be limited, too. Also the acceleration α is proportional to the loom speed; thus, loom width and speed are related.

The above limit only applies if it is assumed that there can be no intermediate guides along the rapier path which can provide lateral support to the rapier blade and prevent buckling at those points. If the guides were packed together to form a continuous tunnel, the rapier would not buckle but it would not then be possible to have a warp capable of shedding. Obviously there has to be a guide spacing that minimises rapier buckling but does not unduly interfere with the warp. The guides have to be somewhat similar to those shown in Fig. 16.1(c) and there has to be sufficient room for the warp, which means that there must be a limit on the number of guides. If the distance apart of the guides is λ, and since $\lambda \ll \ell$, it should become apparent that if the loom with guides as shown in Fig. 16.1(b) can work at speeds in excess of 250 p.p.m. then there should be little trouble with the more elaborate guide system irrespective of width unless it be due to wear of the guides. Thus from a purely mechanical standpoint, it is possible to use rapiers on very wide looms and the ultimate limitations are found elsewhere.

End Breakages

Any wide loom is more prone to warp end breakages and the production lost due to a single end break increases with the width. Hence to make the use of a wide loom economically feasible, the warp and filling breakage rates have to be reduced. The reason for a warp breakage is that the applied force exceeds the strength of the weakest warp end exposed to load. Local weaknesses in the yarn increase the warp breakage rate and it is important, therefore, to have yarn that has a good regularity and which has been slashed properly. This is particularly important with wide looms, and strict *quality control* should be applied to get the best results out of these wide looms. An example may help to illustrate the point. Supposing that serious warp yarn faults occur on average every 2000 meters of yarn and the loom has 1000 ends, then the loom would stop (on average) after weaving only 2 meters.

Looms with a stiff reed (which is often the case with shuttleless looms) and a sharply impulsive beat-up do not allow yarn faults to pass so freely as conventional looms; consequently, efficient clearing of the warp yarn is a necessity. Positioning of the warp can also be more critical; so can the tying-in process.

Another approach is to reduce forces acting on the warp. The majority of these forces are generated during shedding and beating. By reducing the depth of warp shed, the load on the warp can be reduced and the use of a small gripper or rapier permits some relief in this respect; however, these reliefs are offset by the increase in speed with looms of this sort. By having more accurate control of beating, it is possible to reduce the end breakage rate also. This implies that a lightweight, stiff and accurate mechanism should be used. Such precision made components are expensive and this increases the *capital investment* needed; economic considerations have to be weighed very carefully if the new technology is to be used successfully.

The winding of the filling packages in those cases where a storage system is not used can be important. A cone is normally used; the angle and wind are critical and *winding patterns* can increase the end breakage rate to an untenable degree. The breakage rate using a given wind of package varies according to the yarn in use; a smooth yarn tends to allow coil slippage which is a frequent cause of end breakage.

Commercial Considerations

To get a good return on money invested it is necessary to ensure that the machinery installed has a high *productivity* and is kept in operation for as large a percentage of the working time as possible. Thus if the new machinery is more expensive, it must also be more productive and require less *down time* than the machinery it replaces. The new looms should thus work at higher speeds or with wider widths or both, since productivity is measured by the algebraic product (speed × width). Also a more closely controlled technology has to be applied. A further factor is the marketability of the fabrics produced. If the quality is higher than can be produced by the older equipment, then it will either fetch a premium (which increases profits) or will displace poorer products and thus preserve the market (and the jobs that go with it). If the quality is poorer, the reverse will apply; thus care has to be taken in this matter irrespective of productivity.

Yet another factor is the availability of labor. As years pass, labor becomes more expensive and scarce. Fewer people will work in a poor environment and most will seek pleasant and modern working conditions. Many will wish to work at a higher level of skill than today and few will wish to carry out manual labor. The use of sophisticated high-production machinery helps in this respect and makes it possible to recruit labor which otherwise would be unobtainable. The higher cost per man hour has to be offset by the higher productivity so that the cost per unit output of the textile product is kept down to the levels decided by the market. In this respect it is the competition that helps set this price, and the more competitors introduce modern machinery, the more imperative it becomes to follow suit. Thus there is a continuing swing from man to machine, from a *labor intensive* to a *capital intensive system*.

As looms become more expensive, so the cost of keeping them idle rises. *Overheads*, *interest* and other charges still have to be paid on an idle machine and therefore the idle time must be minimized. Even if no interest charges are paid, they should be charged against the machine on the basis that the capital might have been better invested elsewhere. The annual fixed cost contains an appreciable interest component; therefore the cost of *idle time* goes up with the cost of the machine and with the interest rate. The labor cost per unit production goes up with the cost of labor but down as productivity is increased; it goes up with the fault rate. Power and maintenance costs tend to go up with speed but such trends can be offset by good machine design. Hence, to be successful, it is necessary to be able to choose appropriate machinery and then manage it so as to produce the quality of goods required at the minimum cost. This involves technical knowledge and management expertise to keep the looms and other machinery running efficiently over extended periods.