A Study of Weaving Systems by Means of Dynamic Warp and Weft Tension Measurement

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An account is given of a study of the within-yarn tension behaviour for three weaving looms. Dynamic tension traces for both warp and weft yarns were obtained for three common looms from different manufacturers: A Picanol President tappet loom, a Northrop worsted loom and a Sulzer weaving machine. The traces have been investigated in detail and related to the behaviour of the looms themselves. Some aspects of these traces have also been used to illustrate how the proportion of the weaving cycle taken up by the basic functions has changed during the development of the modern weaving loom.

The extent to which the mechanical and physical properties of woven fabrics are determined by loom setting parameters is of fundamental importance in the engineering of certain behavioural characteristics into the fabric. This is an area of fabric research not yet examined in depth, and only vaguely understood. A small number of papers are available on the subject, mostly dealing with the effect of changes in the average level of yarn tension during weaving.

Tension is applied to both the warp and weft yarns during weaving to assist the mechanical functions of the cycle. These tensions and the relative alignment of the yarns at the moment of fabric formation have an important influence on fabric structure. It should be possible to derive a set of criteria which relate these parameters to fabric properties and which are independent of the specific mechanical means by which they are achieved.

Difficulties associated with the measurement of dynamic weft yarn tensions on the running loom have tended to discourage work in this area. An earlier paper by the present authors gave details of the development of a system based on radio-telemetry which overcame many of these problems.

This paper describes a study of the dynamic warp and weft yarn tension within the weaving cycle of three different looms, two of the conventional shuttle type and one of gripper shuttle type. In each case, the prominent features of the traces of warp and weft tension have been compared and related to differences in both the basic loom construction and the settings of the major mechanical parameters of the weaving process.

Experimental Procedure

The three looms investigated were: A Picanol President Model CMC tappet loom; a Northrop Model F worsted loom; and a Sulzer gripper-shuttle machine weaving light-weight sheeting fabric. In all cases, the fabric construction was plain weave. Weft yarn tension traces for the conventional looms were obtained using the radio-telemetry system. Weft tension on the Sulzer machine was monitored by a small transducer inserted on the yarn just behind the feeder gripper. Both this transducer and that used to monitor warp yarn tensions were based on cantilever arms fitted with semiconductor strain gauges. The transducers are similar in principle to the transducer described for conventional shuttle looms.

The warp tension transducer was placed in the warp sheet slightly forward of the back roller on each loom. One yarn from each of the two opposing centre heddle shafts was fed into the device to produce a single-cycle trace, which averaged both upper and lower shed positions.

The signal from each of the warp and weft transducers was fed into separate channels of a storage oscilloscope, and a third channel was used for a time base signal derived from a reed relay switching device mounted on the loom mainshaft. Tension calibration levels were also stored together with the corresponding traces and the entire display photographed. Full details of the transducers used, the recording system and calibration techniques have been given by Holcombe.

Analysis of the Tension Traces

A typical set of traces for each of the three looms is shown in Fig. 1, (A), (B) and (C). For clarity, the amplitude of each trace was adjusted, so that warp and weft filled the upper and lower halves of the screen.
Fig. 1—Traces of dynamic single cycle warp and weft yarn tension for the three looms used in the experimental programme. [(a) beat-up (b) picking, (c) checking, (d) shedding starts, and (e) shedding stops]

respectively. The loom settings and levels of yarn tension used on each loom were typical for the types of fabric produced.

Observation of these traces shows a number of important differences among the tension variations of each loom. Although these may be partly accounted for by yarn elasticity, there are clearly other effects involved. An analysis of such differences may serve to highlight the more critical aspects of the weaving system. Important parameters of the three looms have been summarized in Table 1 to simplify explanation of the features of the traces. All timing was measured as degrees of rotation of the crankshaft from the front centre or beat-up position of the sley, which was taken as zero.

**Warp Yarn Tension**

The prominent within-cycle features of the warp tension traces are the response to the primary motions of shedding and beating-up. These features are clearly visible for each loom. The timing of these two operations varies slightly from loom to loom, as does the magnitude of the beat-up peak relative to the shedding tension. These small variations can be attributed to changes in loom technology, and in fact these three looms represent a progressive improvement in the areas of picking and shedding performance since about 1900. The period of time for which the shed remains open occupies a greater percentage of the cycle in the conventional looms (Northrop 43%, Picanol 42%) than in the Sulzer loom (38%). This difference reflects the higher projectile speed and considerable reduction, in projectile size in the Sulzer loom. With modern looms, the proportion of the cycle taken up by the actual shedding operation has been increased, allowing a smoother interchange and a consequential lower strain on shedding mechanisms.

Average open-shed warp yarn tensions were approximately 6 mN/tex for the Northrop and Picanol looms and 17 mN/tex for the Sulzer. Beat-up tensions were about 1.8 times greater than the open-shed tension for the Northrop, 1.6 for the Picanol, and 1.3 for the Sulzer.

The magnitude of the beat-up peak in warp yarn tension is a combination of the tension in the yarns due to the state of the shed at that point and the tension increment resulting from extension of the warp sheet as the new weft yarn is forced into the fell. The first component is a function of the average level of tension set by the warp let-off, the geometric parameters which control the shape of the shed, and the timing of shedding. Beat-up usually takes place during the later stages of shed interchange, where the tension is rising rapidly and the timing has a significant influence on the total level of beat-up tension; early timing increases this tension, and vice versa. The variation in timing between looms is quite marked (Table 1). The smaller

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<th>Table 1—Details of Loom Parameters</th>
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<tr>
<td>Northrop</td>
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<td>Front centre (or beat-up)</td>
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<tr>
<td>Shedding-starts</td>
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<td>-crosses</td>
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<td>-stops</td>
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<td>Picking</td>
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<td>Let-off</td>
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<td>Warp yarn-type</td>
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<td>Weft yarn-type</td>
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<td>Warp denting/cm</td>
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<td>Weft take up-picks/cm</td>
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<td>Maximum pick sett, %</td>
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<td>Loom speed, picks/min</td>
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<td>Pick duration as % of cycle time</td>
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shed opening of the Sulzer loom would tend to reduce the ratio of open-shed to beat-up tension relative to the conventional looms. The second component of the beat-up peak tension is determined by the width of the beat-up strip and the load-elongation behaviour of the yarns. The beat-up strip is, in turn, a function of the average tension levels and the pick density (relative to the maximum fabric sett). Consideration of yarn counts and loom settings indicates that pick spacings expressed as a percentage of the maximum sett (after Brierly8) were 93% for the Northrop, 89% for the Picanol, and 90% for the Sulzer.

In varying degrees, all the factors mentioned above are present in the traces. Thus, the very prominent beat-up peak of the Northrop loom, for example, is due to a combination of low tension, high pick density, and early shed timing. As previously mentioned the ratio of beat-up peak tension to open-shed tension is about 1.3 for the Sulzer loom, 1.6 for the Picanol, and 1.8 for the Northrop. Thus, although the shed opening required for weft insertion is much less for the Sulzer loom than its conventional counterparts, a far greater level of base tension was employed, resulting in a similar order of change from closed to open shed tensions for both Sulzer and Picanol. The fact that the beat-up to open-shed tension ratio was smaller in the case of the Sulzer is a result of this high base tension. A lower base tension would have still given a similar increase in beat-up tension relative to open-shed tension, and a greater ratio of beat-up to open-shed tensions.

One final point worthy of mention is the influence of the warp let-off motion on the tension during the open shed. Following beat-up on the Sulzer loom, warp tension undergoes a marked transient vibration in the form of a damped simple harmonic motion. This vibration is present to a lesser extent on the Picanol loom and does not appear at all on the Northrop loom. Such vibrations are the natural response of the spring system comprising the mechanical components of the warp let-off control, and the warp yarns themselves to the impulse of beat-up.

**Weft Yarn Tension**

Fundamental differences in the methods of weft insertion and control between the conventional and gripper shuttle looms make direct comparison of their respective weft tension cycles meaningless. The two systems are, therefore, discussed separately.

*Conventional weft insertion—*Both Northrop and Picanol weft tension traces conform to a similar general pattern, with slight differences in certain areas which may be traced back to differences in loom construction.

At front-centre, the shuttle is stationary and the free weft yarn between selvage and shuttle eye is at a steady tension. The moment picking begins (95° for the Northrop and 70° for the Picanol), the yarn is slackened and its tension drops to zero as the shuttle moves towards the warp yarns. At some point during shuttle flight all slack is taken up, weft tension rises sharply and yarn is unwound from the pirn. The weft tension fluctuates about a high level during unwinding until shuttle checking takes place, when it decays rapidly to a steady value. The level of weft tension retained after shuttle checking is largely a function of the tension arrangement of the shuttle eye, although such factors as yarn over-run have some influence.

One obvious feature of the weft tension traces for the conventional looms is the difference in duration of the unwinding tension plateau between consecutive picks. This difference results from the fact that the yarn emerges from one end of the shuttle rather than the centre. Different lengths of slack are, therefore, created between selvage and eye for each box. Since the total picking duration remains constant for each loom, the duration of the unwinding plateau varies for picks from each side of the loom.

Another noticeable difference between these two looms is the proportion of the total cycle time taken up by the shuttle flight. The higher cyclic speed of the Picanol loom demands this, assuming similar orders of shuttle speed. The increased proportion of cycle time for this loom has been achieved by making refinements in the picking and shedding systems. Closer control over the shuttle flight has enabled more critical tolerance of the overlap between shed interchange and the entry and exit of the shuttle from the shed. Thus, despite shortening of the open-shed period, it has been possible to increase the duration of shuttle flight relative to the total cycle.

The retained weft tension, i.e. the tension in the yarn while the shuttle is in either box, does not remain completely static between picks. There are in both looms tension peaks associated with the lateral contraction of the fabric as the reed leaves the fell. The reed forces the fell out to its full drafted width during beat-up, and, as it begins its return stroke, the fell contracts a little, thereby pulling yarn from the shuttle and causing weft tension to increase. This effect may be seen in the weft tension traces, starting from the point where the beat-up peak of the warp tension trace ends. The effect is quite noticeable in the case of the Northrop loom, where contraction was much more significant than for the Picanol. A secondary effect here is the withdrawal of yarn from the shuttle as the sley undergoes its backswing, thus increasing the distance from selvage to shuttle eye.

A less obvious secondary peak in weft tension results from the interaction between the yarn and the weft fork. The Northrop loom was equipped with a centre
fork and the timing of contact relative to shed cross had no influence on the weft yarn (that could be detected as tension at the shuttle). However, the Picanol loom uses a side fork (adjacent to the left-hand box) which pushes against the yarn close to the selvedge as they sley moves forward, thus introducing a small tension in the weft yarn. This small peak is visible immediately after the shuttle enters the left-hand box (approx. 335°).

**Gripper shuttle weft insertion**—The complex nature of the Sulzer weft insertion system demands a very precise form of yarn tension control. To simplify the explanation of the weft tension behaviour for this loom, a chart (Fig. 2) has been prepared setting out the timings of those mechanical functions which have a direct influence on either the yarn or the gripper shuttle.

The shuttle is in contact with the picking shoe for approximately one-third of the distance required by the conventional shuttles, and leaves the shoe at almost twice the speed of a conventional shuttle. The gripper is subjected to a maximum accelerating force about 675 times that due to gravity. Such a force, when imparted directly to one end of the yarn, would almost certainly result in yarn breakage, particularly in the case of relatively fine yarns. Deceleration is also very severe, and the yarn must be braked during checking to prevent over-delivery.

Control of the yarn is achieved in practice through the action of the weft tensioner arm in conjunction with the weft brake. The weft tension arm stores a predetermined length of weft which is progressively released into the system over the initial stages of picking. This process reduces the rate at which tension increases in the yarn, and allows the yarn unwinding from the package to be accelerated more slowly than the gripper.

The weft brake is applied during flight at two levels. The drag on the yarn due to the action of the brake prevents over-delivery during checking and straightens twisted loops, which might lead to fault formation in the fabric.

The transducer was mounted directly behind the weft feeder, and, therefore, information derived from this instrument while the jaws of the feeder are in contact with the yarn (i.e. from 288° to 40°) is not representative of the yarn within the shed. The

![Relative Locations of Weft Insertion Elements](image_url)

Fig. 2—Breakdown of the mechanical operations of the Sulzer loom which have an influence on the weft yarn
separation of the yarn from the weft feeder at 40° represents the start of the observed tension cycle. Tension at this point was quite low, with both yarn and gripper stationary. At 50°, the tensioner arm starts to move downwards, releasing yarn in preparation for picking and causing weft tension to fall to zero. At 68°, the gripper is fired, although weft tension remains at zero for a few degrees as slack in the yarn released by the tensioner is absorbed.

The initial rise from zero tension is rapid, but is soon damped by the action of the tensioner. There follows a period of 100° in which tension fluctuates widely as yarn loops are unwound from the package. It is possible to see in the traces peaks superimposed on the unwinding effects which correspond to the application of the first, light brake and the cessation of tensioner influence.

At 193°, the tensioner starts to return to the storage position. After another 10°, the second, hard brake is applied. The effect of the brake, combined with the drawing-off of extra yarn by the tensioner, leads to a substantial tension rise which continues until checking takes place. The extent of this rise in weft tension depends on the setting of the second brake.

Shuttle checking is followed immediately by a sharp fall in weft tension, probably due to differences between the running and static frictions of the brake and other yarn contact points, as well as a slight yarn over-delivery. This fall in tension continues until it is reversed at 240° by the accelerating upward movement of the tensioner. At 255°, the gripper is contacted by the positioning mechanism (which prepares it for return) and the associated backward movement slightly counteracts the effect of the tensioner, causing a further reduction in tension. A levelling off, as the gripper positioner slows, is followed by a short rise in weft tension until the yarn is gripped by the jaws of the weft feeder at 288°.

From this point onwards for 112°, tension variations appearing on the trace correspond to the movement of the weft feeder to the reload position, and continued motion of the tensioner. It is interesting to observe that these two functions appear to be timed to minimize the fluctuations in weft yarn tension over this period and also to prevent the yarn from becoming completely slack.

It can be assumed that tension in the weft yarn within the shed remains constant following contact with the weft feeder until beat-up, as the only external influence on the yarn over this period is the affixing of the selvedge grippers (which cause no yarn length changes whatsoever). Consequently, the tension of the weft yarn as fabric formation commences may be taken as that present at the time of contact with the weft feeder, i.e. at 288°.

Conclusion
The information available from within-cycle tension traces for warp and weft yarns provides a means of examining the dynamic behaviour of the weaving process in detail for different types of looms. Further, it is possible, by careful choice of the time-base of a cathode ray oscilloscope, and by the use of delayed triggering, to study specific areas of the weaving operation in even greater detail if required.

Single-cycle traces were recorded for three commonly used weaving looms which illustrate some aspects of the development of weaving technology to its present state. The traces show how improvements in the areas of picking and checking have enabled much closer control over shuttle flight to be achieved. Thus, the timing of the overlap between shed interchange and checking is today more precise, and shuttle flight time has been increased relative to the total cycle. These developments have allowed cyclic speeds to be increased without directly increasing the strain on the more sensitive loom components.

The traces show how the warp yarn tension at beat-up is dependent on factors such as the shed size, the width of the beat-up strip, and the timing of shed cross. Other less obvious details, such as tension arising in the weft yarn due to interaction of the weft fork and contraction of the fell, may also be observed. Clearly, the system is adaptable to suit virtually all types of weaving looms, and provides a useful tool for loom development and tuning, as well as a basis for research into the influence of yarn tensions on fabric formation and properties.

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