Development of hybrid type warp let-off systems for weaving and warp knitting

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The developments in warp let-off motions have been reviewed in brief and the main causes of warp tension variations in weaving and warp knitting have been examined. Further, the development of a hybrid type warp let-off system to be used on both warp knitting and weaving machines has been described with regard to its design and performance and some recent research with on-line computer-controlled warp let-off and fabric take-up in weaving is reported.

Keywords: Warp knitting, Warp let-off system, Warp tension, Weaving

1 Introduction

Although warp knitting and weaving differ greatly with regard to the process and the product, they have important features in common such as the withdrawal of the fabric from the processing zone by means of a roller and the warp feed from one or more beams. In both the processes, this feed is controlled by means of a let-off motion which has the dual function of feeding the warp to the loom at the rate corresponding to the production speed and of keeping the warp tension constant. Considerable improvements have been made in the uniformity of warp tension on warp-knitting machines and more recently, the possibility of applying similar principles to the warp let-off in weaving has been examined.

This paper reviews in brief the developments in warp let-off motions and examines the main causes of warp tension variations in the two processes. Further, the improved let-off motion for warp knitting is described with regard to its design and performance, and some recent research with on-line computer-controlled warp let-off and fabric take-up in weaving is reported.

2 Let-off Motions for Weaving Machines

Weaving is a much older process than warp knitting and the development of let-off motions began in the days of the handloom as soon as the weaving became a continuous process. The changeover from weaving with a short stationary warp to weaving with a long warp from a beam was by no means clear cut. On the early handlooms using warp beams, the weaving process was intermittent in the sense that both the fabric take-up roller and the warp beam remained in a fixed position while weaving was in progress and it was only after some 10 to 15 cm of fabric had been woven that the warp beam was unlocked and sufficient warp unwound to provide for the next fabric increment. This resulted in a complete slackening of the warp and the fabric and the tension was then restored to the desired value by rotating the take-up roller forward. Thus, the warp tension was controlled by the take-up rather than the let-off motion. This is of interest because in modern loom and warp-knitting machine design it has become axiomatic that the warp tension is controlled by the let-off motion. It is also of interest that the early looms did not use the warp tension itself to rotate the warp beam; the rotation was carried out by the weaver.

The next main development was the early (non-automatic) powerloom where the warp itself was rotating the warp beam and where the warp tension was controlled by means of the braking torque applied to the warp beam. This development had a profound effect on weavers' attitude to the let-off motion. Whereas for the handloom weaver, the length of warp he had to unwind from the beam was an important parameter under his direct control, the powerloom weaver almost completely lost sight of the let-off motion as a means of controlling the length of warp per pick.
For him, the control of warp tension became virtually the only function of the let-off motion and one of his main tasks was to keep the warp tension constant by reducing the braking torque (usually by adjusting weights) as the warp beam diameter diminished. This attitude to the let-off motion of weaving machines still persists and is reflected in the next stage of development in the more recent past, i.e. the introduction of semi-positive let-off motions where the rate of warp let-off is controlled by a tension-sensing device (usually the back rest). With the modern semi-positive let-off motions came a return to the principle of not using the warp tension itself to rotate the beam. Whereas in the days of the handloom, this principle took the form of the weaver rotating the beam; on modern looms, this is done by the loom drive.

In spite of many differences between the old fully negative and the present semi-positive let-off motions, the modern weaving technician sees the let-off motion entirely as a means of keeping the warp tension constant. He neither knows nor cares whether the rate of warp feed is constant or not. In relation to the practical short-term perspective, this attitude is quite acceptable but when one considers future developments, it is a serious omission to lose sight of the fact that warp tension control is not the only principle which can form the basis for the design of let-off motions and that the use of the let-off motion as a means of directly controlling the warp supply, i.e. a fully positive let-off motion is a possible alternative.

3 Differences in Industrial Usage

Warp knitting is a much more recent development than weaving and it was closely associated with the growth of man-made fibres, particularly in the form of textured continuous filament yarns. Although theoretically, the options with regard to the design of let-off motions are the same for warp knitting and weaving, the designs used in commercial practice differ considerably from each other. These differences can be summarized as follows:

- While in weaving (at least in the advanced industrial countries) the use of the fully negative let-off motion, which uses the warp tension as a means of rotating the warp beam against a braking torque, has virtually disappeared, this type of let-off motion is still extensively employed on Raschel warp-knitting machines.
- In weaving, the above type of let-off motion was almost invariably associated with a manual adjustment of the braking torque as the beam diameter diminished. In warp knitting, it became (and still is) linked to a tension-sensing device in the form of a bar which releases the brake when required so that the tension is maintained roughly at the desired level.

- The semi-positive type of let-off motion which is now almost universally used in weaving and which produces a constant warp tension is not used at all in warp-knitting.
- The most common form of let-off motion in modern warp-knitting machines is the positive one which provides a constant warp delivery speed based on some kind of feedback which adjusts the angular velocity of the beam to compensate for the diminishing beam diameter. This type of let-off motion is virtually unknown in weaving.

The above differences between the let-off motions used in weaving and warp knitting respectively can largely be explained in terms of the differences in the structure of woven and knitted fabrics. In woven fabrics, the length of warp required to weave a given length of fabric is not vastly different from the length of fabric itself except in certain special cases such as the pile wars in towelling, velvets or carpets. In warp-knitted fabrics, the length of warp can be 10-20 times the length of the fabric and, therefore, the rate of warp let-off is also very much higher than in weaving and plays a crucial part in the loop formation. This probably explains the widespread use of fully positive let-off motions in warp knitting and their virtual absence in weaving. Also, the warp tension in warp knitting is usually much lower than that in weaving.

4 Problems with Let-off Motions for Warp-knitting Machines

The advantage of the negative system is that the parameter which affects the fabric structure, i.e. the tension, is directly controlled. It is also very easy to set up the machine for an unknown structure because the tension adjustment ensures that the yarn delivery rate is automatically adjusted to produce that tension. Despite these advantages, the negative systems are less widely used than the positive ones because the tension control with existing commercial systems is very crude. The tension control is based on brakes which hold the beam against the warp tension. Compensation for the diminishing beam diameter is usually provided by the use of a bar which presses against the warp and which eases the braking torque when the warp tension is too high. This design does not
reliably ensure that the fabric weight per unit area remains constant over the long lengths of warp.

Positive systems are widely used because of the advantage of predetermined yarn delivery. However, the required run-in of any unknown new structure can only be estimated approximately and the trial and error required to establish the correct run-in is laborious and can damage the yarn and the machine. The basic mechanism provides a constant yarn delivery and to compensate for the diminishing beam diameter a sensing roller resting on the beam surface senses either the beam diameter or the delivery speed and activates a feedback control system which ensures that the rotational speed of the beam remains constant over the long lengths of warp.

In commercial practice, the solution to this problem is sought by using a drive to the warp beam which is controlled by a device using a predictive formula which is intended to ensure that, as the beam diminishes, the rotational speed of the beam is adjusted so as to maintain a constant unwinding speed of the warp. The parameters required for this formula are recorded during warping and include the diameters of the full and empty beam and the number of rotations of the beam from the beginning to the end of the warp. The formula is based on the assumption that the density of the warp is the same in all parts of the beam irrespective of the distance from the mandrel. The true position, however, is that the bulk density of the yarn assembly is dependent on that distance and, in practice, this means that the actual run-in has to be checked and adjusted from time to time during the life of one warp.

5 Development of the Hybrid Mechanism

In view of these various problems encountered with both the negative and positive let-off motions, a mechanism has been developed which combines the advantages of both. With this mechanism, the beam is driven directly by a D.C. motor and positive as well as negative schemes for controlling the rotational speed of the beam are possible. As was pointed out above, starting up the machine is easier with the negative system and, therefore, it will be advantageous to use the hybrid system in the negative mode when a new warp is started, particularly when the fabric structure has not been knitted before. In the negative mode, the feedback control is derived from a tension transducer which monitors the warp tension and provides the information needed to adjust the rate of warp let-off so as to keep the tension constant at the intended level. This makes it possible to vary the tension until the cloth structure conforms to specification. When this has been the case for a sufficiently long operating time, the mechanism can be switched to the positive mode where the beam diameter is controlled by a sensor and feedback system which keeps the run-in rather than the warp tension constant.

With some fabrics, the warp tension level is very critical and for these a combined positive and negative mode can be maintained throughout a production run. Basically, the let-off motion operates in the negative mode but the amount of yarn which has been consumed is monitored in regular intervals and if it does not conform to specification, a slight adjustment of the target tension is made.

6 Short-term Warp Tension Variations in the Two Processes

The main cause of long-term warp tension variations is the gradual reduction in the beam diameter as the warp is consumed. The various ways of overcoming this problem have been discussed above in broad outline. In addition, both processes lead to short-term tension variations, i.e. the variations within one machine cycle. The main components of the let-off motion and, in particular, the warp beam have too much inertia to compensate rapid tension fluctuations and, therefore, if short-term fluctuations are to be eliminated, this has to be done by some additional components which, although not part of the main let-off motion, are still part of the let-off system as a whole. With regard to short-term cyclic tension variations, warp-knitting and weaving have important feature in common but there are also important differences. The main common feature is that during each machine cycle there is a temporary demand for warp yarn, far in excess of the requirements of the fabric. In warp knitting, this is due to the need to form a loop which is much larger than the ultimate loop in the fabric because it has to allow for the passage of the needle. In weaving, a similar situation exists with regard to the shed formation. Warp threads situated above and below the weft have to be parted to a far greater extent than is necessitated by the fabric
structure because of need for weft insertion. With the changeover from shuttle to shuttleless weaving, the shed size has become much smaller but even with air or water jet looms, the warp shed still needs to be large compared with space required by the weft thread itself. Thus, both loop formation in knitting and shedding in weaving give rise to a temporary excess demand for yarn and insofar as this is not met fully or fast enough, it gives rise to a tension peak.

In weaving, there is usually no special provision to eliminate the tension peak due to shedding but in modern loom design, the free length of warp, i.e. the distance from the front to the back of the loom, is generally much larger than in the older type of loom and this tends to alleviate the problem. Also, the elimination of the tension peak due to shedding is not necessarily a desirable objective because differences in shedding tension between the top and bottom warp sheet (an unsymmetrical shed) often have the beneficial effect of overcoming reediness in the fabric and of allowing a greater weft density to be achieved than with a symmetrical shed.

In weaving, the warp tension cycle contains a second peak, the beat-up peak, whose magnitude depends primarily on the fabric structure and only to a much lesser extent on the nature of the weaving operation or machine design. The higher the cover factor of the structure, the greater is the beat-up peak. The existence of the beat-up peak is a characteristic of weaving but not of warp knitting because only weaving requires a beat-up, i.e. the application of considerable force to place every new weft thread at the right distance from its predecessor. This force needs to be balanced by an excess of warp tension over fabric tension, i.e. by a sharp rise in warp tension accompanied by a simultaneous sudden fall in fabric tension which, when becomes excessive, creates a characteristic noise known as "bumping". Thus, the warp tension cycle in weaving includes two tension peaks, i.e. the shedding peak whose elimination is possible but not necessarily desirable and the beat-up peak which is fundamental to the process and which cannot be eliminated.

In warp knitting, however, there is only one major tension peak, the one due to loop formation, and the effect of this tension peak is entirely negative, leading to yarn abrasion and breaks. Therefore, it is a common practice for warp knitting machines to be fitted with a storage device which can hold the extra amount of yarn when it is not required and release it when necessary. The magnitude of the extra demand for yarn during loop formation was measured and a typical curve is shown in Fig. 1. The storage device which is commonly used is a flutter bar as shown in Fig. 2. This bar is pressed against the warp by leaf springs and the warp tension created by the loop formation pulls the bar down, thus meeting the extra demand for yarn. The problem with such a device is that it can reduce the warp tension peak caused by loop formation only to a very limited extent as can be deduced from Fig. 2. As the yarn pulls the bar down, the resistance of the leaf springs increases and the component of the yarn tension which opposes this resistance diminishes. Both these effects lead to a substantial increase in warp tension. This was confirmed by measurements and a typical tension trace is shown in Fig. 3. This trace consists of two elements: the
base tension and the cyclic fluctuations. The flutter bar design shown in Fig. 2 has drawbacks also with regard to the former because different knitted structures require different base tensions and this has to be catered for either by changing the leaf springs or their adjustment. To overcome these problems, an alternative design was investigated as described below.

7 An Improved Flutter Bar Arrangement

The cyclic tension variations can be compensated by a positive or a negative device. With both systems, the required yarn release during loop formation and its storage during the rest of the machine cycle is achieved by means of an oscillating bar like the one shown in Fig. 2. In the negative system, the oscillation is caused by the tension whereas in the positive system it is derived from the loom drive. In order to operate a positive system satisfactorily, it is necessary to know the amount of yarn that needs to be released during loop formation and that amount varies from fabric to fabric as does the required base tension. Thus, a considerable amount of preliminary experimentation is required when a fabric structure is changed. The problem could be overcome by monitoring the tension and adjusting the amplitude of the oscillation by means of a feedback system. However, at current machine speeds, which are in the region of 1000 courses/min, such a device would have to have an extremely short response time and would, therefore, be prohibitively expensive.

Thus, for a compensating system which can be used for any machine and any fabric structure, a negative device is preferable. As was explained above, the main shortcoming of conventional flutter bars is the use of leaf springs where the load increases sharply with the deformation of the springs. Two systems were, therefore, investigated where the load is only very slightly affected by deformation. The two systems were a constant-load coiled spring and a rubber tube filled with compressed air. Both these devices led to a virtual elimination of the cyclic tension fluctuation but the air pressure system was preferred because it is simple and the tension can easily be adjusted by varying the air pressure.

The main elements of the tension compensation system which was developed are shown in Fig. 4. The connecting arm B is hinged on bracket A which, in the conventional system, normally carries the leaf springs. The other end of arm B carries a small nylon bush C to hold the flutter bar D. A shoe E is attached to the arm and rests on the rubber tube F which extends across the width of the machine and is filled with compressed air. The tube is protected by a casing (not shown) in such a way that only the part which is in contact with the shoe is exposed.

The compressed air presses against the shoe and thereby causes the arm B to raise the flutter bar, thus imparting tension to the yarn. When the bar is pulled down by higher yarn demand during loop formation, the pressure of the shoe against the rubber tube causes a comparatively large deformation of the tube with very little change in volume and hence in air pressure as can be seen in Fig. 5. The compensating system was fitted to a machine where the warp was supplied by the hybrid let-off motion described above.

Fig. 6 shows the tension traces obtained with the conventional and with the newly developed system and it shows that the new system reduced the cyclic tension variations from approx. 8.0cN per thread to approx. 2.5cN. This reduction in the peak tension is beneficial not only from the point of view of yarn breaks but also with regard to machine productivity because the high peak ten-
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Fig. 5—Deformation of the rubber tube due to warp tension

Fig. 6—Comparison between new and spring tensioning systems

Positive Let-off in Weaving—Some Recent Experiments

In view of the improvements achieved in knitting, an attempt was made to apply similar principles to the weaving process. Experiments were carried out on a Bonas Weavematic Mark VII narrow fabric needle loom. Before it was modified, the loom had a negative let-off and a continuous positive take-up system where warp tension was adjusted by changing weights. Weft density was adjusted by means of spur gears and the synchronisation of the various loom motions was effected by mechanical couplings. The loom was designed to weave two fabrics—one above the other—but in the experiments, only one fabric was woven at any particular time. Before the loom was modified, some preliminary investigations were carried out with a view to obtaining the design data required for the new systems.

In all the experiments on the modified machine, the same new mechanisms were used but with regard to the control system, two different approaches were investigated. The first approach was to use a fully positive system and the take-up and let-off systems were redesigned for this system. When the investigations revealed certain shortcomings of the fully positive system, it was decided to introduce feedback controls based on monitoring the beat-up force and the warp tension.

8.1 Preliminary Experiments

The purpose of these experiments was to obtain the design data for a fully positive let-off motion and, in particular, the quantitative relation between the rate of let-off and warp tension.

At first sight, a weaving system with fully positive take-up and let-off is similar to a drafting system on a yarn processing machine. In weaving, however, the situation is complicated by the presence of warp crimp, which, in turn, is dependent on warp tension.

If, for instance, the surface speed of the take-up roller is 100 mm/min and the warp crimp is 5%, the effective rate of warp take-up is 105 mm/min. This means that a rate of let-off, say 103 mm/min, represents an underfeed (or draft) of approx. 2% although, when compared with the surface speed of the take-up roller, it would appear to be an overfeed of 3%. The effect of such a draft is to generate a warp tension but the actual tension level depends on the elastic modulus of the warp. The effect of a change in draft, however, depends not merely on the modulus but also on the effect of tension on crimp.

Because of these complications, the experimental studies on the unmodified loom were accompanied by a theoretical analysis. This analysis is
beyond the scope of this paper but the gist of it was to show how the crimp effect tends to minimize the variations in warp tension which result from irregularities in the rate of let-off.

8.2 Modification of the Loom

The modification of the loom involved changes in the fabric take-up and warp let-off motions. With both these mechanisms, the original mechanical linkage to the main loom drive was eliminated and replaced by a direct DC motor drive.

Since the original loom design included a positive take-up and a negative let-off system, the changes that had to be made were far greater with regard to the let-off than with regard to the take-up motion. The latter consisted of a set of continuously moving nip rollers and these were retained in the new design. The DC motor was driving these rollers via two gear boxes with gear ratios of approx. 1:10 and 1:20 respectively and the desired weft density was obtained by changing the motor speed while keeping the picking rate constant.

In designing the modified let-off motion, it was decided to use essentially the same principle as was already in place on the take-up. This involved the introduction of a feed roller system as shown in Fig. 7. In this system, the warp was positively gripped by a set of five rollers whose rotational speed determined the rate of delivery so that no adjustment of their speed was necessary as the beam diameter diminished. The braking of the warp beam was achieved by means of a simple rope and weight arrangement where the braking torque was only just large enough to prevent any overrunning of the beam so that the warp tension between the beam and the feed rollers was negligibly small compared with the tension generated by the delivery rollers.

Fig. 8 shows the let-off drive system and the transmission of the motion to the delivery rollers. The motion was transmitted from the DC motor to the roller G11 through gear boxes Gb1 and Gb2 with an overall gear ratio of 200. Such a high gear ratio was preferred because it provided a locking effect and prevented any reverse motion caused by the warp tension. The motion of roller G11 was transmitted to roller G14 by a timing belt and the other three rollers were driven by frictional contact with the two positively driven rollers. The position of the whole feed roller unit was adjustable both in the vertical and horizontal directions so as to allow variations in the symmetry of the warp shed and of the free length of warp, both of which are parameters which have to meet the requirements of the warp and of the fabric.

8.3 Computer Control of the Weaving Parameters

In addition to the loom modifications described above, a computer was linked to the various loom motions for the purpose of:

- Recording and analyzing performance data,
- Replacing manual adjustments of loom settings by keyboard operation, and
- Introducing feedback control to rectify deviations of loom settings from their target values.

To achieve these objectives, it was necessary for the computer to measure on-line the following parameters:

- The absolute position of the main shaft,
- The take-up and let-off speeds and positions,
- The warp tension, and
- The beat-up force.

In the fully positive system, the latter two parameters were measured to check the loom performance. In the later stages of the work, they were used within feedback loop systems designed to keep warp tension and beat-up force constant.
The absolute angular position of the main shaft (i.e., the time base) was measured from the output of an incremental shaft encoder. Similarly, separate shaft encoders provided the information about the position and rotational speed of the take-up and let-off rollers.

The warp tension was measured by means of a commercial capacitative single-end tensiometer with a range of up to 100 cN. At first, attempts were made to use an instrument which measures the tension of a large number of warp ends simultaneously but it emerged that single-end measurement was a much more practical procedure.

For measuring the beat-up force, the original reed was replaced by a more flexible one which was mounted on the sley by three bolts and had no upper support as shown in Fig. 9. During beat-up, the reed is deflected not only by the beat-up force but also by its own inertia. Therefore, two sensors were used. One of these measured the combined effect of beat-up and inertia while the other measured only the inertia effect. From these two measurements, the deflection due to beat-up was found and used (after calibration) to indicate the magnitude of the beat-up force.

### 8.4 Operating Principle

The take-up and let-off motors were controlled in such a way that their absolute speed could be varied while keeping their speed ratio (and hence the warp tension) constant. Such variations in the absolute speed were used either to cater for variations in loom speed or (at constant loom speed) for varying the pick spacing. The speed ratio itself could be varied too as required to adjust the warp tension. The whole arrangement was linked to the computer so that changes in the various loom parameters could be carried out by the use of the computer keyboard rather than by any direct mechanical adjustment on the loom. This system allowed the loom to be programmed for variable pick spacing, thus introducing a patterning potential which is not normally available on looms. Another important feature was that both motors could be driven forward and backward, allowing for adjustments of the cloth fell position whenever required while keeping the warp tension constant. The basic arrangement is shown in Fig. 10, while the computer control scheme is illustrated in Fig. 11.

In the fully positive system, the loom was started up with the desired loom speed and with the take-up speed dictated by the desired pick spacing. The let-off speed was chosen on the basis of some approximate estimate derived from the warp modulus and the anticipated warp crimp. As weaving progressed, the warp tension was monitored and the let-off speed was adjusted so as to produce a warp tension level which was considered appropriate for the particular yarn and fabric. After these initial adjustments, all the speeds were kept constant and the measurements of warp tension and beat-up force merely served to monitor the loom performance.

When the feedback system was used, the warp tension signal was fed back to the let-off drive. When the tension was too high, the let-off speed was increased and vice versa. The beat-up force signal was used to move the cloth fell towards the front of the loom if the beat-up force was too high or vice versa. This
movement of the cloth fell was achieved by changing the absolute take-up and let-off speeds while keeping their ratio constant. An increase in speed led to the cloth fell moving forward and vice versa.

8.5 Software Development
The computer program developed to control and monitor the loom motions was written in the C programming language and the required data were received either from the keyboard or from the tension and beat-up force sensors. Various algorithms were used to process these data and generate the signals to be sent to the control elements through the interface circuit. In this way, the various loom mechanisms were synchronized and controlled. In the real time part of the software, the pulses received from the main shaft encoder were taken as the reference parameters and all the real time operations were conducted over 500 segments of one main shaft revolution and this was repeated at every pick.

8.6 Performance of the New Systems
Because of limitations in time and availability of materials, it was not possible to test the newly developed systems by way of long production runs. Instead, the reaction of the systems to various situations, which are liable to arise in practice, were tested.

8.6.1 Performance of the Fully Positive System
The effect of the overfeed ratio between delivery and take-up rollers on warp tension is shown in Figs 12 and 13. The overfeeds quoted here are the ratios of the roller surface speeds. As explained earlier, these nominal overfeeds were in fact underfeeds (drafts) because of the warp crimp effect. Fig. 12 is a plot of tension against the number of picks woven for various overfeeds while Fig. 13 is a direct plot of tension against overfeed. It is seen that the warp tension was maintained reasonably constant from pick to pick and that there was a quasilinear relationship between overfeed and tension. The transition response of the warp tension to changes in the overfeed ratio are presented in Fig. 14 which shows that the effect of changing the overfeed from 1% to 3% and then back to 1%. The transition time is different for the two changes but with both changes it is very long (approx. 1200 and 1800 picks respectively).

The effect of changes in warp tension was tested by stopping the loom and increasing or decreasing the warp tension by turning the let-off rollers backward or forward. The loom was then started again with the same overfeed as it had before and the return to the original warp tension was recorded. This too was very slow. Similar experiments were carried out with stepped changes in the count of the weft yarn and in pick density. All these tests indicated that the fully positive sys-

Fig. 12—Warp tension traces for different overfeed ratios [(A) 0.5% overfeed, (B) 1.0% overfeed, (C) 1.5% overfeed, (D) 2.5% overfeed, and (E) 3.5% overfeed]
8.6.2 Performance of the Feedback Systems

The two feedback systems too were tested with regard to the speed of their reaction to changes in various parameters. In the tension control system, the desired tension was fed to the left-off drive by the computer and tests involved the recording of the tension change that resulted from a change in the tension input. The result of one such test is presented in Fig. 15 where the input tension was changed from 25 to 40 cN. The resulting change in actual warp tension was completed within approx. 3 seconds. Similar response times were obtained when other parameters were changed. Thus, the tension feedback system proved to be a considerable improvement on the fully positive one.

The performance of the beat-up force control system was evaluated in terms of its response to a displacement of the cloth fell from its correct position. Since the spontaneous displacements, which occur during a loom stoppage, were negligibly small, some artificial displacements were created by stopping the loom, taking a few picks out of the fabric and restarting the loom. Typical results obtained in this kind of experiment are presented in Fig. 16 which shows three curves of pick spacing in the vicinity of the stopping place. One of these curves is a blank and relates to normal running conditions when there was no loom stoppage. The other two curves show the result of a displacement of the cloth fell with and without beat-up force feedback respectively. It is seen that with the feedback, the deviation from the correct pick spacing was greatly reduced and so was the time required for the return to the correct pick spacing. Thus, the beat-up control system also demonstrated its superiority to the fully positive system. The work reported above did not reach the stage of a viable design for industrial use but it yielded a great deal of information for the de-
sign of the computer-controlled loom of the future.

9 Conclusions
The experiments and analyses reported here have led to identification of important differences which exist between the warp let-off requirements of warp knitting and weaving. These differences derive mainly form the very different rates of let-off and warp tensions and the very different forces involved in the process of cloth formation. The experiments also suggest that a great deal can be gained by a cross-fertilization of design ideas between weavers and knitters, particularly at a time when the computer control of both the processes is on the agenda.

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