Technological innovations in woven fabric manufacturing process

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The key to the gradual evolution of woven fabric manufacturing process has been traced to the introduction of the gripper shuttle, application of electronics and widespread use of composite materials in the modern looms. The cascading effect on the development of peripheral hardware and software as also on the yarn preparatory systems has been highlighted. Further innovations in some core areas should make the ‘Computer Integrated Manufacture’ a distinct possibility.

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1 Introduction

Innovation broadly covers activities involving the introduction and commercial use of a new method of production and also sale of a new or improved product. Innovation also involves finding new uses for existing products and new markets and distribution channels. While ‘invention’ is the creation of a new idea or concept, ‘innovation’ turns the new concept into commercial success or widespread use. Innovation has, therefore, an economic and social dimension rather than an exclusive technological domain. This article is restricted to technological domain of innovations in the woven fabric manufacturing process commercialised during the past fifty years.

The initiatives for such innovations have invariably sprung from the developed western economies. The rising living standards fuelled by accumulation of wealth and the declining but increasingly demanding population of skilled labour set against the backdrop of rapid strides in technology made during and after the second world war have spurred ambitious ideas to fruition.

2 Innovations in Weaving Looms

2.1 Shuttleless Machine

The innovation which marked a qualitatively new stride in this continuous process was surely the introduction of shuttleless looms. Modifications on shuttle looms had been taking place gradually over a long period of time through the introduction of underpick systems, automatic weft replenishment systems, automatic loom stop motions, positive and semi-positive let-off systems and even cleverly designed continuous take-up systems.

In spite of these improvements in shuttle looms, the maximum weft insertion rate hovered around 400 m/min, the reed width around two meters and the number of machines per operator at around 6 - 8. The deafening noise in a loom shed filled up by a large number of operators, jobbers, beam gaiters, battery fillers and other skilled and unskilled supporting staff continued to be its defining image. Most of the systems on an automatic loom were purely mechanical in nature while a few electromechanical ones employed in warp stop or weft feeding systems constituted novelties.

The introduction of shuttleless looms opened up completely new vistas for the weaver. The shuttle was suddenly gone, taking away the pirn winding department with it. This meant straightaway a reduction in manpower previously engaged in pirn winding, battery filling and pirn cleaning as also those looking after and repairing the large contingent of shuttles, taking away the large inventory of wooden shuttles and pirn tubes along with. The damages to warp, fabric and reed caused by the shuttle were also things of the past, resulting in improved fabric quality and reduced interruption in the production process. Reduced loom stoppages not only meant higher loom efficiency but also higher loom allocation per operator, leading to a further reduction in manpower.

The gripper shuttle loom was the harbinger of this class of looms. The gripper is ten times lighter, six times thinner, five times narrower and four times shorter than the wooden shuttle of a cotton yarn.
weaving automatic loom. This results in a smaller shed depth, shorter sweep of the sley and longer flight path of the gripper. A reduction in shed depth and sweep of sley leads to higher loom rpm while a longer flight path of the gripper permits a wider reed. Effectively, the smaller gripper boosted the weft insertion rate of shuttleless looms and enabled production of really wide fabrics. Consequently, the number of looms required for an unchanged production capacity went down proportionately, leading to further reduction in manpower.

The gripper does not carry a reserve of weft yarn to be inserted in successive sheds; it simply grips yarn from a cone by a clamp located at one of its ends and drags it across the shed. Thus, during its insertion in a shed, the tension in the weft thread can be measured by placing a sensor in the yarn path near the supply cone and therefore controlled by a suitable feedback system. In conjunction with the control that can be exercised on the warp tension, the gripper loom provides the conditions necessary for controlling the yarn crimps in the fabric, a parameter that in effect determines the fabric properties. This unique ability due to the weft insertion system improves the quality of the product considerably.

It is observed from the above that the act of replacing a wooden shuttle with a much smaller and lighter hard steel gripper led to a substantial reduction in manpower and a radical improvement in fabric quality. Such a development was in line with the requirements of the textile industry of the western economy. Hence, in spite of a much higher initial cost of such looms vis-à-vis the automatic shuttle looms, shuttleless looms led by the gripper looms caught the imagination and became the subject of further developments. One can state with a degree of confidence that this one development fuelled the subsequent spate of developments in woven fabric manufacturing process.

Focusing attention solely on the criterion of productivity of a loom, namely the weft insertion rate (WIR), it is observed that a steady but linear rise took place during the first 60 years of the 20th century till the advent of the Sulzer projectile (gripper) loom. Since then the rise has been exponential, although somewhat oddly the growth in the WIR of the projectile system itself has been sluggish over the past 40 odd years. The projectile loom is now a very important type of shuttleless system for the production of an array of technical textiles that demands large width and versatility in terms of converting a wide range of materials into a broad palette of products. Nonetheless, the economics of projectile weaving, which was established during the 60s and 70s, fuelled the development of alternate forms of weft insertion techniques. As a result, the technology of air jet, water jet and rapier weft insertion systems improved by leaps and bound. For example, a modern air-jet loom, which is equipped with tandem nozzle, booster nozzle, relay nozzles, suction nozzle and profile reed, can operate at a WIR value of around 3,000 m/min, almost twice that of the most modern projectile loom. Evidently limits are imposed on the acceleration and deceleration processes by the inertia of the projectile, which has a mass varying between 20 g and 40 g. For the jets however, the deceleration phase does not come into question at all while limitation on the acceleration phase due to inertia of the fluid is also negligible. Similarly, the sley and the healds can be operated without any dwell in the jet looms and therefore the corresponding looms can run faster as the space requirement of the fluid stream within a shed is nominal. For the same reason, the amplitude of sley oscillation is also much lower than that of shuttle or gripper loom. Thus, very serious bottlenecks, that restrict the development of both shuttle and gripper looms, are elegantly overcome by changing over from solid propulsion to the fluid propulsion system. Indeed, a WIR of around 3,000 m/min has been achieved by both forms of jet systems. However, on account of the absence of any equivalent relay jet system, the width of water-jet looms hovers around a maximum of 1.9 m only.

Restriction on the width and WIR is imposed upon the rapier systems by the buckling rigidity of the band, the space occupied by the insertion systems on the two sides of a loom and the inertia of the moving elements. Similarly, the tip transfer from one rapier head to another in the centre of the shed is a unique phenomenon that must be subject to a risk of failure. In spite of such heavy odds, the WIR achieved currently with this system is at par with that of the projectile while the width of 3.6 m with flexible rapier is a testament to the development and application of new composite materials. The rapier happens to be the only positive weft insertion system, implying that the motion of weft throughout its journey can be controlled very precisely. This facility permits insertion of picks of diverse nature during the course of weaving. A typical example of a rapier woven ladies' dress
material exhibits a sequence of picks comprising textured PES of 78 denier, cotton yarn of 102 Ne, lurex of 69 Nm, chenille of 40 Nm and Boucle silk of 3.8 Nm (ref. 2). Insertion of such a wide range of count and material is possible owing to the versatility of the weft insertion system. As a result, this system has created a niche for itself in the apparel and household textiles sector. However, in addition to the versatility inherent in the rapier system, the ability of the modern loom to operate at different speeds and different rates of take-up and let-off while different types of weft are inserted, has contributed significantly to the scope of this system. This ability owes much to the growth of application of electronics in the modern loom.

2.2 Application of Electronics

The transformation of the air-jet loom from low WIR, single nozzle and narrow width machine into the modern version of more than 5 m width and 3,000 m/min WIR has been possible primarily due to the application of electronics. Indeed, the major problem of dragging the tip of weft over a large distance at a speed larger than that of the trailing segments could only be solved by the relay jets. These jets, designed quite differently from the main nozzle, are mounted at specific intervals on the sley. They pierce the bottom shed line and approach very close to the path of the weft thread as the sley rocks to the back centre. As and when the weft tip passes by a relay jet in its journey from the main nozzle to the suction nozzle, a blast of air is sprayed for a given duration of time. Thus, accelerated again, the tip of weft moves ahead and as it crosses the next relay jet, a blast is essayed by this jet. There is an overlap between the blasts of the first and second rely jets. The timing of these blasts from the array of relay jets and their duration are crucial to the smooth passage of the weft. For example, there may be a difference of 600° of a second between the blasts of two neighbouring jets while the duration of a blast may be over 200° of a second. Managing such a system demands a precision and alacrity that can only be associated with microprocessor control. For that matter the precisely controlled braking of weft after its tip has reached the end near the suction nozzle of an air-jet loom or the braking and positioning of the projectile upon its arrival on the receiver side is possible because of microprocessor control.

Microprocessor control in a modern loom is however not restricted to the weft insertion system alone. Over and above, a modern shuttleless loom can be distinguished from the conventional automatic shuttle looms broadly in two respects, namely the transmission of motion and the high level of automation.

The classic prime mover from which power used to flow to various moving elements of the traditional loom has given way to a large number of servomotors. As a result, each unit is free to move in any direction and by any amount independent of the others. For example, in a modern loom the normal sequence of the movement of healds during the weaving process can be reversed during the pick finding process without having to move the sley at all. The let-off or take-up motions can also remain totally idle during this process of repair. This is not possible in a conventional shuttle loom. Moreover, the speed of heald during the reversed motion is kept much lower than its normal speed during the weaving process. All these are a result of replacement of the rigid mechanical links between prime mover and rest of the moving units, as found in the traditional looms, by flexible links between a central processing unit (CPU) and various servomotors responsible for the movement of individual units. These flexible links are the independent signals that are continuously sent to the various servomotors by the CPU. The centralized power of the prime mover is replaced by multiple centers of power which are coupled directly onto the units to be moved. The technical knowledge of the weaver, which is enshrined in the database and the software, gets translated into signals emanating from the CPU which in effect are commands to the various units to function in a manner most appropriate to the type of work being carried out. The location of the backrest that would give the best cover of the fabric, the tension in the warp that would be most appropriate to the material being woven, the angular deflection of the weaver’s beam required at a particular stage of weaving, the proper time-displacement profile of individual heald, etc. and similar other settings and motions are known to the CPU. The continuous command flowing to the multiple centers of power are based on this knowledge. Any update on this knowledge can in principle be incorporated in such a system without needing a substantial change in the hardware. The characteristic feature of this system is therefore the flexible space and supremacy accorded to this knowledge base. It is eminently possible to continuously improve upon solutions and offer better options to the customer without having to carry out major changes in the machine itself.
The other dimension acquired by a modern loom owing to incorporation of electronics, is the quality of automation in domains that could not be taken under purview otherwise. The process of automation in looms was initiated with automatic weft replenishment, automatic stop motions and automatic let-off systems. These systems are in essence open looped in nature and rigid. Once the settings are in place, the operations would be repeated faithfully but without any possibility of variation that may be desirable at different stages of fabric production. Similarly, if the settings have not been exact or suffer some accidental alteration during the production process, no automatic rectification of the same is possible. With electronic controls, it is possible to build closed loop systems which may even be intelligent. As a result, complex operations that require an evaluation about the effect of an exercise undertaken followed by a course correction can be attempted with such systems.

An illustrative example is the automatic repair of broken picks. Considerable amount of damage to the fabric used to result out of the operator’s exercises in locating the shed at which a pick had broken, removing the broken segment from within the shed and then inserting a new pick and restarting the loom without causing a starting mark. This entire exercise is carried out in a modern loom automatically, thanks to the microprocessor control and some ingenuity of the machine manufacturer. The electronic let-off and electronic take-up systems permit a programmable variation in yarn tension and free length of warp during the course of weaving not only for accommodating different weft threads at different phases of the production process but also for varying the fabric structure through different warp and weft crimp distributions. Similarly, during the insertion of extra weft threads the take-up and let-off systems may be brought to a complete halt automatically. Indeed, the surveillance systems associated with such automation permits a fairly high degree of reliability. The quality of automation achieved in modern weaving machines permits one even the fancy of looking ahead to an intelligent loom that can analyse a given fabric sample and weave the fabric when the warp and weft required by it has been supplied.

2.3 Application of Composite Materials

The course of innovations in loom has also been strongly influenced by the developments and application of composite materials. A modern loom running at nearly 1000 rpm would require the healds carrying a large number of warp threads under a fairly high tension to reciprocate at a frequency of nearly 16 Hz. The peak acceleration and deceleration involved in such motions exceed 100G, assuming the very conservative figure of 10 cm heald displacement. The enormous amount of power that would be required to maintain a number of 2.5-3 m wide healds in such a motion as also the dynamic strains that the healds would be subjected to in this process clearly constitute serious hurdles. A part of this problem is negotiated by the positive cam or doby drive to healds as also the lateral guidance given to healds in clearly defined channels, thus eliminating any unnecessary movement. Additionally, the light and strong fibre reinforced composite materials which have replaced the aluminum alloys also play an important role in achieving such high frequencies. For example, carbon fibre reinforced composite materials are very light (density of $1.5 \text{ g/cc}$ as compared to $2.7 \text{ g/cc}$ of aluminum alloy and $7.8 \text{ g/cc}$ of steel) and extremely stiff in tension (tensile strength of 800 MPa as opposed to 193 MPa of Al-alloy and 1100 MPa of steel). Heald frames made of such materials are capable of withstanding the strain while offering less inertia for attainment of the very high frequency. The modern loom is also so well designed that there is minimal vibration so that the no floor anchorage is required.

3 Peripheral Systems

3.1 New Systems of Shedding

A superior design of the shedding systems has also contributed to the attainment of high loom frequency. The picking and checking systems create the bottleneck to a high level of production in shuttle looms. Once these bottlenecks are removed in shuttleless looms, the shedding system becomes the new hurdle. A switch over from the negative shedding tappets to positive matched shedding tappets was the first step towards overcoming this problem. However, the intricate fabric constructions require dobbyes and jacquards. In generating signals from punched tapes or cards and transmitting those over a number of mechanical elements to the hooks of a doby or a jacuard, considerable amount of inertia as also frictional resistance have to be overcome. Moreover, flexible linkages, prevailing as for example between the knives and hooks, give rise necessarily to chattering which is detrimental for high speed. A switch over to electronics permits the signals to be generated right at the point where it is needed. The principle of ener-
gizing a magnet for influencing the position of a hook at a particular point of time has been widely employed in electronic dobies and jacquards. In this way, the entire set-up comprising the signal generating cards/tapes and the transmitting elements fall through. In the latest electronic jacquards, even the requirement of the hooks and oscillating knives has been overcome by employing stepper motors for operating every harness cord. The microcontroller has therefore to send signal to the stepper motors to move by a certain amount in a certain direction at a certain speed or simply not move at all. This also takes care of upward and downward motions of every cord and therefore of the corresponding warp. Jacquards equipped with such facility are claimed to control between 5,000 and over 20,000 threads independently across the entire width of a fabric. These cords are arranged perfectly vertically and can therefore be moved rapidly up and down. A typical example of application of this type of system is a 12,288 machine used in conjunction with an air-jet loom with a reed space of 390 cm running at 650 rpm weaving tablecloths and napkins. This effectively means a 20% increase in speed over traditional jacquards.

Thus, the very complicated and slow mechanical jacquard has finally been reduced to an array of stepper motors only. Such a remarkable transformation is yet to take place in dobies. Here the jacks are linked to healds and therefore have to do considerable amount of work in displacing them. However, very high speed has been achieved with rotary dobies owing to the absence of any reciprocating element; the rotary motion of a central shaft is transmitted to the jacks by a process of electromagnetic coupling. The jack moves in case the coupling is enabled; otherwise it remains stationary. Electronic signal is therefore sent to magnets of the corresponding jacks, a principle also employed by electronic jacquards of the earlier generation. Evidently, the next stage of development makes the dobby as a whole redundant, as signals are sent directly to servomotors that move the healds independently.

3.2 QSC and Automation in Drawing-in

Application of electronics in weaving loom thus resulted in qualitative improvements so far as productivity, product quality and product ranges are concerned. It also enabled a certain improvement in flexibility as the change over from one type of woven construction or woven design to another does not require a great deal of time with a CAD system. However, this facility cannot be fully exploited if the change of warp remains as time consuming as ever. A change of warp involves to begin with the removal of the reed, healds and the set of drop pins along with the partly finished weaver's beam in an orderly manner and keeping the whole set on a suitable stand till it is required again. This has to be followed up by bringing in a new set of weaver's beam along with the drop pins, the healds and the reed. Finally, all these have to be put in place in the loom and linked to their respective driving elements after which the new warp has to be tied up to a piece of fabric gripped by the take-up system in such a manner that weaving may be restarted. The entire process would usually take many hours, depending on the beam width and the number of healds in question. Speeding up the production process of woven fabric demanded a solution for removal of this bottleneck. This issue was addressed by the manufacturers of looms and of accessories, leading to the commercialization of the concept of 'quick style change' (QSC). Under this concept the rear segment of loom is detachable from the rest of the machine. It is this segment that supports the weaver's beam. Once the reed is removed from the sley and the links joining the shedding system to the healds are disconnected, the rest of the system can be moved away from the main body of the loom by a suitable mechanized handling system and replaced by a new one. The two facilities, i.e. the mechanized handling system and the detachable rear segment of loom, permit quick and orderly removal of the existing system and replacement by a new one. Hence, these two facilities are central to the first stage of the operation. The time consuming tying-in of the new warp is taken care of by welding the free edge of the warp sheet, that extends beyond the reed, to a plastic sheet in the drawing-in section itself. Once on the loom, this sheet is simply tucked into the take-up system and the weaving can be started without any delay. The QSC loom as such does not involve any additional electronics although its developmental need was partly fuelled by the flexibility that a modern loom has achieved owing to the large scale application of electronics. Undoubtedly, the rapidly changing style variations dictated by an ever demanding market have also played a major role in this respect.

As a logical sequel to the mechanized replenishment system of the warp on a loom, the entire process of drawing-in of warp threads through drop pins,
heald eyes and dents of a reed has undergone major changes. Here too microcontroller systems have taken over this manual and slow job. It is claimed that the ends from the warp beam are being automatically drawn through drop pins, healds and reed at speeds of up to 140 cycles/min.

4 Multiphase Loom

In spite of considerable advances with shuttleless looms, developmental efforts at overcoming a major conceptual shortcoming of this system have been going on over the past century. This refers to the single-phase nature of these looms because of which the shedding, picking and beat-up motions follow each other sequentially during one complete loom cycle. On the other hand, if all these motions are executed simultaneously and continuously then the potential of the system can be exploited fully. If one considers 80 m/s as the average speed of weft during insertion by a stream of air jet then a continuous insertion process should yield an average weft insertion rate of 4,800 m/min and not a maximum of 3,000 m/min, as recorded by the fastest of air-jet looms. This discrepancy is caused by the intermittent nature of the picking motion in any single phase loom. The multiphase loom is based on the concept of producing different segments of the fabric simultaneously as opposed to single phase loom in which only one pick is added in one loom cycle. As an illustration one might conceive of beating up for the \( \frac{n}{n} \) pick, picking for the \( \frac{(n+1)}{n} \) pick and shedding for the \( \frac{(n+2)}{n} \) pick taking place at any given instant simultaneously. This implies that the yarns from a number of weft feeders are continuously and simultaneously inserted into various sheds created from the same warp sheet. Such sheds may be along or across the warp sheet. The circular loom, which comes closest to this description, exhibits multiple shuttles within a number of sheds along the periphery of the circular warp sheet. However, the central problems associated with shuttles limits the scope of circular looms. The shuttleless weft insertion system requires that all the warp threads of the top and bottom shed lines are maintained at a certain distance while the piece of weft thread is dragged through. Hence, such systems call for multiple sheds along the warp line. Evidently, the concept of one heald/mail eye, moving along a particular vertical plane and thereby controlling the up and down movement of the corresponding warp thread, cannot be employed for keeping the same warp at various heights along its length. Moreover, the shed forming elements should be able to disengage from the warp threads after the pick has been completely inserted so that the same can be beaten up by the reed. Thus, the sheds are continuously formed across the warp sheet and close to the weaver’s beam that keep traveling in a wave form up to the cloth fell. During this journey of the shed, a pick that gets inserted in it has to move across and also along the length of the warp sheet. As one shed reaches the cloth fell the weft insertion in it is also completed. The beating up is the only intermittent operation that follows subsequently.

Hence, central to the commercial acceptance of the multiphase shuttleless looms is a shedding system which has the versatility of a traditional shedding system as also the ability to form multiple sheds along the length of the warp sheet that travel continuously to the cloth fell. The design of the weft insertion system too needs to ensure a continuous insertion of picks in the different sheds and make the picks travel with the sheds to the cloth fell.

The most successful multiphase loom till date is equipped with a weaving rotor for creating the wave of sheds along the warp. A limited range of constructions, aided by specially designed weft positioners, can be commercially produced on such a loom. Four picks inserted continuously at speed varying between 20 m/s and 25 m/s across a warp sheet of up to 32 ends/cm over 190 cm effective width yielding a weft insertion rate of 5,400 m/min (ref. 4), offers considerable advantage over the latest single phase air-jet loom so far as weaving of a fabric like shirting is concerned. However, the limitations of the existing shedding system in terms of inability to handle yarns finer than 40° Ne and to interface with electronic warp selection systems need to be overcome for a realistic transition of the woven fabric formation system into the next generation.

5 Preparatory Process

The advances in the conversion process of a warp sheet and weft threads into a woven fabric, outlined briefly in the foregoing, have had considerable repercussion on the preparatory processes. The warp sheet has become progressively broader, the frequency and the amplitude of dynamic strain on warp yarn have become higher and the tolerance on cleanliness of shed has become narrower. Moreover, as very high quality fabrics can be produced on these looms – meaning thereby a very narrow spread of the critical
variables such as width, areal density, thread spacing and crimp and a very low count on defects such as missing ends, starting marks, reed marks, etc. as also a very high capacity of designing through warp and weft selection systems – the demands made from the downstream processes have been getting more and more exacting. Quantification of appearance, feel and comfort for apparel fabrics or of permeability, modulus and electrical conductivity for technical textiles demands that woven fabrics be engineered and produced to specifications. The performance of the product would obviously be better when the tolerance is narrower. The consequential demand pull on the quality of the warp and weft fed to the loom has resulted in some remarkable innovations in the preparatory systems.

5.1 Modern Cone Winder

The most notable effect has been on the transformation of the cone winding machine. The quality of package produced on such a machine can be specified in terms of weight, conicity, height, diameters at the nose and base, hardness and length of yarn. It can also be used to specify the level of acceptable objectionable faults in the yarn or in that of the package geometry and build. The incorporation of electronic clearer with ability to detect foreign matters backed up by a suitable splicer in all modern winding machines enables cleaning and joining of yarn to be carried out with a very high degree of precision. However, innovative attempts at winding the cleaned yarn onto a shell at a constant tension through the package build have resulted in features that would have been impossible but for the wide application of electronics.

Each winding drum on a modern machine is driven directly by a servomotor whose direction and speed of rotation at any instant of time are commanded by a central system based on the inputs that it receives continuously from various elements within a spindle unit. Thus, a thread break would cause the motor to stop at once, avoiding in the process unnecessary abrasion between the surface of the package and the drum. Consequently, the package drum contact is not broken so that when the splicer comes into operation, the drum rotates slowly in a direction opposite to that of its normal mode, thus permitting the free end of the yarn to be located on the package surface, sucked-in and pulled out by the respective arm of the splicer. After the splicing is accomplished, the drum accelerates slowly till the proper winding speed is reached. Similarly, the rpm of the drum changes continuously as a function of the yarn unwinding point on the supply package. This is meant to cancel out the unwinding tension fluctuation caused by the ballooning effect. All of these speed variations of one drum are independent of those of other winding drums on the same machine.

The tensioner is driven by a miniature servomotor so that the tension it adds to the yarn can be varied continuously in order that the final tension in yarn near the yarn trap is maintained within specified limits. The location of the balloon breaker is also continuously shifted so that as the unwinding point on the supply bobbin gradually shifts towards its base, the average balloon height remains constant. This measure results in minimizing the long term tension fluctuation in the yarn being unwound.

The cradle itself is controlled by servo systems so that the conicity of the package and its hardness are maintained within well defined boundaries. In fact, the cradle setting can even be changed in a pre-programmed manner without interrupting the winding process so that the effective point of contact between the conical package and the cylindrical drum can be shifted away from the package base towards its nose and brought back conveniently to the original point over a certain period of time. Such a measure is adopted to alter the package rpm at diameters conducive to the formation of ribbons. Provision of yarn length and package diameter measuring units in conjunction with cradle pressure regulating system on the modern winding machine results in packages of very precise dimensions.

The development of step precision winding systems must count among one of the major innovations in cone winding. It is well known that in precision winding systems, embodied by the spindle driven winders, the coils can be laid very accurately on package surface on account of the number of coils per traverse remaining constant throughout the package build. This facilitates the winding of very dense and ribbon-free packages. However, a constant change in coil angle occurs during this process that tends to destabilize the package and alter the package density. The attributes of a random winder, embodied by the grooved drum winding machine, are however exactly the opposite. The coil angle remains constant throughout the package build but ribbon formation is a serious issue. A periodic disturbance to the effective package rpm is the accepted solution which however
affects the production. The hybrid step precision winder combines the positive attributes of the two by reducing the yarn traverse speed, without disturbing the drum rpm, in a programmed manner over specific intervals of package diameter in such a manner that the number of coils per traverse remains constant during these intervals. Hence, over these intervals of diameter the build of the package resembles that of a precision wound one. At the transition points between two successive intervals, the traverse speed is reversed to the original value. These transition points occur at specific package diameters which are equi-distant from those at which ribbon formation is most severe. Subsequent to the resetting of yarn traverse to its original value, it is reduced again in a programmed manner for keeping the coils per traverse during this diameter interval constant. However, this interval corresponds to a diameter value which is higher than that of the previous one. Therefore, the value of coils per traverse in this interval is lower than in the earlier one. Thus, there is an overall hyperbolic decrease in coils per traverse during the entire package build that takes place discontinuously in many finite steps, avoiding those values at which ribboning may occur. Hence, no measure of anti-ribboning is necessary while fairly large, stable and dense packages can be produced on such a system.

In spite of rapid strides made, the grooved drum cone winding machine suffers a major flaw because of the grooved drum itself. A large short term tension fluctuation is imposed on the yarn due to the forced variation in yarn path length and geometry between the yarn trap and the instantaneous winding-on point of the package. Moreover, the abrasion between certain portions of the inside surface of the groove and the yarn is detrimental to the surface of the yarn. Thus, a part of the good work done by the advanced features of the modern winding machine is to some extent undone by this final element. A major development in this particular aspect can be expected in the near future.

5.2 Modernization in Sizing

The sizing process plays a central role in the overall performance of a loom shed. Sizing is an energy intensive process and it is also a polluting one, especially so because of desizing. Innovations in this process have therefore been plenty and many new methods of sizing are still being tried out. The transition from the double cylinder to the multi-cylinder and then to split drying systems has resulted in an improvement not only in productivity but also in the quality of protection provided by the size film to the yarn. Similarly, a wetting of the warp sheet prior to its entry into the saw box, application of multiple saw boxes and multiple immersions within the same saw box are practices aimed at regulating the wet pick-up for various types of warp sheet without sacrificing the machine speed. The wide spread acceptance of high pressure squeezing in conjunction with modified sizing ingredients, which can be made into high concentration but low viscosity emulsions, is aimed at an optimum anchorage of the size film in the body of yarn while lowering the energy consumption considerably. Drying by hot air and infrared ray has been tried out to replace the steam heated cylinder drying process, especially where contact drying is detrimental for the yarn. However low efficiency at the desired machine speed and operational difficulties have limited their application. As the application medium of conventional sizing material is water, which is becoming scarce, and as the same has to be evaporated costing energy which is expensive, the conceptually different techniques such as hot melt sizing, solvent sizing or cold sizing have been explored with limited success. The sizing ingredient for the hot melt process should flow very easily in the molten state and solidify very quickly after a kiss roll has applied a layer of the same to the yarn. It also should have reasonably good adhesion to the yarn as no additional anchorage in the yarn body can be generated. The solvent sizing has many practical limitations, most important being the recovery of the carcinogenic solvent itself. Cold sizing process bypasses the need of size cooking and the size application is also in cold state, and hence some energy is saved but still requires that the aqueous medium be evaporated. In all these cases, the polluting desizing process poses a major challenge. Evidently, there is scope for innovation of a sizing process that would be low on demand for water and energy and pose minimal threat to the environment.

6 Woven Fabric Engineering

The properties of woven fabrics are influenced by the weave. Hence, by varying the woven construction it should be possible to achieve wide range of properties. However, the actual number of commercially produced woven constructions is very limited although a much larger number can be generated on any weave repeat unit. A method for determining the number of different woven constructions possible on a
certain weave repeat unit, worked out in course of a study, reveals that on keeping the number of ends in the repeat constant, the number of regular woven constructions \( (Y) \) increases exponentially with the increase in number of picks \( (X) \) (ref. 5). Accordingly, 
\[
Y = A \cdot e^{BX},
\]
where \( A \) and \( B \) are the constants.

It is also found that the rate of exponential rise in number of constructions gets higher with the rise in number of ends in the repeat. Thus, a regular weave repeating on 4 ends and 8 picks can yield 1000 constructions while increasing the number of picks to 12 would result in 8,000 constructions. The corresponding values with 7 ends per repeat would be 2,000 and 18,000 respectively. Apparently, a very large number of possible woven constructions are never tried out in practice. However, when a woven fabric has to be designed for performance it becomes necessary to work out the relevant construction. In this respect, the concept of weave factor\(^6\) was found to be very useful as it relates very well with variables that affect fabric properties. For example, it was found that with the rise in weave factor, fabric strength falls in the two principal directions while the air permeability goes up. Such an approach can be expected to permit development of an integrated CAD system for woven constructions where one of the inputs can be the desired performance of the fabric.

7 Conclusions

Innovation of the gripper shuttle can be viewed as the prime mover for the entire gamut of advances registered in the modern woven fabric manufacturing processes. Progress in material science and electronics propelled the weft insertion system further from the domain of solid to that of the fluid. The large scale application of electronics also affected the manner of transmission of power in a loom and the quality of automation. The flexible space and supremacy accorded to knowledge base has become a characteristic feature of these modern systems. The rigid mechanical links between the prime mover and rest of the moving units, as found in the traditional looms, got replaced by flexible links between a central processing unit (CPU) and various servomotors responsible for movement of individual units. The automatic repair of broken picks illustrates automation bordering on an intelligent system. A superior design of the shedding systems based on electronics not only contributed to the attainment of very high loom frequency but also to a highly elaborate warp selection. As a result, the modern loom acquired such a high potential that fundamental modifications for quick style change both in the loom design and in the back processes of drawing-in and warp replenishment became necessary. A CIM based weaving system is today a distinct possibility, not only for centralized on-line monitoring but also for product engineering. As designing woven fabrics for performance requires conformation to specified tolerance limits in the quality of input materials, a series of demand-driven developments in the preparatory process has also taken place during the past two decades. The modern cone winding machine, although by no means as complex as a weaving loom, exhibits qualitatively similar flexibility and automation typically illustrated by the computer-aided anti-patterning system. The sizing process has yet to attain a similar level of elegance although the transition to a system that is less demanding on water and energy as also less polluting is clearly evident. Although a considerable amount of progress has been achieved through innovations in the design of looms, accessories and preparatory systems, the exercise aimed at a transition from single-phase to multiphase weaving systems has yet to yield a commercially versatile solution. This transition must await a conceptually new shedding system.

References