THE EFFECT OF LOOM SETTINGS ON WEAVING RESISTANCE AND FABRIC PROPERTIES

A thesis submitted for the degree of
Doctor of Philosophy

by

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August, 1982

ABSTRACT

The previous work on measurement of weaving resistance, i.e. the force needed to beat the weft into a fabric, is reviewed and the refinement of one method is described. That method is then used in a comprehensive set of experiments in which the tension applied to the warp and the balance and timing of the shed are all varied. A consistent pattern of influence of the settings on weaving resistance is established and illustrated in graphs. The main experiments relate to plain weave, but the weaving of 2/2 twill is covered in a rather less comprehensive way. The optimum settings are found to be different for the two weaves, and these differences are explained in terms of previous theoretical work. It is shown that the adoption of optimum settings permits the weaving of denser fabrics.

ACKNOWLEDGEMENTS

The author wishes to express his thanks to Dr. K. Hepworth for his guidance throughout this work and for his help in overcoming the writing-up problems of this thesis.

Thanks are also due to the EGYPTIAN GOVERNMENT for their financial support, Mr. L. Brayshaw and Mr. D. Bland for their technical assistance, and for everyone who has given me sincere help.

CONTENTS

Page No.

CHAPTER I

CHAPTER II

Page No.

CHAPTER III

CHAPTER IV

CHAPTER V

GROUP I EXPERIMENTS

Page No.

CHAPTER VI

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CHAPTER X

CHAPTER I

1. INTRODUCTION AND REVIEW OF LITERATURE

CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

1.1 Introduction

Since Greenwood[1,2,3,4] drew attention to the way beat-up force, fell position and pickspacing interact, there have been many investigations of the factors that affect the weaving resistance, i.e. the beat-up force[8] needed to produce a fabric. Most of those widely reported have been theoretical studies or descriptions of methods of measurement. There are few reports that give measured data showing how weaving resistance depends on the pickspacing being produced as other factors change. The theoretical studies suggest that it depends not only on pickspacing and yarn properties, but on factors such as shed timing, shed balance and warp tension.

The purpose of the work reported in this thesis is partially to fill that gap by making a very comprehensive study of how these factors interact to influence the weaving resistance of one or two particular fabrics. It is not part of the objective to put forward new theoretical ideas, but in order to be able to discuss the experimentsl results a brief account of some of the more important previous theoretical work will be given.

1.2 Theoretical studies of beat-up

Virtually all theoretical studies of textile structures or operations are based on simplifying assumptions, and beat-up is no exception. Apart from almost all taking the simplest structure, plain weave, the different investigations differ according to the degree of simplification made. The more recent ones, making use of the computer, can deal with more complicated models; but even now, they assume that warp and weft have circular cross-sections and usually, in the case of models of the weaving process, that the weft is like a rigid rod. For this reason the outcome of these studies cannot be relied on for practical application unless they are confirmed by experimental results. The theory may help to explain what happens in practice, but cannot replace experiment because a realistic theoretical model would still have too many variables to permit a solution.

One of the earliest studies was that of Stein[5] who considered the friction forces between warp and weft and the movement of picks at the fell of the fabric as cloth was formed. Greenwood[1,2] referred to that work when presenting his own account of the fabric-forming process. That has usually been taken as the starting point of later studies because he first set out the way in which pickspacing is controlled. He noted that the beat-up force that is applied to squeeze the new pick into the cloth cannot be greater than the reaction of the cloth against which the force is applied (Fig 1). That increases as the fell is displaced by the reed, because if the original tension in the cloth is T_o, مشوش کردن disturbing the fell through a distance x towards the cloth stretches the warp by x and "unstretches" the cloth by x, so increasing the warp tension to $T_1 = T_o + x\dfrac{E_1}{L_1}$ and decreasing the cloth tension to $T_2 = T_o - x\dfrac{E_2}{L_2}$. The beat-up force, B, is the difference between T_1 and T_2 i.e. $B = x\left(\dfrac{E_1}{L_1} + \dfrac{E_2}{L_2}\right)$. If the cloth-fell distance, L, is the distance the reed travels beyond the position of the fell then, providing the pickspacing, p, formed when the reed is at front centre remains as the actual pickspacing in the cloth, the maximum fell displacement is L + p and $B = (L + p)\left(\dfrac{E_1}{L_1} + \dfrac{E_2}{L_2}\right)$. That gives the beat-up force developed for a given fell position.

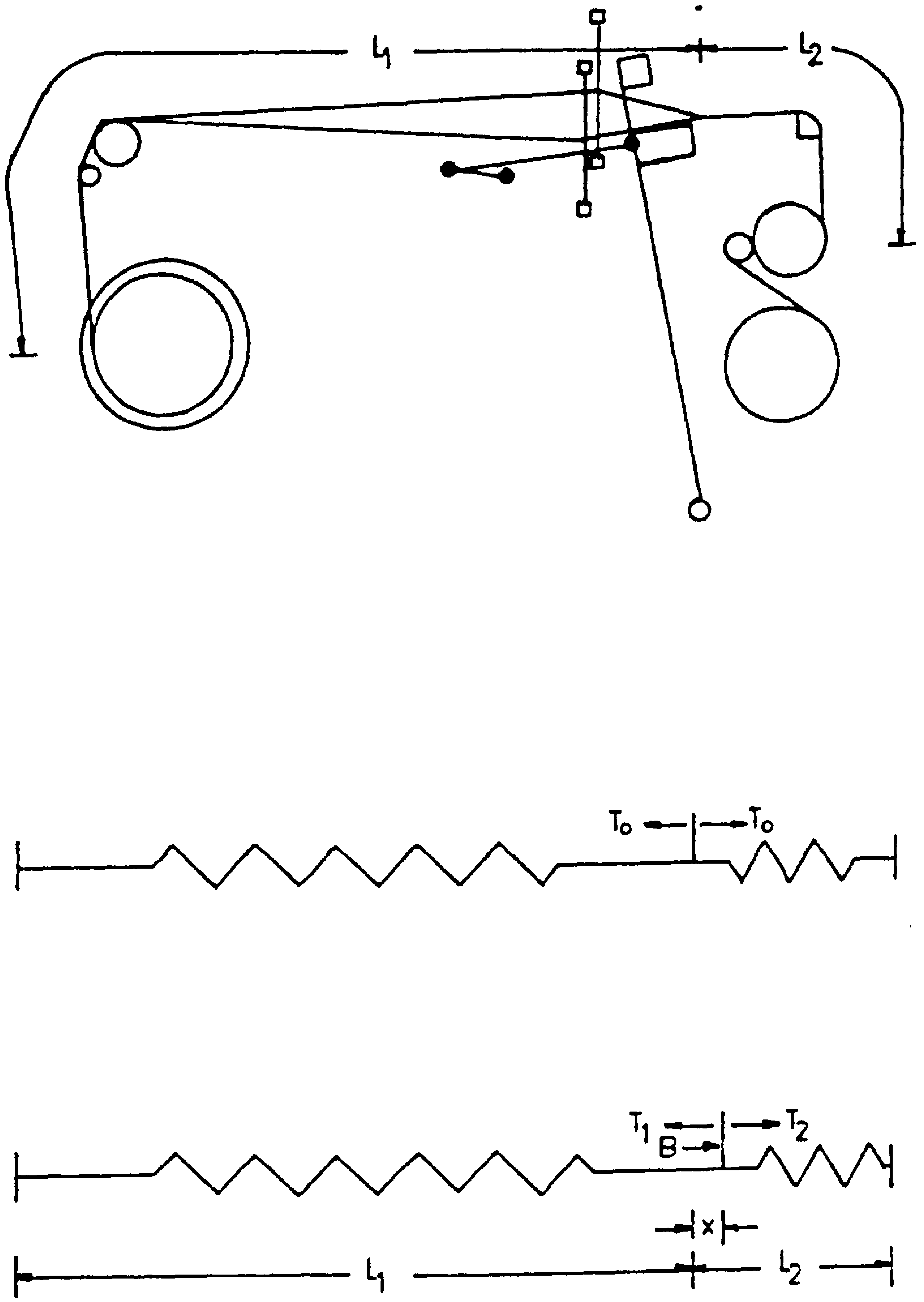


Figure 1. Warp and cloth representation at beat-up

The beat-up force needed - or weaving resistance - is a property mainly of the cloth and yarn. Greenwood made a simple assumption to describe in the simplest possible way the kind of relationship that was believed to exist - that weaving resistance is k/(p-D) where k and D are constants. That leads to

$$\frac{k}{p-D} = (L + p)\left\{\frac{E_1}{L_1} + \frac{E_2}{L_2}\right\}$$

or $(L + p)(p - D)$ is constant, which shows that if the assumptions are valid, p is determined by L. However, L, in turn is affected by p because, if p is not the same as the amount of cloth taken up, the next value of L is increased by p and decreased by the take up and so is different from the present value. Therefore, the next p is different and so on until the difference between p and take up disappears.

Most later work has either repeated Greenwood in a slightly different form, or has modified his assumptions to make them more realistic, or has set out to include other factors.

Plate[6] set out to substitute a cloth-fell model for $R = k/(p-D)$. He assumed circular yarns and rigid weft and allowed the warp to have some rigidity. He used a friction law F, friction force, = CW^n where W is normal load and C, n are friction coefficients (or coefficient and "index") - a law which he had confirmed and for which he had found empirical values of C and n. He calculated the forces and the way the picks slipped in and out of the cloth, and so obtained a relationship between weaving resistance and pickspacing that was discontinuous.

Ito[7] followed a similar overall procedure, but assumed the warp to be perfectly flexible and used the simpler Amontons' friction law. Without warp rigidity, all forces depend on cloth tension and so the results are inaccurate if tension is low because the major factor, rigidity, has then been neglected, but for many purposes the method is acceptable. This simpler treatment allowed Ito to study a cloth cell that was unsymmetrical, that is one formed on a loom with an unbalanced shed. He divided the effects of unbalancing the shed into two kinds, which he described as "static" and "kinematic". The first is simple to analyse and calculate, but the second was not possible to complete. However, when he measured the effects of unbalancing the shed on a model loom (weaving glass rods into a flexible warp), it seemed that the "static" effect explained all the difference.

This static effect is simply that if two warp sheets enclose a pick, the pressure they exert on it (and hence the friction force) for a given total tension reduces as the tension is shared more unequally between the two sheets. For example, in the extreme case where one has zero tension, the tight sheet lies straight and gives no component of pressure, while the slack one deflects round the pick but has no tension.

These results (Fig 2, in which T_O, S_O represent the tension in the tighter and slacker sheets) are in agreement with mill experience where it is usual to raise the back rail of the loom to reduce weaving resistance as well as to reduce reediness.

In Plate and Ito's studies, the weaving resistance depended very much on the "weave angle" - the angle of the warp threads within the cloth to the cloth plane - which, of course, depends on pickspacing. If the weft is allowed to crimp, those angles are reduced and the resistance should, therefore, be reduced. Galuszinski tried to take account of this using Ito's simple approach and assuming the weft to be flexible, but under a tension that could be deduced from its extensibility. His work extends the range of the study but he does

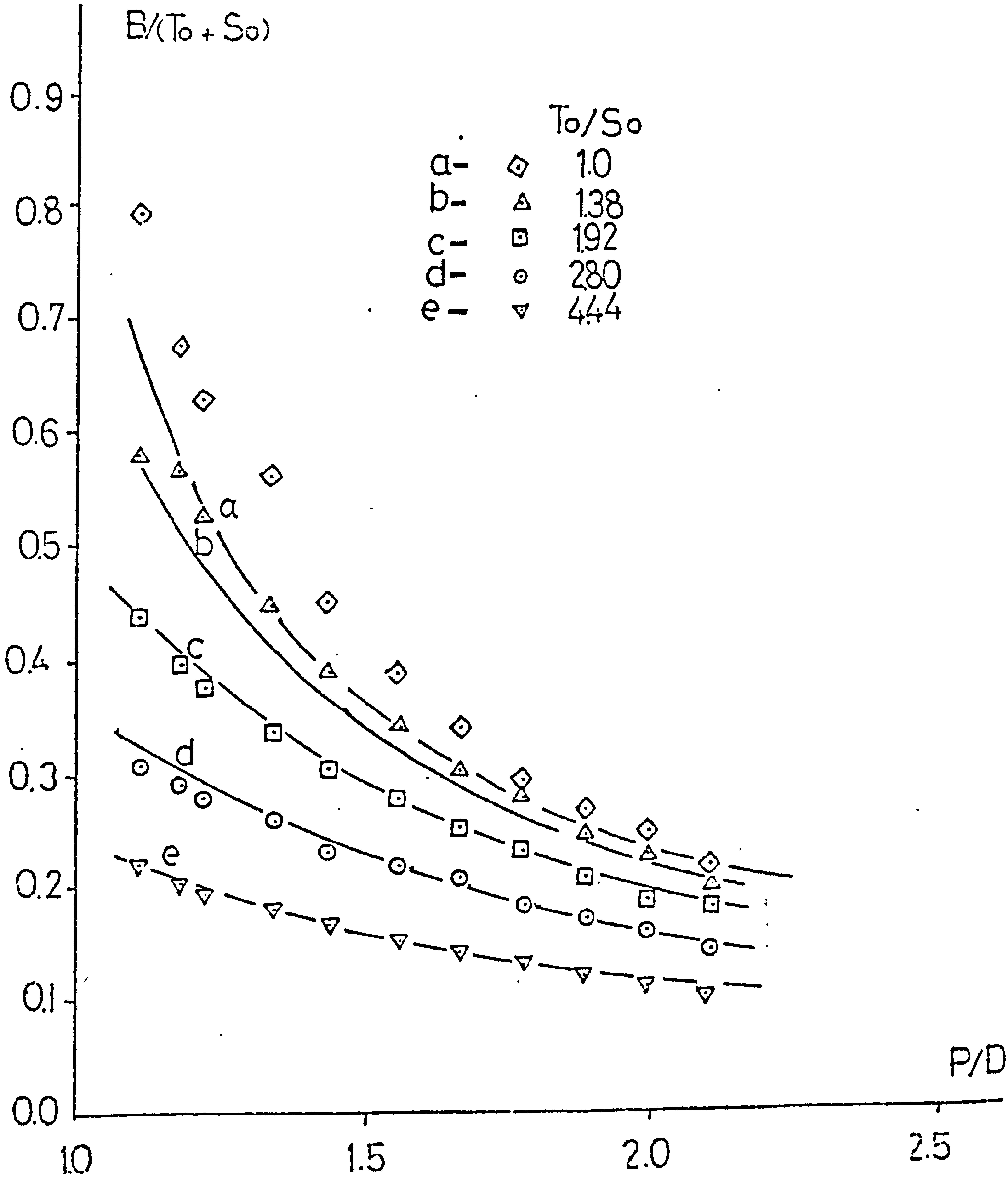


Figure 2. Weaving resistance v. pickspacing for values of tension ratio T_O/S_O. (from Ito)

not correctly allow for changes in crimp balance between warp and weft when the cloth tension reduces during beat-up. He also worked not only on plain weave but on some derivatives, though here again there is an error due to replacing warp and weft diameters by zero and (warp diameter + weft diameter) respectively - valid for plain weave, but not for weaves with two picks in the same shed.

1.3 Experimental studies

1.3.1 Measurement of weaving resistance

Weaving resistance or its counterpart, beat up force, is at the centre of the relationship between pickspacing, yarn properties and loom settings. It is only during the last thirty years or so that it has been practicable to measure rapidly changing forces directly - usually by having them deform some component and measuring that deformation. The introduction of that component to the system must not cause much disturbance to its behaviour and its deformation also must not be big enough to disturb the normal working. The best method, where it is possible, is to use some normal part of the system and to measure its small deformations by electronic methods, but optical or acoustic methods are used sometimes. Snowden,[8] for example, took warp tension as a guide to weaving resistance and first got a rough measure of it by noting how much the weight lever that tensioned the warp was made to oscillate. He also put a warp thread through a system of three pulleys and measured the movements of the centre one, which was spring-loaded, by mounting a plate of a capacitor on it and measuring capacitance changes by electronic methods. The tension in a single thread, however, did not necessarily represent that of the whole warp and there were probably effects caused by the inertia of the pulley.

One of the first methods of measuring beat up force was the one used by Greenwood and Vaughan,[4] which depended on measuring the deflection of part of the lower reed baulk that was left unsupported by removing a small part of the sley. A strain gauge was fixed on the back of the baulk, in the gap, so that it would stretch due to the bending of the baulk by the weaving resistance. It formed one arm of a d.c. Wheatstone bridge. A compensatory gauge does not seem to have been used - the fluctuations caused by temperature changes were relatively small and also, as the force is zero for most of each loom cycle, shifts in zero level could easily be corrected for. The bridge output was fed to a double beam oscilloscope which was triggered by a microswitch operated by a cam on the crankshaft. The sley position was indicated by the second beam using a technique developed by Butler and Cowhig.[9] Photographic recording was used, the trace being formed using a 50 m sec time base. The reed was calibrated by loading it with tensioned warp threads (the fabric being slack) by moving the sley in small steps against the cloth fell and taking warp tension readings by an electronic tensiometer working on four warp ends.

They noted that on the traces there was some oscillation after the beat up signal, and attributed it to inertia effects in the system. These effects then seem to have been ignored, though they would be expected to cause invisibility of the zero level and might have affected the results. However, the clear recorded signal they were able to publish inspired other researches to explore similar methods and to try to improve the technique and cause less disturbance to the loom.

Chen Jui-lung[10,11,12] also recorded beat up signals, but in his paper did not indicate just how he obtained them. He tried, using a roller supported by a strain-gauged cantilever, to measure the changes in cloth tension, but said that the readings showed less variation than would occur at the fell because of the friction of the temples.

Badve,[13] following Greenwood's published work, set out to measure the deflection of individual reed wires at chosen points across the reed width. By using the member that actually beats up the weft, he considered his method would be less affected by inertia forces than would Greenwood's. He also hoped to study variation in force across the loom. However, he soon realized that the deflection of a wire is affected by forces applied to other wires (even unloaded wires are bent by being connected by the baulk to loaded ones) and he did not take readings at different points except when a gauge failed and he had to transfer to another. The gauges were delicate, and to make them involved a very laborious process of cutting a groove down the front and back edges of each reed wire used. The grooves were cleaned and polished and single lengths of .001" diameter resistance wire laid in each and fixed and insulated by Araldite. Front and back wires formed two arms of a Wheatstone bridge. He used an all-metal reed because early experiments with a pitch-baulk one showed hysteresis effects when the single wire was loaded (in fact these may not have occurred when weaving because the whole reed would bend together). To fit the metal reed into the grooves of the sley and sley cap designed for a pitch baulk reed, it was usual to fit over the thin baulk of the metal reed a brass tube with a slot cut along its length. This was probably an important part of the system as it would allow the baulks to rotate slightly and make it easier for the reed wires to deflect. It had not originally been realized that the system would only give readings if the baulks could rotate - because it measures the integral of curvature over length of the reed wire. Later workers were to use the rotation directly as a measure of force.

Badve also measured fell displacement by a capacitance method and, less accurately, the displacement attributable to shedding and back rail movement, so that the displacement caused by the reed could be obtained as the difference. He strain-gauged and pre-calibrated the crank connecting arms and used these to measure the total warp tension during static calibration of the reed by a method similar to Greenwood's.

Yehia[14] aimed to develop a method easier to apply than Badve's by measuring the small rotation of the reed baulks. A small cantilever of feeler-gauge steel was fixed to a small metal block clamped to the lower reed baulk and allowed to project into the slot in the race that normally houses the weft fork. He got what seemed to be good traces of beat up force - but they were also there, reduced, when the loom was run without any weft due to the effects of the reciprocating mass of the sley. It was realized then that if a cantilever were also mounted at the top baulk, inertia effects should rotate both baulks the same way, but beat up force would rotate them opposite ways, and so there should be some combination of the two signals that would not be sensitive to inertia effects, but would still give some beat up signal (Fig 3). He finally managed to reduce the main effects of inertia in this way, but there was still some higher frequency vibration. The method was much easier than Badve's, but the traces were not as clean. Yehia recognized that sensitivity would depend on the height at which the cloth fell met the reed and he added calibrations of this to the normal calibration experiments.

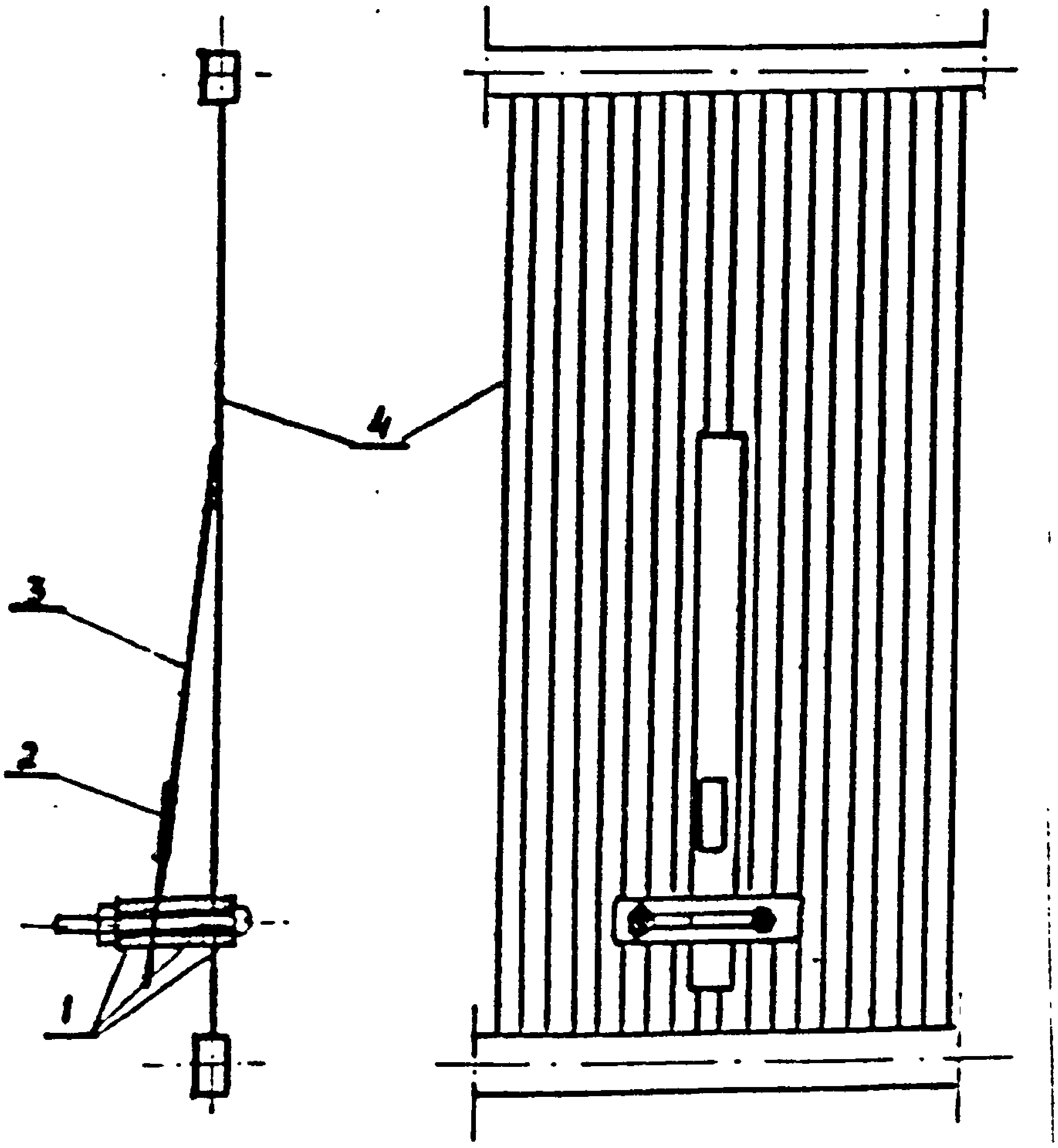
Leung,[15] following a suggestion in Yehia's thesis, slightly

Figure 3. Two cantilevers method for measuring B.U.F. (from Yehia)

improved the electronic arrangement used, having separate bridges and pre-amplifiers for the two cantilevers and combining the signals by a potentiometer after emitter-follower buffer stages.

Backmann is reported, and later Wnuk[16] had used a single strain-gauged cantilever supported behind the sley to measure the movement of the lower reed baulk in a reed, or section of a reed, supported in the manner of loose reed looms. It is difficult to see how this method could be free of inertia effects, although they may often be small in relation to beat up forces and some of their traces show considerable effects of vibration.

Recently Galuszinski[16] searching for an indicating device that could be transferred from loom to loom, had the idea of clamping a strain-gauged strip to the reed (Fig 4a) so as to bend when the reed bent. It was located just outside the selvedge. However, although it gave an indication it suffered from hysteresis due probably to the friction between the unclamped end and the reed. Instead of that system, he filled the spaces between a number of adjacent reed wires with Araldite for a distance of about 1 cm close to the upper and lower baulks, and on the surface thus formed mounted his strain-gauges and combined the signals in the usual way (Fig 4b). He was working on the MAV rapier loom on which this method was possible because the warp sheet is never allowed to come close to the lower baulk. He then found that on this particular loom, the signal from only the lower gauge provided the best indication of beat up force. This method was also used by Saad[17] on a Dobcross loom on which the sley had been modified to allow the reed baulk to be placed about 3 cm below race level, but in that application it was not possible to cancel out the effects of vibration caused by picking.



1. Clamp
2. Strain gauges
3. Cantilever
4. Reed wires

Figure 4a

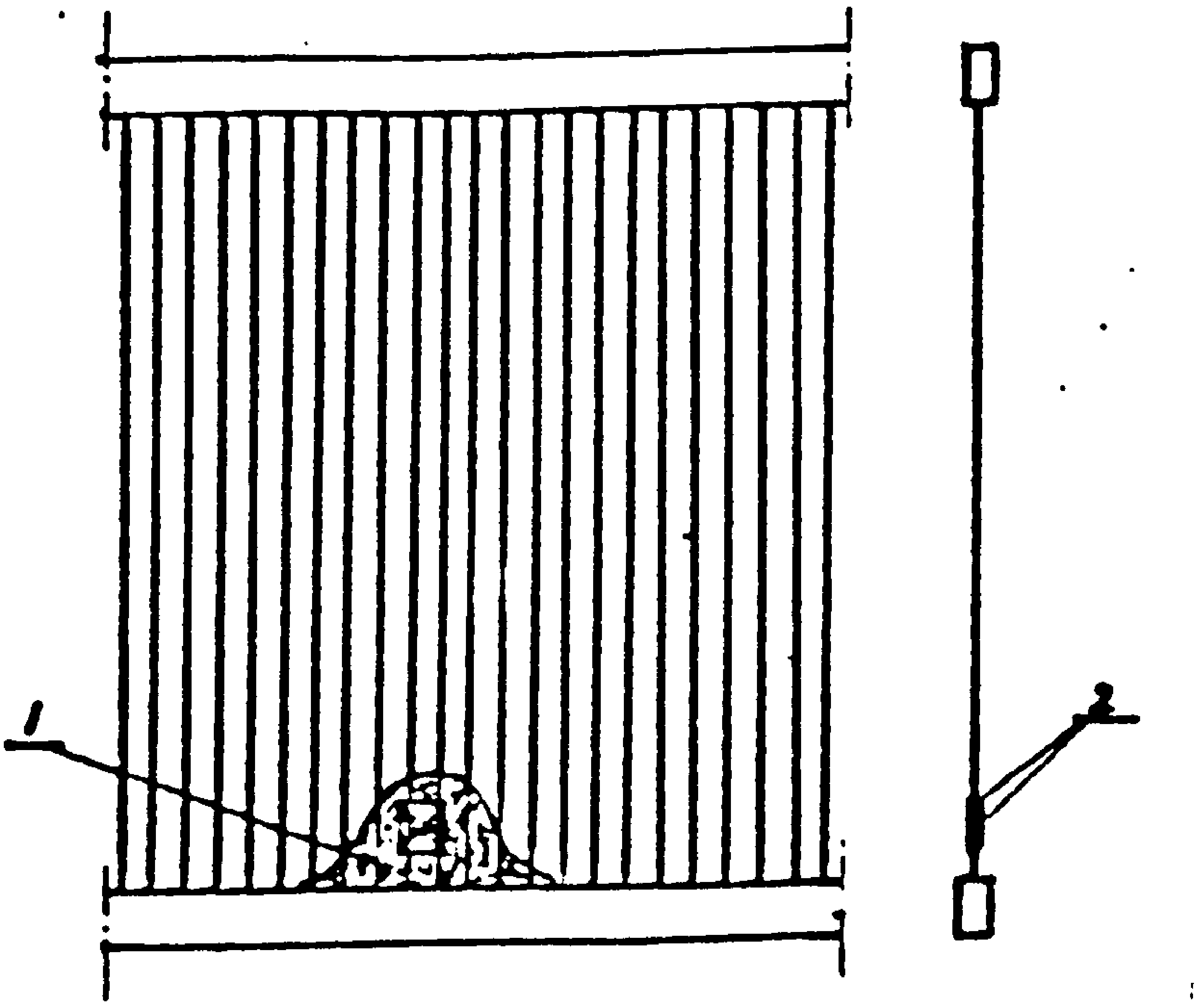


Figure 4b
(from Galuszynski)

The work reported in this thesis began before that of Galuszinski and Saad. The objective was to perfect, as far as possible, the method used by Yehia and by Leung and, as reasonable progress was made, and eventually good results obtained, no other methods were explored.

1.3.2 Cloth fell distance measurement

When Greenwood set out to test his theory of pickspacing control he not only measured beat up force, but also the cloth fell distance and fell displacement. The cloth fell distance is easily measured when the loom is stationary, but when it is running, the position of the fell is changing so that it is really necessary to measure it at about the time of beat up. Greenwood used an optical arrangement that used a lamp under the fell to throw an image of the fell onto a screen above the loom.

As has already been mentioned, Badve[13] measured changes in cloth fell position by a capacitance method. What he actually measured was the movement of the reed while it was in contact with the fell, that is the distance from the point where it met the fell to its front centre position and the return distance to the point where it broke contact. His traces showed, however, that beat up force was not always a maximum at front centre, and this made him realise that part of the displacement would have existed even if the reed had not beaten the fell, being caused by shedding and back rail movement. He noted that it was only the additional displacement caused by the reed that was effective in developing beat up force, and he used a "dummy" end that passed from the beam over the back rail and through a heald to the fell, but was not allowed to become part of the fell so that it received the displacements of the other ends but not that caused by the reed, to obtain a signal that could be subtracted from the original one to give the true effect of the reed on fell displacement.

1.3.3 Measurement of warp tension

Until Greenwood's work was published, there seems to have been, except from Stein, little interest in the actual beating up. The interest that had been shown in the forces on the loom had been mainly directed to warp tension or to movements of the back rail of the loom associated with warp tension. Warp tension was of direct interest in relation to end breakage. Also it could be measured without attaching instruments to the moving sley of the loom. Thus Snowden made considerable use of measurements of weight lever oscillation caused by dynamic variations of warp tension as an indication of weaving resistance. Direct measurements of warp tension using mechanical or electrical methods and applied to single threads or to read the average tension of a large number of threads or even the whole warp, have also been used.

The mechanical devices transform the tension into deformation of some elastic element, the deformation then being magnified by a light lever system. Such devices have too much inertia to give accurate readings of dynamic tension, but may be damped and used to indicate average value. The MANRA lease rod system used a lease rod in the form of a rubber tube sandwiched between two metal strips and used in the same way as a lease rod, in conjunction with an ordinary lease rod. The warp tension caused a resultant compressive force on the rod, so deforming it. The rubber tube was sealed at one end and connected to a U-tube manometer at the other. The difference in liquid levels related to the pressure in the tube and so to the warp tension. If the shed was unbalanced, however, the relationship would change, just as the pressure on a pick at the fell is changed by a change in shed balance.

Electronic methods have allowed the magnification of a signal to be obtained without having too much inertia, but as in all such systems the response depends on the transducer. Most of them rely upon deflecting a thread or a sheet of threads around a system of three pulleys, three rollers or three rods of which the centre one is caused to move against elastic resistance. The movement is then converted into an electrical signal by means of capacitance gauges, reportedly used by Stein,[5] and later used by Snowden and Chamberlain[18] in a frequency modulation system and by resistance strain gauges, very widely used in both a.c. and d.c. bridge circuits. A particularly simple and convenient method, which has been used in the present work, is that of Wetzel,[19] illustrated in Fig 5, based on the use of resistance gauges to measure the bending of a thin metal plate that carries on two short supports a centre rod, while the ends of the plate are bent at right-angles to the centre position so that they serve as the two fixed outer rods. The deformation need only be very small, and there are no rotating parts so that inertia effects are minimized. The unit is threaded on a strip of the warp and travels with it, so the effects of friction are reduced, though they may not be completely eliminated. It has, of course, to be drawn back along the warp at frequent intervals. The unit can easily be calibrated by threading it on a ribbon or tape which is allowed to hang vertically and loaded by weights.

All the transducers referred to have to be used on the warp close to the back rail, so they do not interfere with shedding. That means they do not measure the tension near the point where the fabric is formed and may not measure the maximum value - friction at the healds

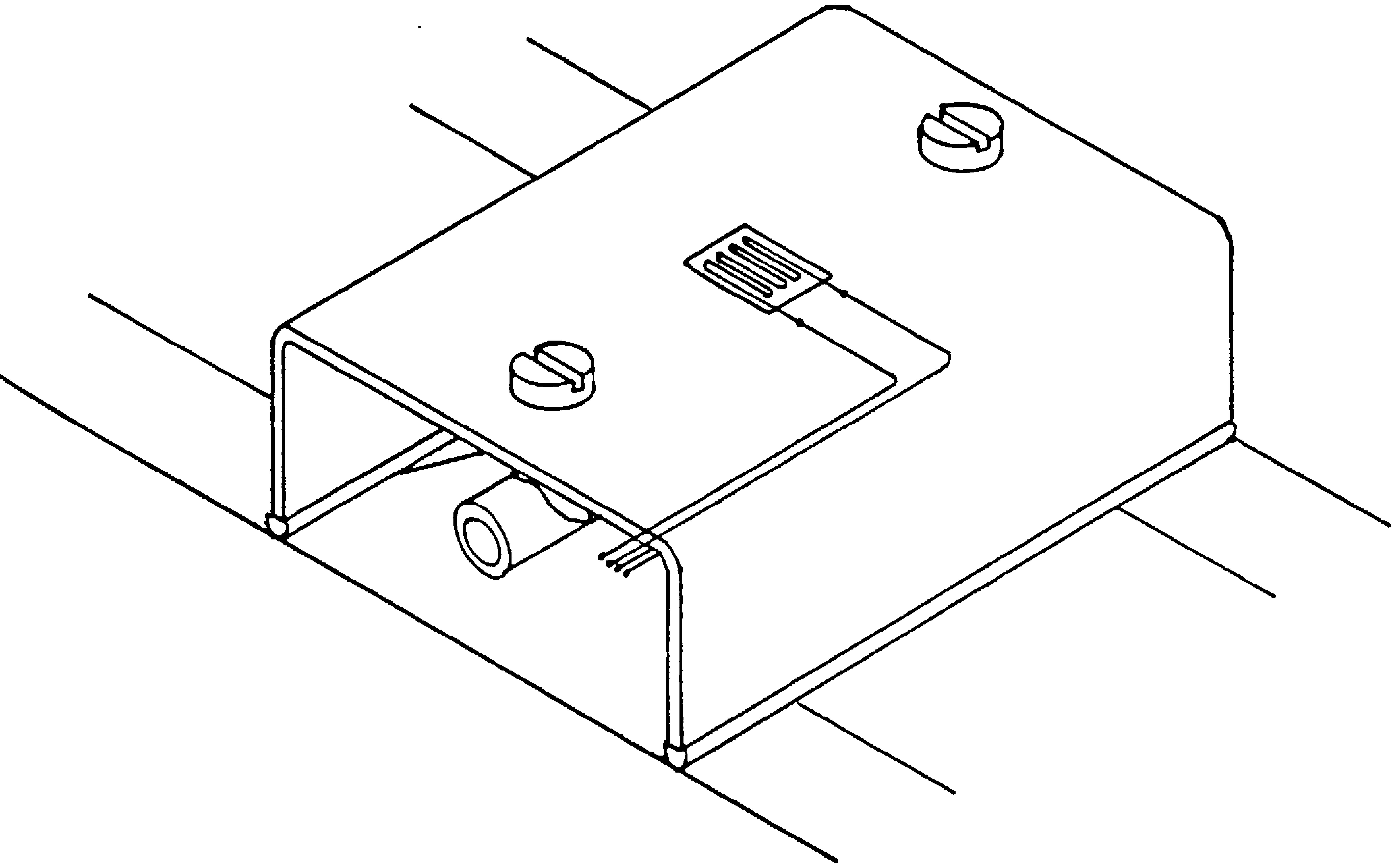


Figure 5. Warp tension gauge

and perhaps at the reed may act to increase or decrease the tension near the fell relative to that which is measured. Mallah[20] used strain guaged links in the cords supporting the heald shafts, but these were sensitive to inertia forces on the shafts. Also assumptions had to be made about heald-eye friction to convert the results into warp tension values.

Probably the tension values obtained from devices inserted in the warp at the back of the loom will, for most of the cycle, give a value that is proportional to, but smaller than the tension near the fell. But at certain times in the cycle, e.g. when the shed is closing or at other times when the back rail oscillates violently, the reduction in tension may be under-estimated when using such devices.

1.4 Factors affecting weaving resistance

All theoretical studies suggest, and all experiments seem to confirm the general rule that if nothing else is changed, then to obtain closer pickspacing requires a larger beat up force or, for a given spacing, a thicker weft requires a larger force. Simple theories suggest a discontinuous relationship between pickspacing and weaving resistance, but that has not been confirmed by experiment - possibly because irregularities in yarn properties would smooth the discontinuities. Loom settings are also known to influence the relationship. In particular, it is well known that it is generally easier to produce a dense fabric if the shed timing is early and the shed unbalanced, but there is little information about how much easier it is. Also there have been conflicting accounts of the effect of shed timing. One of the problems is that the range of variation possible depends on the type of loom and on the weave and the yarns being used. Another is that the settings are not always independent and the effects depend on combinations of settings. Therefore, results given in the literature have to be treated with caution. To give just one example: Badve studied the effects of shed timing on beat up force, but makes no mention of shed balance, implying that the loom was in its normal state and that the shed was balanced - almost certainly not true. It will be seen that the effects of timing depend very much on the state of unbalance.

1.4.1 The effect of warp tension

There seems to be general agreement that increasing warp tension increases weaving resistance. Theoretically increased tension increases interyarn forces and hence the effect of friction; Greenwood's[4] and Chen Jui-lung's[10] experiments confirm the effect. However, the influence seems to be fairly small, both indicating a rise of about 10% in weaving resistance for a doubling of the basic or average tension.

1.4.2 The effect of shed balance

Ito's simple theory and his model loom experiments have been referred to (Fig 2). They show a very significant effect of tension ratio in the two warp sheets on weaving resistance. It had earlier been reported by Bramma[21] and Snowden[8] that an unbalanced shed was helpful in achieving high setts. Jederan[22] considered the effect on weaving resistance and, according to the English abstract of his Hungarian paper, found that "contrary to what is generally accepted" no reduction resulted. Mallah[20] had reported that peak warp tension was reduced when the shed was unbalanced and both Yehia[11] and Leung in their limited experiments, from which the present study has evolved, showed a significant reduction in beat up force when the shed was unbalanced. Yehia's work suggested that the effect was influenced by shed timing. Leung used a crude method of unbalancing that avoided Ito's "kinematic" effect and was incidentally independent of shed timing; he inserted a heavy roller like a lease rod in the warp so that each of the slacker and tighter sheets was always composed of the same threads. With the more normal arrangement, using a raised back rail to unbalance the shed, each yarn is alternately in the slack and tight sheet of the open shed; but when the shed is closed, i.e. crossing, it is by definition also balanced. So it would be expected that the timing of the shed relative to beat up would affect the weaving resistance.

1.4.3 The effect of shed timing

In view of what has already been said, it is not surprising to find contradicting statements about shed timing. Greenwood said the effect was so small that its significance must be doubted. Badve found a difference but not all his results show the effect consistently. Yehia's results suggested a "normal" timing gave least resistance to a small extent. Theoretical studies suggested that it was not so much the effect of timing (and hence shed angle at beat up) on the actual beating up that mattered, but its effect in opposing slipping back. In industry it seems generally to be accepted that an early timing enables picks to be beaten more closely. So a confused picture emerges and it is clear that a more detailed and more precisely defined range of settings should be used than the "late", "normal" and "early" often adopted.

1.4.4 Cloth fell distance and beat-up force

Although cloth fell distance is not a basic or independent parameter (except when it is set at the start of a period of weaving) it is a visible feature that forms an important link in the relationships between other variables and so has received some attention. Badve set out to measure c.f.d. in order to test Greenwood's equations and pointed out that in developing the beat up force it is not the fell displacement in absolute terms that is related to beat up force, but the displacement relative to that which would occur due to shedding, back rail movements, etc., in the absence of beat up. When he had developed a means of measuring that relative movement, the modified c.f.d. or, as he termed it, the "interference" between reed and fell, was still often greater than seemed necessary for the force, even when true load/extension curves were used instead of constant moduli in the relationship. These results led him to suggest slipping back of picks might be responsible, so that the cloth fell was not clearly defined but was rather a region that was neither warp nor cloth. Greenwood found some evidence that c.f.d. was influenced by loom speed being slightly increased when the speed was reduced. That might be explained in the elastic moduli being slightly lower for slower rates of strain but it could also be an effect of fell movement rather than displacement by the reed.

1.4.5 The effect of weave

For given yarns it seems obvious that, just as maximum possible sett depends on the density of intersections in the weave, so weaving resistance would also depend on that density. Galuszinski, working on plain weave derivatives, claims to show a direct simple relationship between weaving resistance and setting formulae. Chen Jui-lung had previously reported similar results but expressed in less precise terms.

1.5 Scope of the present study

As already stated, the first objective was to set up a reliable and consistent method of measuring the force exerted by the reed during beat up, based upon the methods of Yehia and Leung, which showed promise of success. This development is described in Chapter 2. In the same chapter, methods used for the measurement of other relevant parameters are described, with details of instrumentation and calibration procedures.

The next objective was to use those methods to measure these variables for a comprehensive range of loom settings covered in sufficiently fine detail as to leave no doubt about the nature of the inter-relationships. In order to obtain that degree of detail, it was necessary to limit the number of variables, and it was decided to concentrate on just two weaves - plain weave and 2/2 twill - and to use just one pick wheel setting for each weave and one type of weft. The factors to be varied were warp tension, tension ratio in the unbalanced shed, and shed timing. The methods of varying the settings and their possible range of variation are discussed also in Chapter 2.

Chapter 3 collects together the basic data about the loom, yarn and fabric which may be required to understand the experiments and their results. Chapter 4 sets out the procedure for each experiment, the codes which identify the sets of independent variables, and the groups of experiments to be performed. The first two groups, while they do accumulate data for general use, have the specific objective of economizing on the number of experiments needed to cover the intended ranges of variables. The range of warp tension values is explored in Chapter 5 and the range of unbalancing in Chapter 6. These lead to the comprehensive set of experiments on plain weave which form the heart of the thesis, in Chapter 7 and a rather less comprehensive set for 2/2 twill in Chapter 8. In Chapter 9, there are collected some data on the properties of the fabrics made in the experiments. The exploration of fabric properties was not initially an objective, but as it is probably not very often that a range of fabrics produced in such a well-documented way is available, it seemed a pity not to explore those properties that could be measured relatively easily. Finally, in Chapter 10, an attempt is made in summarizing and reviewing the data, to draw conclusions about the way the settings interact in influencing the process of cloth formation, and an experiment is described which shows the practical use that can be made of the knowledge about optimum settings in the weaving of fabrics of very high sett.

CHAPTER II

2. MEASUREMENT TECHNIQUES

CHAPTER II

Measurement Techniques

2.1 Introduction

The main objective of this study is to measure the beat up force exerted by the reed on the cloth fell under a wide range of weaving conditions. In order to specify these conditions, and to try to understand how they influence the weaving process, other related parameters have to be measured. Some methods used by previous workers have already been described. Here the methods developed or used in the present study are described and criticized, and calibration procedures together with correction factors are discussed. They relate primarily to the measurement of beat up force, but warp tension, cloth fell distance, shed balance and shed timing are also discussed. This chapter, together with the next one, in which all relevant loom and fabric details are assembled, prepare the way for an account of experimental procedure and presentation of results in subsequent chapters.

2.2 The measurement of beat up force

Of the methods previously described for measuring beat up force, that used by Badve gave the most convincing traces, while that tried out by Yehia and developed by Leung was the most practicable and eventually gave results that were useful although not perfect. The first objective of the present work was to improve that method as far as possible.

The traces of beat up force against time - which had mostly been recorded on a Bruel and Kjaer level recorder, showed two features that seemed to need improvement or explanation. They can be seen in Fig 6

Figure 6. Recorded B.U.F. traces (from Yehia's work)

and reproduced from Yehia's thesis. They show mechanical vibration and/or a residual inertia effect (i.e. incomplete cancellation of the unwanted signal) which made it difficult to measure small values of beat up force, to study the shape of single traces or to determine clearly the position of the datum line. There are also alternating higher and lower values of peak value, repeating regularly under some conditions of weaving, and the question arises whether these are true variations or are introduced by the system of measurement.

By examining critically the methods used, a number of possible ways of improvement can be seen. Firstly, the pen recorder itself, because of its inertia, is always liable to distort rapidly varying signals and its controls have to be used to obtain the best compromise between over-damping and over-shooting. Fortunately there had become available a storage oscilloscope that overcame these difficulties, and yet was almost as convenient to use. It permitted photographic recording, or even tracing from the screen, of those traces that resulted from successful experiments.

An obvious possible source of error in the strain-gauged cantilever system arose from the angle at which the upper cantilever had, for convenience, been mounted. This had been chosen so that the reed cap could be used as a stop to make the cantilever bend, but it also meant that it was sensitive to horizontal movement of the reed in its mounting. Symmetry could be improved by mounting this cantilever horizontally like the lower one, so that more efficient cancellation could be achieved. A shaped clamp was made which was locked to the reed cap and a new fixing arrangement for the cantilever introduced. Two separate a.c. bridges were used for the two cantilevers and their amplified outputs were combined in adjustable proportions by feeding each through an

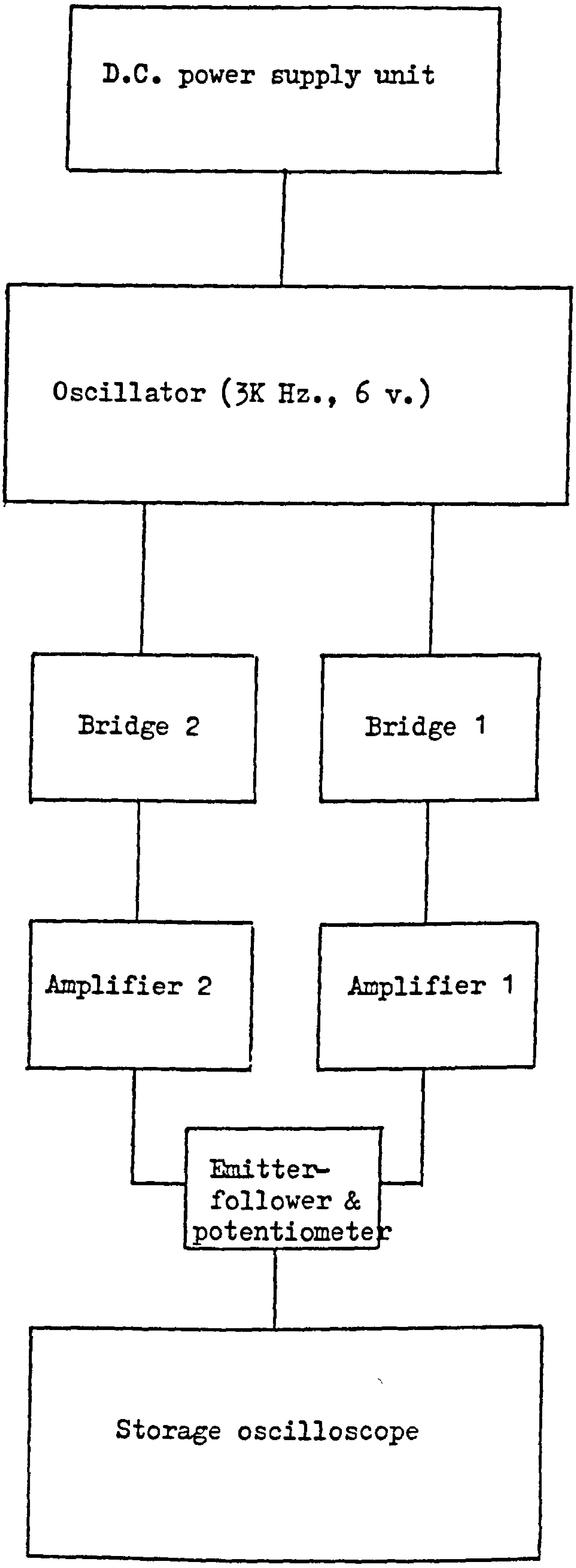


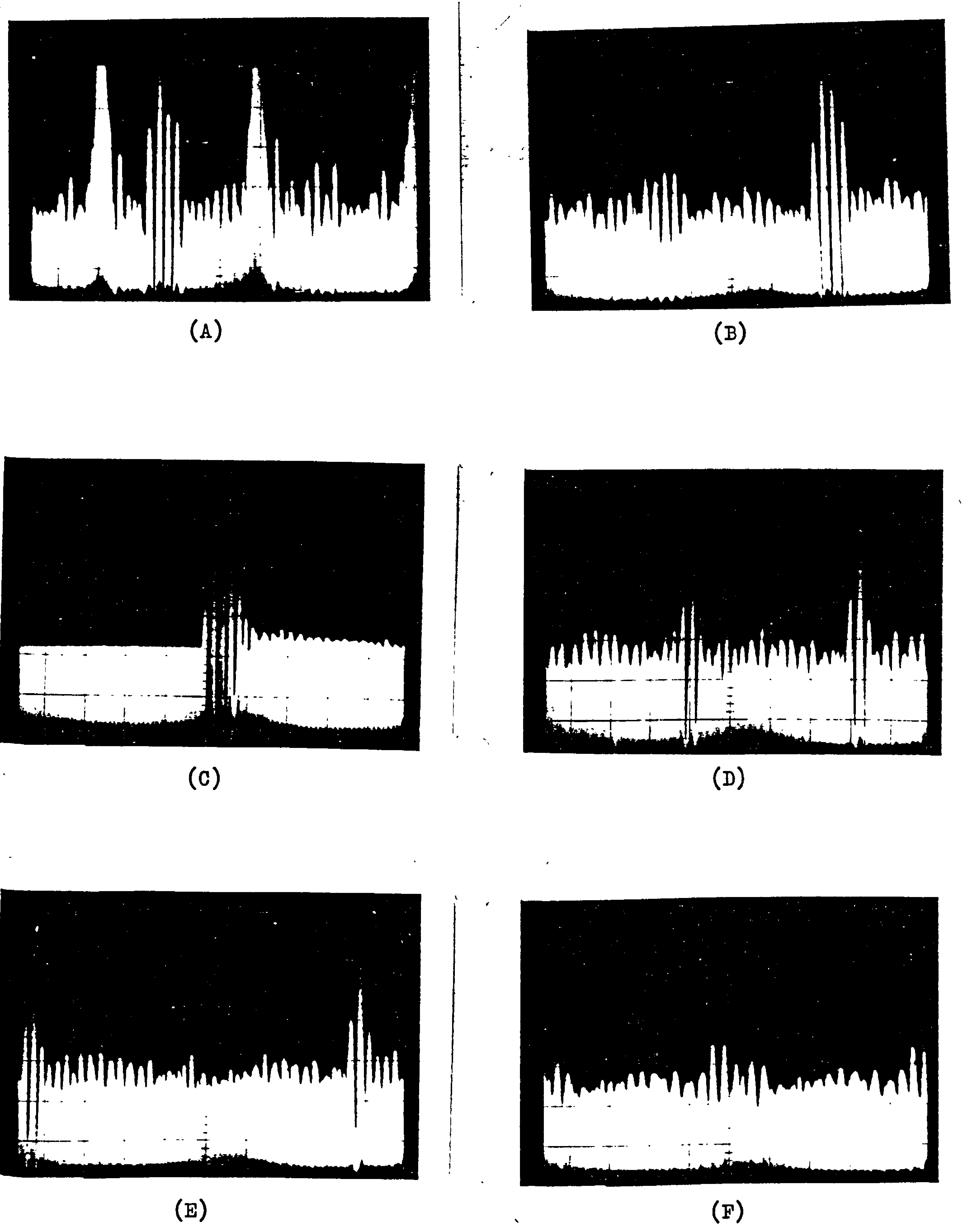
Figure 6.1

Beat-up force measuring circuit block diagram emitter-follower buffer stage, to the one end of a linear potentiometer with the output taken from the slider. Care was taken to use identical bridges and amplifiers so that the carriers of the signals to be combined were, within 1 or 2 degrees, in phase.

2.3 Preliminary results - first loom

The system was fitted to the same Dobcross loom used by Yehia and Leung. Fig 7A shows the output trace. It shows the beat up force signal emerging from considerable noise, with a particularly severe burst of noise at the time of picking. These do not mask the beat up signal but they may affect its value.

Before attempting further development, it seemed necessary to study this signal. By withdrawing the cloth fell, a trace without beat up force was recorded at (B). It is not exactly like that at (A) minus beat up force, but is fairly similar. The group of four large peaks repeating on alternate cycles with a similar, but much smaller group inbetween was confirmed to be due to sley vibration by recording, at (C), the signal caused by drawing the sley forward until it struck the emergency stop ("bang off") mechanism. To confirm that the sley vibration was caused by the sudden speed change due to picking, the loom was run without a shuttle, giving the trace at (D) - still showing the peaks but in modified form. Then the picking sticks were tied back so that the cams did not contact the bowls thus completely eliminating the effect of picking, first at the right-hand side (E) and then at both sides (F). Even at this stage, smaller peaks remained at about the same frequency and arising, possibly, from vibration of the sley or reed cap, or looseness of the reed in its mounting, and probably caused by speed variations due to the driving gears. There was also



(A) (B)

(C) (D)

(E) (F)

Figure 7. Reed-strain-gauge records, first loom

apparent some uncancelled effect of inertia forces arising from the normal sley movement. The method was not yet as effective as Badve's, though it could probably be used if the trace were suppressed at the time of picking by shorting the input to the oscilloscope with a crank-shaft operated micro-switch.

2.4 Change of loom

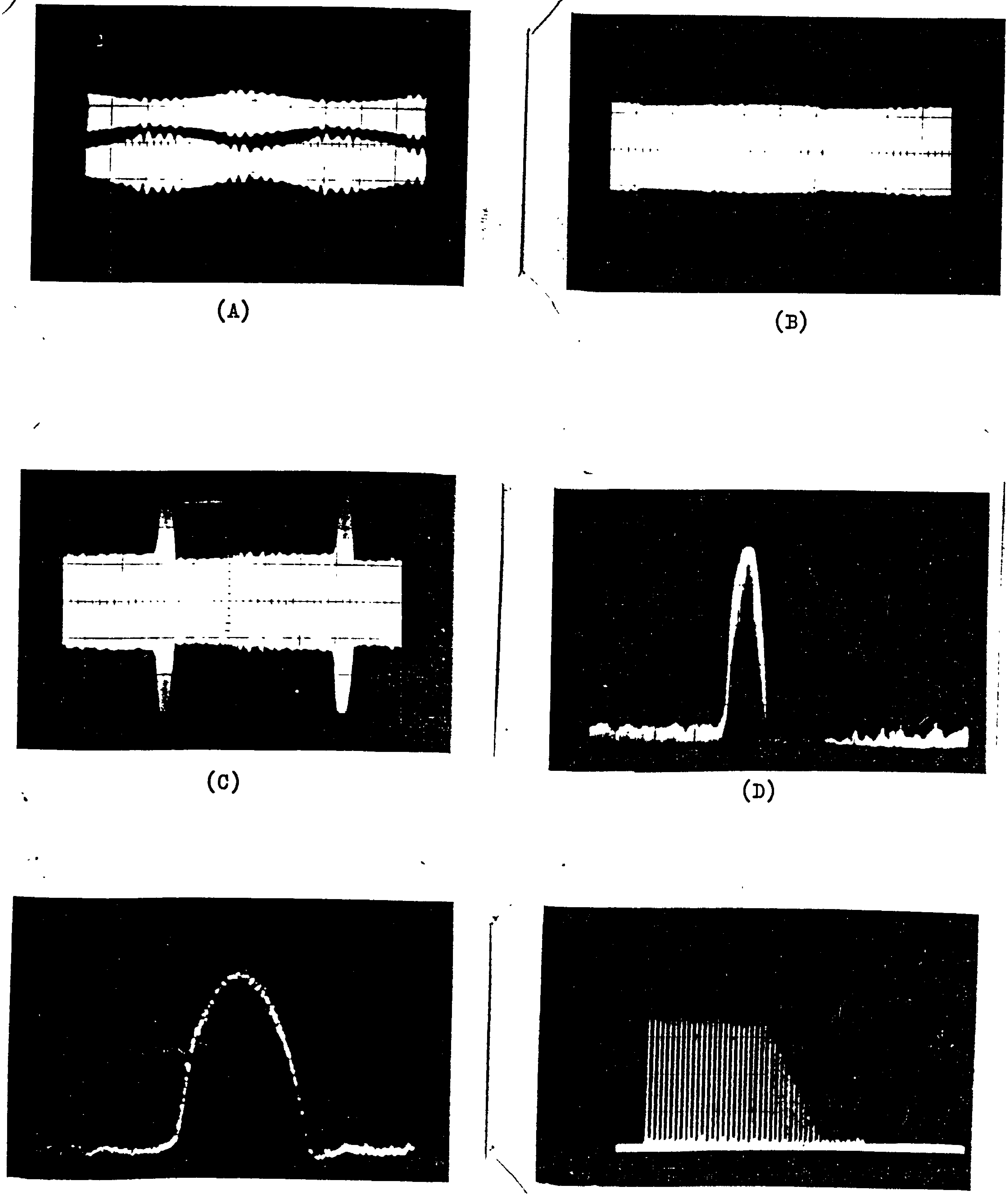
At this stage a major disturbance occurred when, due to a re-organization of the department, this loom was to be scrapped. The research had to be transferred to a different loom, the one allocated being a Crompton and Knowles P.A.P.A. loom, new in 1958. This change was fortunate in two ways. First the loom was in a better state than the much older Dobcross; secondly, because of the experience with the earlier loom, this one was overhauled and carefully "tuned", and the instrumentation applied with particular care.

The reed cap, made of wood and of rectangular cross-section, was easier on which to fit the cantilever-stop. The original reed, slightly shortened, was transferred to this loom, but new cantilevers with new 100 ohm gauges, carefully fixed, were used. The weft fork was removed and its slot in the sley deepened to take the lower cantilever and its support. Signal leads were run through carefully fixed four-core screened cable, along the back of the reed and down the sley-swords. The measuring circuit consisted of the two bridges fed by an oscillator giving 3 k Hz at about 6 v peak to peak. The rest of the circuit was as before and is shown in the block diagram, Fig 6.1.

2.5 Preliminary results - second loom

When all preparations had been completed and the gauges had been checked, the signals from the two bridges were recorded separately but simultaneously with the loom running without weft. The results were encouraging as can be seen in Fig 8A, which shows the two signals adjusted to have the same amplitude of modulation - i.e. ready for combining. Each trace represents the amplified bridge-output, the bridge being set slightly out-of-balance so that the trace can increase or decrease to indicate forces in either direction - i.e. the envelope of the trace represents the signal from the bridge. Not only the main inertia effects seemed likely to cancel, but the remaining vibrations were of small amplitude and also very largely in opposite phase. This is confirmed in (B) which shows the combined trace (with no weft) while the degree to which noise has been reduced in comparison with the signal can be seen at (C)* and at (D) which gives an enlarged trace that is the upper edge of the envelope seen in (C). The improvement may be due partly to the improved instrumentation, but is probably due largely to the change of loom. The wooden reed cap is probably more damped than the metal one of the Dobcross loom; there is a central "sword" supporting the sley of the C & K loom and there is probably much less back-lash in the gears and bearings. At (E) is seen a single beat-up trace, elongated on the time scale by use of a faster time-base, and having the brightness adjusted so that just the envelope of the carrier is visible. At the other extreme, a very slow time-base is used at (F) so that a succession of traces are seen as vertical lines, the height of which represents the peak beat-up force. Variation in that force is easily seen in this display as, for example, when the pirn is allowed to run empty so that beat-up occurs on a fell that is gradually being drawn forward by the take-up roller, away from the reed, so giving a decreasing series of forces. This trace also illustrates the very low noise level.

* with weft



(A) (B)

(C) (D)

(E) (F)

Figure 8. Reed-strain-gauge records, second loom

Having obtained a method of measuring beat up force that does not contain obvious large errors, it is still advisable to examine the traces carefully to see that what they show is reasonable and is the information required. When the traces of Fig 8 are inspected closely, there are a number of points of interest. In trace (B) there is a small variation that might be a residue of the inertia force due to the sley oscillation. However (C) shows that it does not have the correct phase for that - the sudden reduction in trace height seen in (B) actually occurs during the peak seen in (C) and the two levels are visible at either side of that peak, gradually changing during the rest of the cycle. This is considered to be the effect of friction forces between the warp ends and the reed wires. When a number of warp ends pass through one reed dent, they are caused to group together. The interlacing of the weft, however, tries to return them to a more uniform spacing and so they are pressed against the reed wires. In addition, because the crimped (and therefore stretched) weft is under tension, the cloth tends to contract in width (hence the use of temples) and so the warp threads are drawn to one side of the reed dent and press against the wire. The direction of the friction force on the reed changes when the direction of the reed movement changes, at front centre and back centre. That at front centre is larger (especially as at (C) when weft has been inserted) because the fabric holds the ends so they press the wires; at back centre they are more free to bunch together and the yarn/reed pressure is less. By moving the reed backwards and forwards by hand, it was confirmed that a step of the right order was produced.

Another feature of more direct importance that needs to be explained is the shape of the single trace at (E). If the peak is assumed to coincide with front centre, then it appears that the period of contact with the fell is greater after front centre than before. The opposite might be expected as the resistance of the new pick will be sensed before it takes its place in the cloth, and so the suspicion of hysteresis is raised. However, it is more likely that the peak of the trace does not coincide with front centre (because of the influence of shedding and back-rail oscillation on fell position). Subsidiary experiments (see Chapter 10) in which a front-centre marker was introduced confirm this to be the case. It will also be seen that different rates of decrease of the trace are formed, implying that the rate is not limited by the response of the reed.

Thus the method that has been described seemed likely to give the required information about beat up force (henceforth B.U.F.), but it remains to relate the trace amplitude with the actual value of B.U.F. and to look at possible methods of calibration.

2.6 Reed sensitivity

When a single reed wire or a group of reed wires are used to indicate B.U.F., their deformation is not only caused by the weft that presses against them reacting on the ends that pass between them.[23] They are affected by forces on the reed wires at each side of them for a considerable distance. More loaded wires increase the degree of baulk rotation, while unloaded wires help the loaded ones to resist deformation, because they are all built into the same reed baulks and differences in the degree of rotation of their ends require twisting of the sections of baulk between them. It has been shown that if the baulks are held elastically by the sley and the reed cap, the rotation of the baulk varies exponentially from the centre to the selvedge position on a uniformly loaded reed section and from the selvedge to the free end of the unloaded section (Fig 9). This means that there will not be much variation at points well away from the selvedge and readings obtained at such points will represent B.U.F. provided all or nearly all the reed is loaded. But if only a short section were loaded, then the reading could vary with measuring position. It is reasonable to assume that during weaving the load is fairly uniformly distributed across the central part of the reed. During calibration it is also necessary to load the reed uniformly for a considerable distance on either side of the point where the gauges are fixed. The best way of doing this seemed to be to follow the methods used by Greenwood and, later, Badve, and load the reed by means of the cloth, applying weights to the warp. Such a calibration has to be carried out with the cloth fell set at different heights up the reed in case that influences sensitivity, as seems likely.

2.7 Calibration of the reed

It is possible to load the reed simply by winding the warp back onto the beam and releasing the take up roller. The warp tension then has to be measured either as a whole or at a large number of representative points. It was decided instead to use known applied weights to pull the warp and hence the cloth fell against the reed. In order to be able to attach the weights to the warp, a strip of fabric was woven across the warp near the back rail by manually inserting weft through a series of sheds formed using the dobby. In place of one pick a steel rod was inserted so that it was firmly locked to the warp by the cloth woven on either side of it. Polypropylene cords were tied to this rod, then the warp was slackened and tension applied by

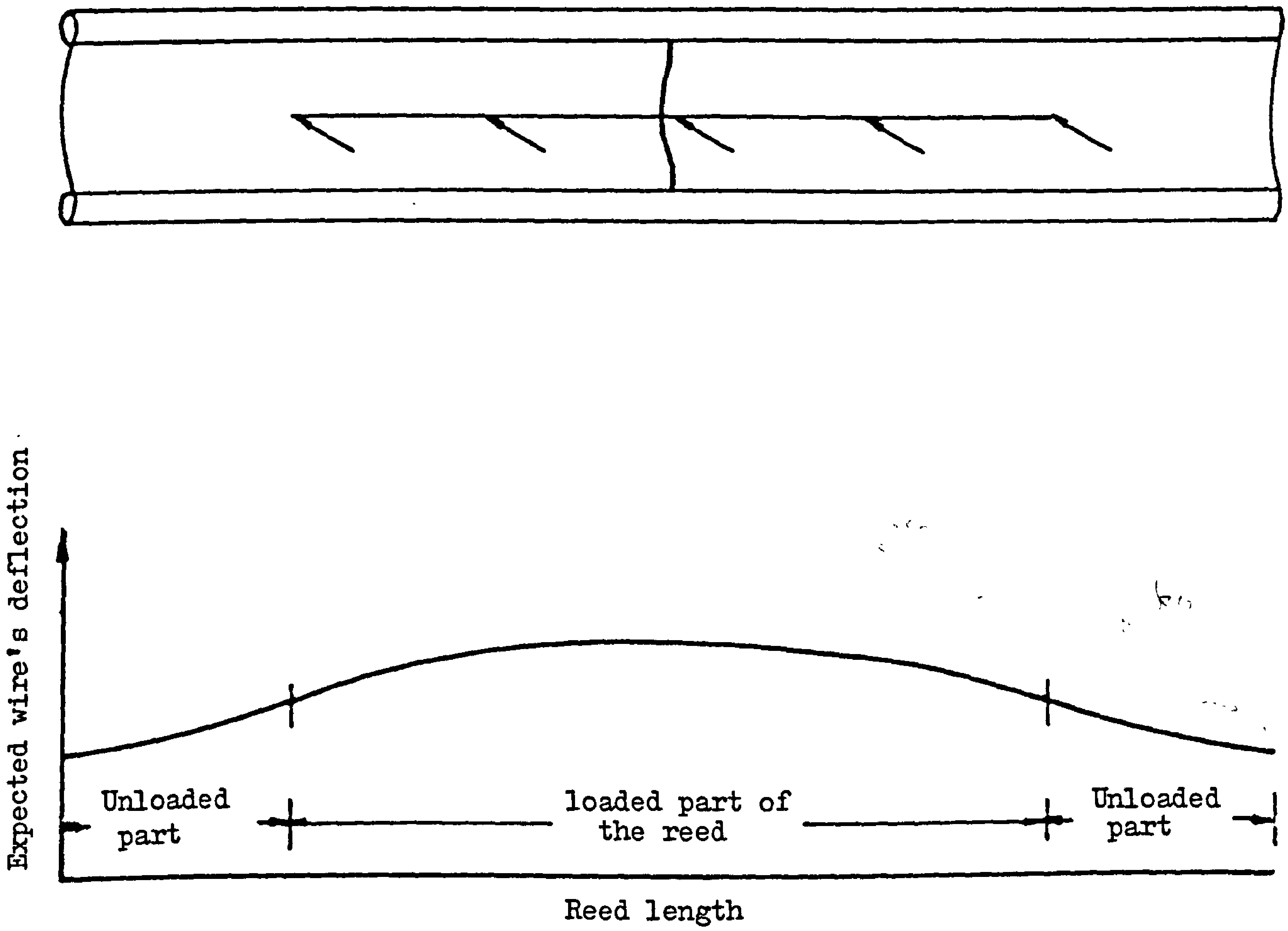


Figure 9. Expected reed wires deflection for party loaded reed

weights attached to the cords which hung over the back rail. The back rail was lubricated and readings were taken during loading and unloading so that errors due to friction could be minimized. The idea of loading by using the cords to deflect ropes, carrying weights, attached to the roof beams so as to avoid friction effects was considered, but rejected as it raised other practical problems. With the system used, the tension applied by a weight W when loading can be expected to be approximately $W\ e^{-\mu\theta}$ and during unloading $W\ e^{\mu\theta}$ where θ is angle of wrap and μ the coefficient of friction. If the trace amplitude varies linearly with load, as it appeared to do, then for calibration purposes, the geometric mean of the two values for each applied load should be plotted against the load.

2.7.1 Calibration procedure

The reed was placed in its front centre position, the healds were levelled and the cloth wound back until it was just slack. Eight groups of weights were assembled, each totalling 45.5 Kg (the value being determined by the available weights) so that they could be hung on eight uniformly spaced cords to give an increasing and then decreasing sequence of loads. The reed strain-gauge bridges were balanced in the normal way for a.c. bridges, i.e. alternate resistance and capacitance balance until the minimum output was obtained, then set a little off-balance in terms of resistance. The combined signal from the two bridges (combined in the ratio already established for cancellation of inertia forces) was displayed on the oscilloscope, and when the standard check on electrical sensitivity had been applied (by putting a standard resistor across one arm of each bridge in turn), loading was carried out. As this was a slow and laborious process, it was reassuring that the trace returned to the same zero level, indicating no creep in the gauges and no drift in the circuits. The whole process was carried out three times and the curves showed no significant differences, but as expected, the loading and unloading curves differed by about 15% (see Table 1 and Figure 10). The curve of geometric mean of these values plotted against load was almost linear (Fig 11).

2.7.2 Effect of fell height

One of the difficulties of measuring beat up force by reed deflection is that deflection depends on the height at which the load is applied. The deflection due to a load at the centre of a wire will be greater than if the load is applied near one end. Simple beam theory suggests that the variation with position will be not too great if the load is near the centre.

During weaving, the height of the fell will depend on the tensions in the two warp sheets - i.e. on the tension in each thread and on the number of threads in each sheet, so it is likely to be affected by weave, shed balance and shed timing. It is well known that under some conditions * the fell can be lifted high off the race and may disturb the shuttle's flight so that control bars have to be used to limit the movement. Weaving with an unbalanced shed is especially likely to cause the fell height to change.

On this loom the fell was normally about $\frac{1}{3}$ of the way up the reed so sensitivity was checked for variations about that position. For this experiment the cloth fell was not used to apply the load. Instead a metal rod about 4 mm in diameter was arranged to be pulled against the reed by cords that were passed through the reed, between the healds

TABLE 1

Reed calibration at 18 (mm) height from the race board

Weight/ cord (kg)	Total weights applied on the reed (1) (kg)	Trace height during loading (mm)	Trace height during unloading (mm)	Geometrical mean of loading and unloading (mm)	Force applied on the reed (2) (g/end)
0.000	0	0	0	0	0
3.250	26	3	4	3.46	9.8
7.600	60.8	6	8	6.92	23
12.950	103.6	10	13	11.40	39.2
20.500	164	17	20	18.43	62
28.500	228	24	28	25.92	86.4
36.500	292	32	34	32.98	110.6
45.500	364	41	43	41.98	137.9

(1) Total weights = weight/cord x 8

(2) Applied force (g/end) $= \dfrac{\text{total weights applied on the reed (g)}}{\text{total number of ends (60 x 44)}}$

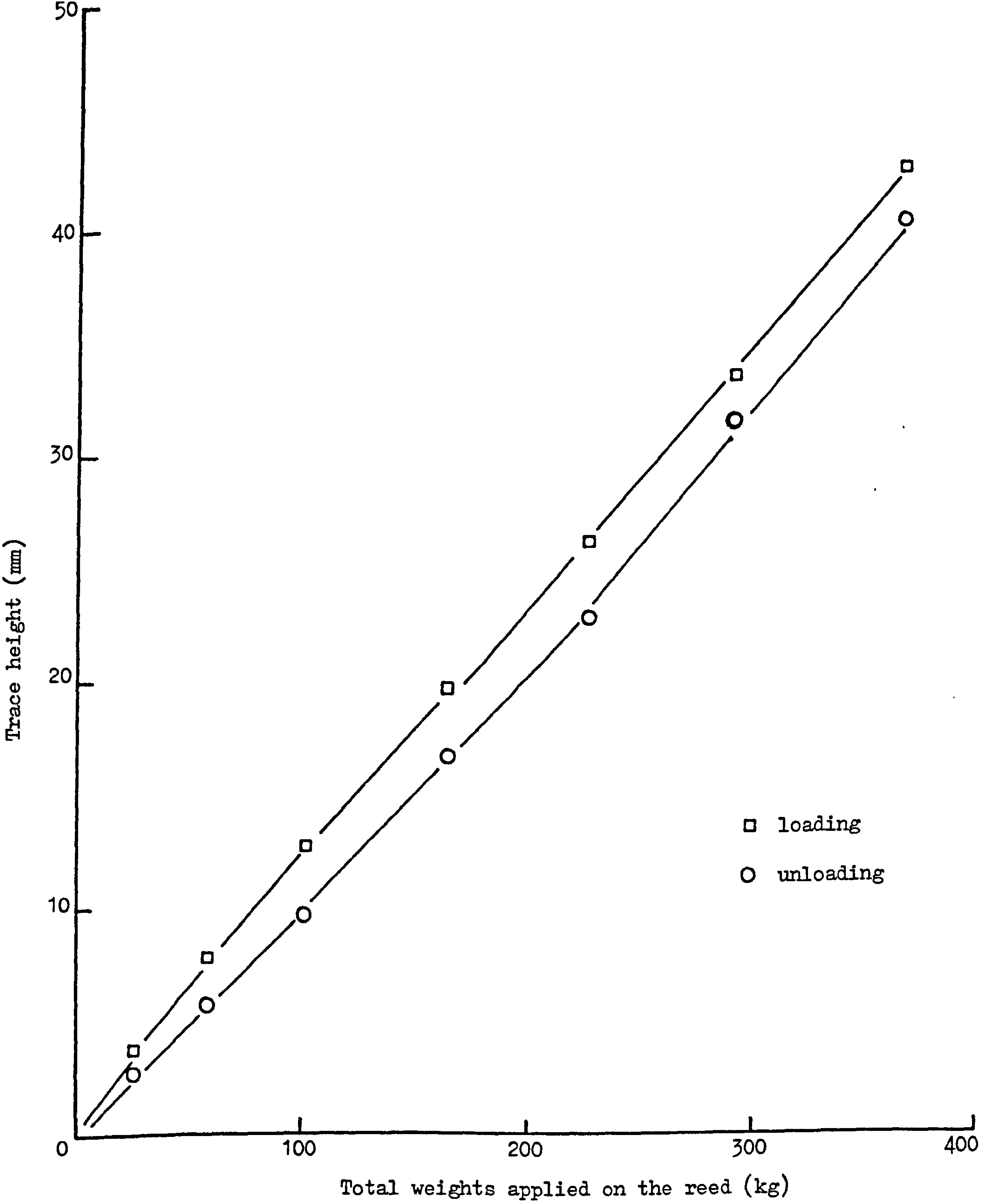


Figure 10. Beat-up trace height during loading and unloading

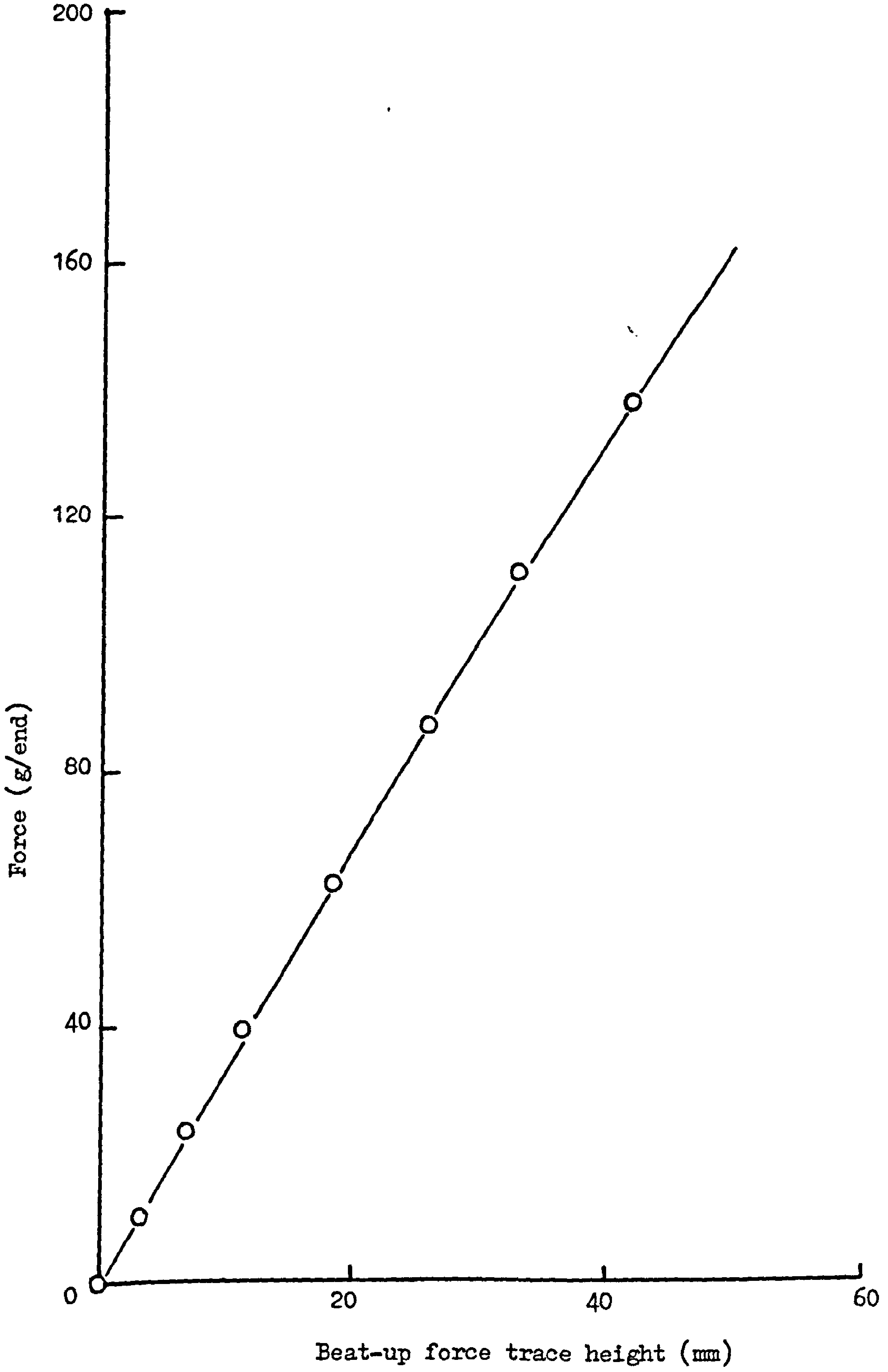


Figure 11. Reed calibration for load applied 18 mm above race

and over the back rail. The rod was easier to control than the fell and its height could more easily be measured. It was moved in 2 mm steps from the race board to the reed cap, a total distance of 8 cm. In each position the trace height was recorded, the tension being kept constant. The small change of angle for this range of movement on a length of cord of 140 cm to the back rail would have negligible effect on the load applied. The calibration was carried out for two values of tension, 48 g/end and 86 g/end.

The results are shown in Table 2 and Fig 12. They are more or less as expected, with a considerable flat region when the load is applied half-way up. It must be remembered that the results apply to a particular combination of the two bridge outputs and might differ for other combinations. Because the normal fell position is in a region of noticeable slope, it is necessary to make a correction for fell height of roughly -1% for each 2 mm rise, and + 1% for each 1 mm fall in fell height.

2.7.3 Expected variation in fell height

The normal fell position, at which the main calibration of the reed had been made was marked on the reed. During the whole range of experiments for measuring beat up force the loom was stopped at least once during each combination of settings, the reed brought to front centre and the position of the fell compared with the normal position. The appropriate correction could then be made for each value, provided that the fell height was the same during static and dynamic conditions. It cannot be proved that they were the same, but there is no evidence that they were not. The total range of movement encountered was ± 16 mm and the associated correction ranged from - 7% to + 18%.

TABLE 2

Correction factor of beat-up force by the cloth fell height C.F.H. (mm)

Cloth fell height* C.F.H. (mm)	Correction factor under 48 g/end	Correction factor under 86 g/end	Average correction factor
+ 16	0.933	0.928	0.93
+ 14	0.933	0.928	0.93
+ 12	0.933	0.928	0.93
+ 10	0.933	0.928	0.93
+ 8	0.933	0.950	0.94
+ 6	0.95	0.96	0.95
+ 4	0.973	0.975	0.97
+ 2	0.986	0.980	0.98
0.0	1.00	1.00	1.00
- 2	1.02	1.02	1.04
- 4	1.05	1.04	1.04
- 6	1.08	1.06	1.07
- 8	1.10	1.08	1.09
- 10	1.14	1.10	1.12
- 12	1.18	1.13	1.15
- 14	1.20	1.15	1.17
- 16	1.20	1.18	1.19

* Measured from normal cloth fell position (18 mm) from the race board at which reed calibrations were made with horizontal back rail and closed shed.

Correction factor $= \frac{B}{A} \times 100$

where (A) is B.U.F. trace height (mm) at the required reed height from the race board,

(B) is B.U.F. trace height (mm) at 18 mm from the race board.

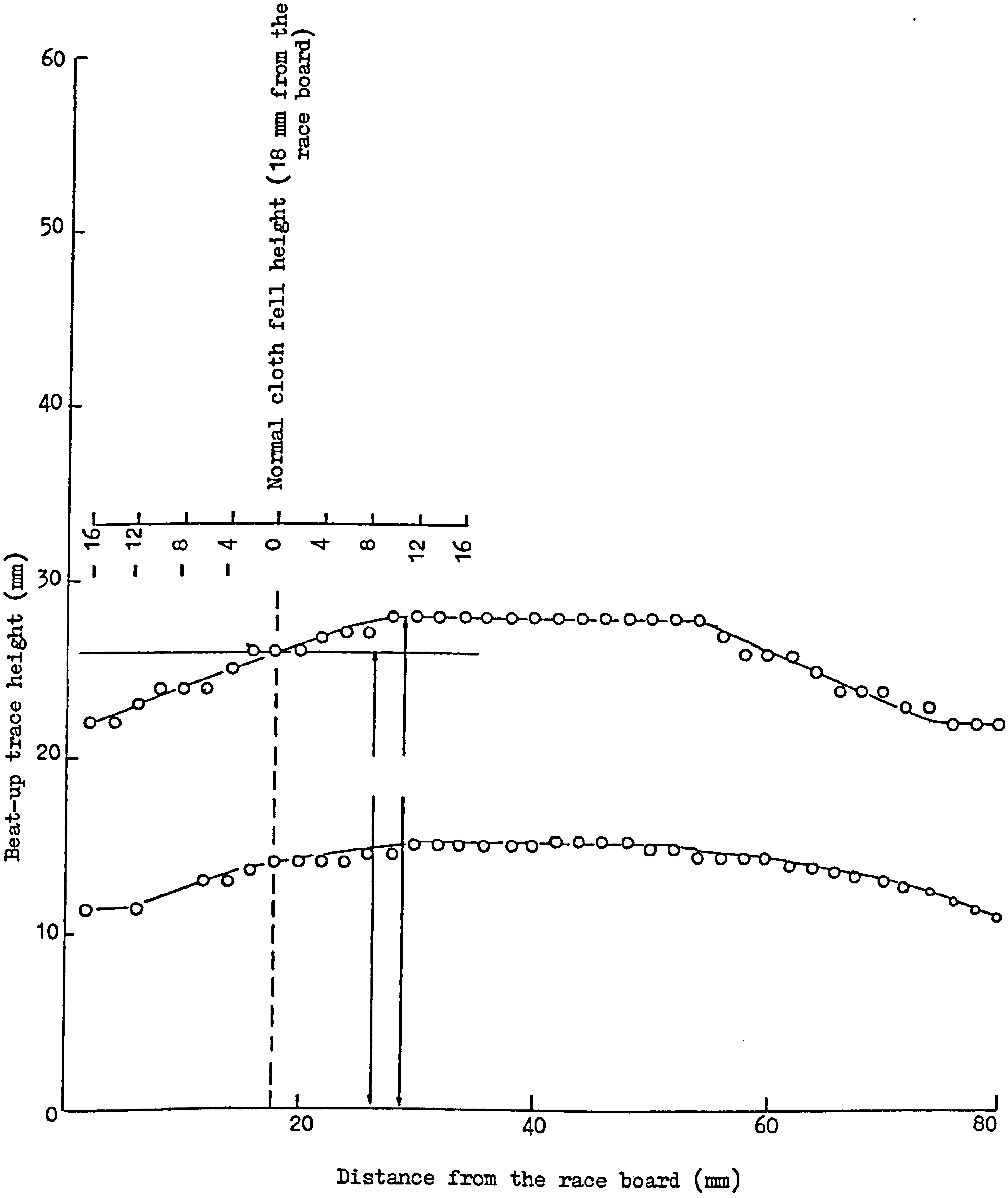


Figure 12. Reed calibration - effect of cloth fell height (C.F.H.)

2.7.4 Effects of spring loaded connecting arms

The connecting arms from the crankshaft to the sley sword of this loom are telescopic and maintained rigid by pre-compressed springs, so that when the loom "bangs-off" due to operation of the warp protector the shock-load on the crankshaft is limited. It is assumed that the springs will not compress during normal operation, but while the reed calibration was being made it seemed a good opportunity to check that the springs would not deflect under the loads available. Dial gauges were mounted on the loom frame to bear against the sley sword and the fell was pressed against the reed, as during calibration, until a trace corresponding to a load of 150 g/end was obtained. The deflection of the sword at race level was 0.076 mm (.003"). This seemed acceptably small and was probably not an indication of any spring-deflection; it did not suggest that sley movement would differ significantly from its nominal form on this account. Probably a greater deflection at the centre of the sley will arise under dynamic conditions due to sley bending.

2.8 The measurement of cloth-fell distance

The beat up force is developed by displacing the cloth fell. That is why the "cloth fell distance" (C.F.D.), the distance between the front-centre position of the reed and the position of the undisturbed cloth fell, is important. When the loom is not running, that distance can be measured, for example, by using dial-gauges to locate the front-centre position of the reed. It is more difficult when the loom is running. Greenwood used an optical system to project an image of the fell onto a screen. Badve's oscilloscope display showed not only the value of B.U.F. but also the position of the reed relative to its front-centre position. From the two the C.F.D. could be found, the position of the fell being the point at which B.U.F. began to increase from zero.

In the present work it was not, initially, one of the objectives to measure C.F.D., the purpose being primarily to measure B.U.F. rather than to explain how it arose. However, almost by accident a possible method of measuring C.F.D. emerged. When B.U.F. was being recorded with a slow time base as in Fig 7F, the weft broke and, because the weft fork had been removed, the loom continued to run. As no cloth was being produced, the fell was drawn forward by the take up roller and struck by the reed with decreasing force on successive cycles until the reed no longer contacted the fell. If it is assumed, as in Greenwood's treatment of the subject, that there is a distinct fell with picks not slipping back, then each beat up trace in that decreasing sequence represents a movement equal to one unit of take up. Knowing the number of peaks in the sequence, the total movement of the cloth up to the point where contact is lost can be calculated; that is the cloth-fell distance. Often the descending sequence is so linear (as in Fig 7F) that estimates to a fraction of one take up unit can be made. However, in many cases, as will be seen, the envelope is not linear. There are a number of possible reasons for this that will have to be examined. Firstly, C.F.D. is, in the simplest view, the extension of the warp and the reduction in the extension of the cloth, so that the envelope of a trace such as Fig 7F represents a load-extension curve for the combination of warp and cloth; but it is one related to the dynamic rather than "static" moduli. Secondly, even the "static" (i.e. slow strain) curves are likely to be non-linear at low loads. Thirdly, this "C.F.D." represents the distance travelled by the reed in contact with the cloth rather than the displacement caused by the reed, i.e. as Badve pointed out, part of that distance represents displacement due to shedding, etc. Fourthly, in practice, it is possible that beaten-up picks slip back, and that when no new picks are being inserted, they slip more than during normal weaving. Values of C.F.D. obtained from such traces will be compared with static measurements and also with values deduced from the duration of contact of reed and fell that can be deduced (but also not with complete confidence) from traces such as Fig 7D.

2.9 Values of other parameters

The parameter of major interest in this work is weaving resistance, measured by recording reed deformation. However, previous work suggests that it is not only a property of the fabric being woven, but also of the loom settings, particularly warp tension, shed timing and shed imbalance. In the present work, the yarns and nominal setts are kept constant so the "independent" variables for the experiments are warp tension, shed timing and tension ratios in the two warp sheets. In fact, these parameters are not truly independent as they tend to interact a little. However, there are some independent variables that determine them and that can be set. The ways they can be set, the range of settings that can be used and their direct effects will now be discussed.

Basic Warp tension

The basic or static warp tension is set on the loom by loading with weights a lever linked to the back rail (see loom details), which presses against the warp sheet. There should be a direct relationship between warp tension and applied weight, but in practice it will be modified by friction in the mechanical system, and also between the warp and parts of the loom that it touches. Dynamic effects will also occur. Therefore, although the applied weight needs to be stated to specify weaving conditions, it is necessary to measure the actual tension.

2.9.1 Range of warp tension

Warp tension is needed to control the yarns, to ensure a clear shed and good shuttle flight (or efficient insertion by other methods) avoiding "stitching". It also has an effect on fabric properties by altering crimp balance between warp and weft. A fairly narrow range of tension values will normally be needed, but in this work the widest possible range was to be explored so as to obtain as much data as possible about the influence of warp tension on weaving resistance.

2.9.2 Limitations to warp tension range

Two obvious limits to this range are the one where the shed becomes slack so the shuttle may be thrown out or a lot of end-breaks occur. At the other extreme, if the tension is too high, the ends also break because of abrasion usually. However, when weaving with a high sett, there are other limitations. Too low a tension results, probably because of reduced elastic modulus at low tension, in a large cloth-fell distance leading to severe bumping and violent oscillation of the back rail and weight lever, which may strike the floor or the frame. Too high a tension may have a similar effect because weaving resistance is increased; on one or two occasions the high resistance stopped the beat up by causing the overload relay to operate. A high tension may cause such a high weft crimp that cloth contraction causes hard rubbing of the selvedge ends or even splits the fabric where it is gripped by the temples so that a stronger or more elastic weft has to be used.

2.9.3 Warp tension adjustment

The warp tension setting was varied by varying the number of weights on the holder suspended from the weight lever, or by changing its position along the lever. The weights used were those provided with the loom which were marked in units of 4, 2 and 1. The units were approximately 2 kg but there was about a 5% variation between the weights. The maximum tension used five-unit weights on the outermost position; the minimum was when even the holder was removed, but it was then difficult to weave, and impossible with late shed timings because of excessive fell displacement.

2.9.4 Warp tension measurement

For the measurement of dynamic warp tension, a method was needed that would have a reasonable response, would be convenient to use and display, and would be able to give representative values for different groups of threads - e.g. upper and lower-sheet threads. None of the available methods is really satisfactory because they all measure the tension at the back of the loom, not near the cloth fell where it is really needed. The gauges used by Wetzel[19] and by previous workers at Leeds University seem to be as good as any, and were used for this work. One is illustrated in Fig 5.[*] A channel shaped piece of ½ mm thick brass had 3.5 mm diameter steel rods soldered along its lower edges and a 6 mm diameter rod mounted on two screws from its centre so as to form a "three-rod" system in which the yarn tension displaces the centre rod through a small distance relative to the other two and by doing so slightly bends the "back" of the channel. The bending is

[*] Page 18

measured by two nominally 100 Ω wire resistance strain gauges mounted on opposite sides of the part that bends. This method avoids the problems of rotational inertia that arise with pulley systems. The gauge travels with the warp and is light enough not to add significantly to the tension. A slight disadvantage is that it has frequently to be drawn back along the warp sheet, but usually continuous recordings equivalent to the production of 5 cm - 10 cm of cloth are possible. Two such gauges were used, one for each of the warp sheets in plain weave; they were connected to bridges and amplifiers similar to those used for the B.U.F. gauges. They were calibrated off the loom by threading them onto a vertically hanging weighted tape. Calibration was almost linear, but differed slightly for the two gauges. A potentiometer was added to the circuit of one of them and set to make both sensitivities the same. The relationship shown in Fig 13 can thus be taken to apply to both gauges.

2.9.5 Warp tension ratio

It was required to weave with sheds unbalanced in different degrees over as wide a range as possible. The normal way of unbalancing (i.e. making the tensions in the upper and lower sheets different) is by what is known as "troughing" the shed. This is achieved by raising the backrail of the loom so that the line from the cloth fell to the back rail passes above the mean of the upper and lower sheets. This normally means that when the shed is closed, in roughly the mid position, the warp sheet dips towards the healds from in front and from behind. The amount the back rail can be raised is usually limited by the loom construction and also because the control of the warp let-off might be disturbed. To allow greater change of tension ratio between the two

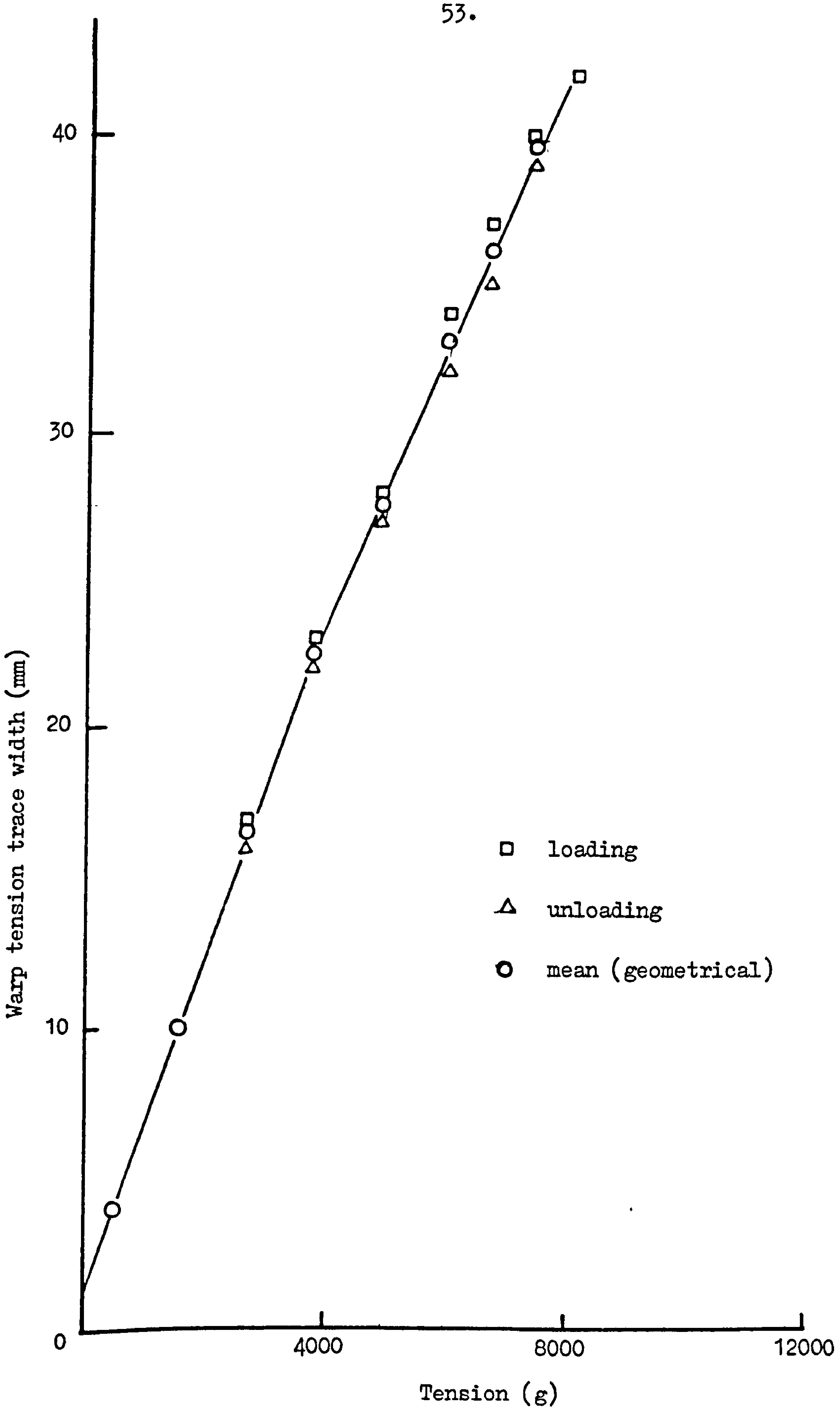


Figure 13. Calibration of warp tension gauges

sheets two additional rollers were fixed on the loom between the healds and the back rail. They had to be placed not too near the healds so as not to restrict the shed opening too much, but also not too near the back rail so that they would leave a section of flat warp sheet on which warp tension could be measured. They were actually placed at a point just over half way from the healds to the back rail where there was a convenient point for mounting them. The arrangement is shown in Fig 14. Two 3" diameter tubes formed the rollers which were mounted in good bearings on brackets, A, that held the rollers so that they were parallel and had a 2 mm gap through which the warp could pass. The whole assembly could be raised and lowered 2 inches above or below the symmetrical warp line, being carefully set by wing screws, D, and then clamped by screws, E, to the support, B, which was mounted on the cross girder, C. It was also possible to widen this range to 5 inches each way by passing the warp sheet outside instead of between the rollers. This large range, together with the closeness to the healds, was expected to give a large range of tension ratios. Some slight reduction in the effect can be expected because the fell moves up or down and the yarns move within the healds, while the healds themselves will move slightly due to the elasticity of the supporting cords, but the effect of all these compensating factors will be small.

2.9.6 Measurement of tension ratio

The tension ratio was measured by passing the two warp sheets (i.e. alternate warp threads) each through one of two identical tension gauges of the kind described earlier (Fig 5). The gauges were arranged in line, the ends which passed through one going under the other and vice versa. They were placed near the centre of the warp and 32 ends were

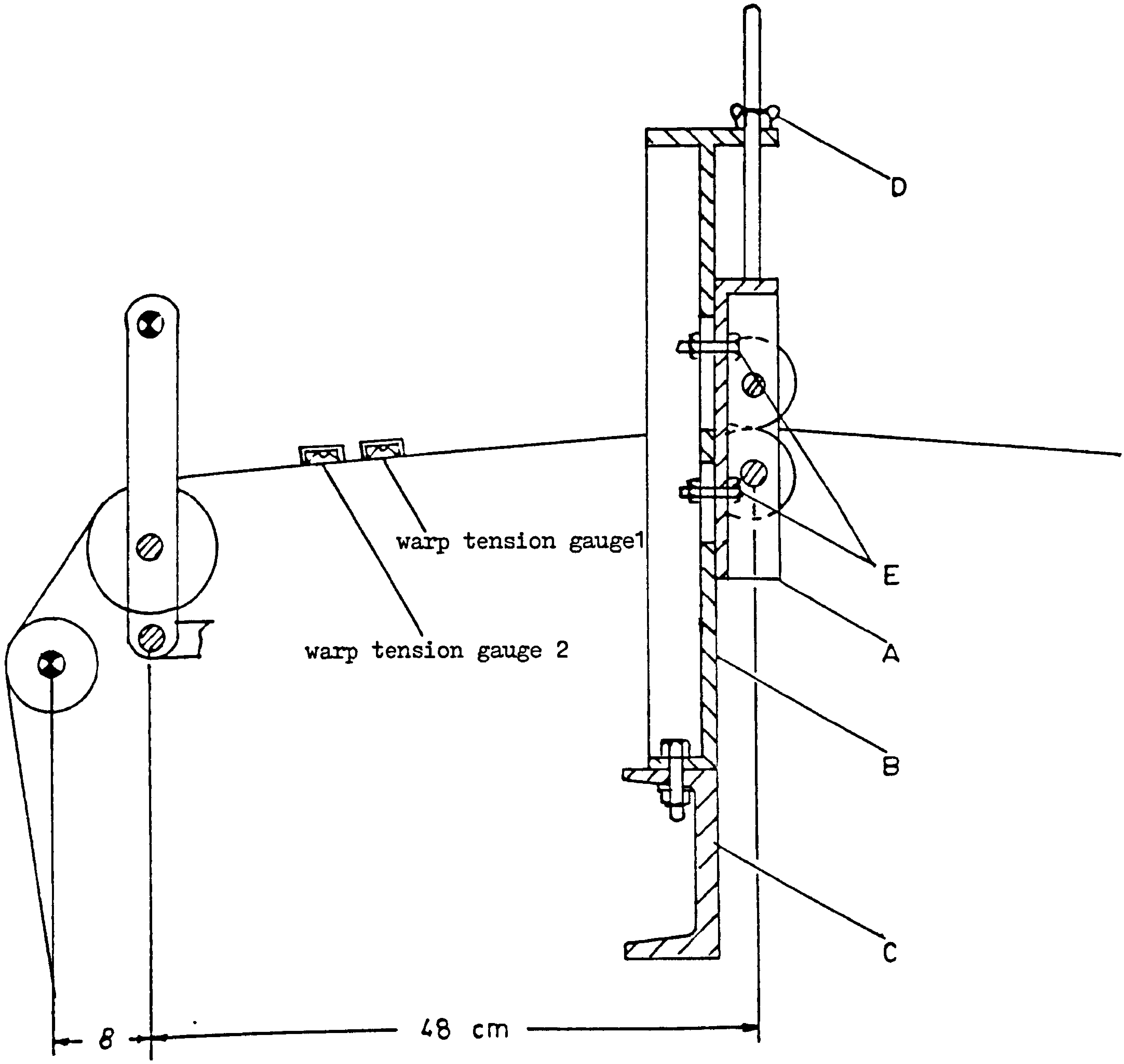


Figure 14. Arrangement of extra rail on loom

passed through each gauge - an equal number from each heald shaft so that the effects of slight irregularities in shaft position or movement would be averaged out. The bridges were balanced to give zero width trace for zero tension. There was no need to be able to measure a negative value and the sensitivity of the units was sufficiently great as not to introduce a noise problem. Therefore, the normal precaution of not working at zero-level was not observed in this case so that more room would be available on the CRO screen to display both traces together. The traces were photographed (examples will be seen later) and from the photographic negatives the outlines were traced under an enlarger (see Fig 15) or measured directly. Fig 15 shows four pairs of traces, each pair indicating the tension variations of the two separate sheds throughout four loom cycles - the tension being proportional to the trace width (because zero tension corresponds to zero width). The four pairs correspond to the warp control rollers being raised 1, 2, 3, 4 inches respectively. Similar results would be expected if the rollers were lowered. The traces not only show, in detail, how the tension levels interchange as the shed changes - they also show the beat up peak of tension, and it is clear even from these preliminary traces that this peak reduces as the shed becomes more unbalanced - although the maximum value may not be less because of the tension being concentrated in the one sheet.

2.9.7 Shed timing

Earlier experimental work has shown, and theoretical work has predicted that shed timing has a noticeable effect on weaving resistance. There are at least four reasons for this. The angle of the shed at beat up affects the pressure that the warp exerts on the weft

Figure 15. Sample of warp tension traces

and so directly affects the frictional resistance to pick movement. The angle of the shed also affects the degree of imbalance of the shed, when that is caused by raising the back rail, because a closed shed is also balanced. Thirdly, the angle of the shed may influence the extent to which picks slip back and the number that slip back after being beaten up. Fourthly, it affects the value of warp tension and, through that, warp and cloth elastic moduli.

Shed timing, in relation to beat up or crank shaft angle is normally adjustable, usually by having the driving gear for the dobby fixed to its shaft by two set screws. It is often specified by the crank angle at which the healds are level, or by the distance of the reed from front centre when the healds are level. Both methods have to be used with care because with some shedding systems, the heald displacement/time or displacement/crank angle curve is not such that the upper part is exactly the same shape as the lower part, and that can lead to the loom being set so that the "healds level" points are not 180^o apart.

The shed should, ideally, be timed so that the shuttle enters a clear shed and leaves a clear shed, but in practice with some yarns it is possible to have the shed closing on the shuttle as it leaves the shed. It is also possible, but not advisable, to have it enter a shed that is not fully open. There is often a good deal of choice in the timing of the shed and one of the aims of this work was to see what advantage could be gained by using that choice. Most previous work has used three timings described generally as early, normal and late. It was decided to use here a much wider range and a greater number of settings within the range.

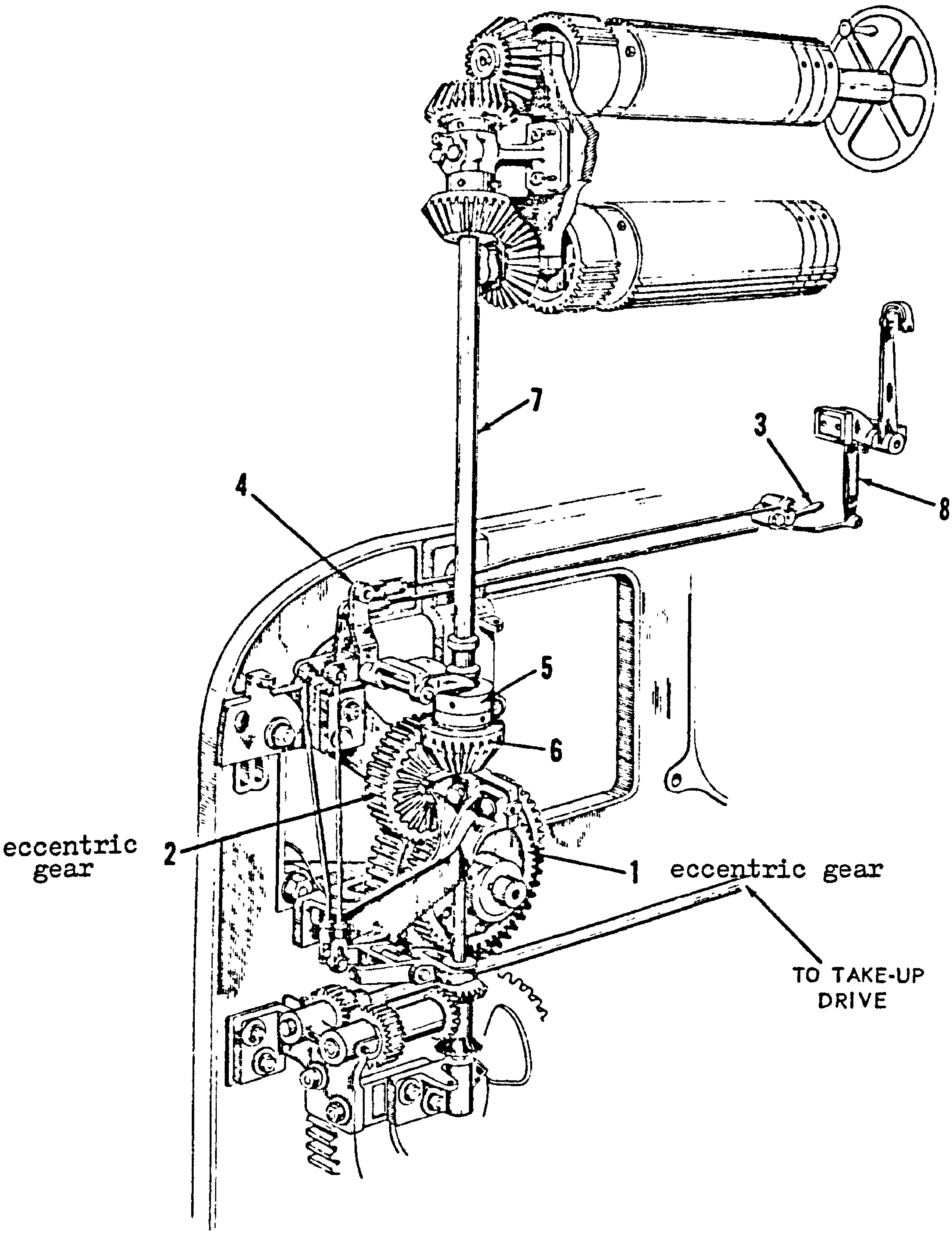
Practical limitations

The shed timing was gradually adjusted from the "normal" settings until the limits were reached. As it was made earlier, it began to close on the shuttle and the loom "banged off", i.e. the shuttle reached its box too late to prevent the warp protector operating to cause an emergency stop. The range could then be extended by increasing the force of picking to make the shuttle go faster, by adjusting the swells and checking mechanisms and the warp protector. One difficulty arose from the fact that the loom was basically a "pick-at-will" loom in which picking was engaged by a jaw clutch operated by the dobby. If engagement was late, because the shedding was made late, the clutch might be only partially engaged when picking took place, causing a weak pick or, on one occasion, a broken clutch. A small extension could be obtained by timing that part of the dobby that controls shuttle boxes and picking earlier than that which controls shedding, and also by timing the picking itself slightly later relative to the rest of the loom.

Eventually it was possible to weave with a range of timings varying from beating up with a closed shed, the latest timing, to beating up with a crossed and fully open shed - a range of 90°. This was divided into 15° intervals, giving seven timings denoted by L (late), L + 1, L + 2, M (medium), M + 1, M + 2, and E (early), although, as will be seen later, the last one was not often used because its effects were hardly different from M + 2.

2.9.8 Method of shed timing adjustment

The dobby is driven by a vertical shaft, through bevel gears, from an intermediate shaft which is driven, through slightly eccentric gears, from the crank shaft (Fig 16). The gear on the crankshaft is fixed by



W-3 HEAD MOTION

Figure 16. Dobby drive mechanism

two radial screws that grip the shaft, allowing its angular position to be adjusted. By slackening the screws when the loom is stopped with the brake on, and then turning the dobby by hand, the relative timings can be adjusted and then the screws tightened.

The healds were levelled with the reed at front centre, and the gear and the shaft marked so that in this "late" position the marks aligned. The gear was then turned through 90° and the shed had then become fully changed. The shaft was marked opposite the mark on the gear. Five additional marks were made at 15° intervals between these two to give the seven standard shed timings already mentioned. Table 3 shows the crank angles, shed size measured at the front heald shaft, shed angle calculated from shed size, and timing code.

TABLE 3

The relation between crank angle and shed angle (θ_o)

Crank shaft angle at healds level	Shed size at front heald (h) with reed at front centre (mm)	Shed angle (θ_o)* with reed at front centre	Shed timing code
0°	0	0.0	(Late) L
15°	20	4.4	L + 1
30°	42	9.2	L + 2
45°	64	14.0	(Medium) M
60°	87	19.0	M + 1
75°	101	22.0	M + 2
90°	102	22.2	(Early) E

$$* \quad \theta_o = 2 \tan^{-1} \frac{h/2}{L}$$

$$L = 260 \text{ mm}$$

where (L) is the horizontal distance from the first heald shaft at the reed front centre.

CHAPTER III

3. LOOM AND FABRIC DETAILS

CHAPTER III

Loom and Fabric details

3.1 Introduction

Although the basic principles of weaving are the same, regardless of the type of loom, the methods of applying them do vary considerably. In this work only one type of loom has been used, of fairly conventional construction. Details of the loom construction do, however, influence the method of making measurements, the interpretation of their meaning and discussion of how they relate to each other. In this chapter, those details of the loom that are particularly important in relation to the later chapters will be described. Then the specifications and some properties of the yarns and fabric will be summarized.

3.2 The loom

The loom used for all except the first preliminary experiments (already described and not referred to again) was the Crompton and Knowles 4 x 3 box "P.A.P.A." This "pick-and-pick automatic" loom was a modified version of the W-3 loom having three boxes at the magazine side with the top one being raised, for the pirn change, to a fourth box position above the race to allow the empty pirn to be ejected between the upper two working boxes. This special feature and its complex programming requirements was disconnected for this research and the loom operated as an ordinary 4 x 1 box automatic loom. The optical weft detection system sensing at the 4-box side was retained.

Loom specification:

Reed width:	82 in
Speed:	115 p.p.m.
Dobby:	Improved "Knowles" gear dobby, 24 shafts. (See Section 3.4)
Let off:	controlled negative (See Section 3.6)

Take up: Continuously gear-driven roller in "breast-beam" position (See Section 3.5).
Warp stop: Electric (not in use).
Weft stop: Centre weft fork (removed).

3.3 The sley

The sley is of wood and metal with a central sword that may help to reduce vibrations. The sley cap is predominantly of wood (Fig 17). The connecting arms are lighter than on many looms and have pre-compressed springs presumably to protect the crankshaft from the shock of a "bang-off" while acting as solid connectors for all normal beat up situations.

The crank radius was 8.4 cm and the length of the connecting arms 49 cm. The front 2.5 cm of the sley displacement curve (Fig 18) was measured using a dial gauge mounted on the frame cross-member between the take up roller and the sley. It was set with its stem normal to the plane of the reed at front centre. As the range being measured was approximately 2° of reed sweep, errors due to that angle would be small. The backlash in the crank-to-sley connection, measured at the same time, was 0.36 mm.

3.4 Shedding

The warp was drafted in a straight draft on 8 healdshafts arranged in the usual way to give a "raked" shed on jack levers Nos. 1 to 8 of the Knowles dobby. In this gear or wheel type of dobby, the healds receive a distorted harmonic motion alternating with a stationary dwell. Because of the distortion, when the shedding is symmetrically arranged (which is not always the case) and the healds cross at points 180° apart, the healds-level position is not midway between the upper and lower

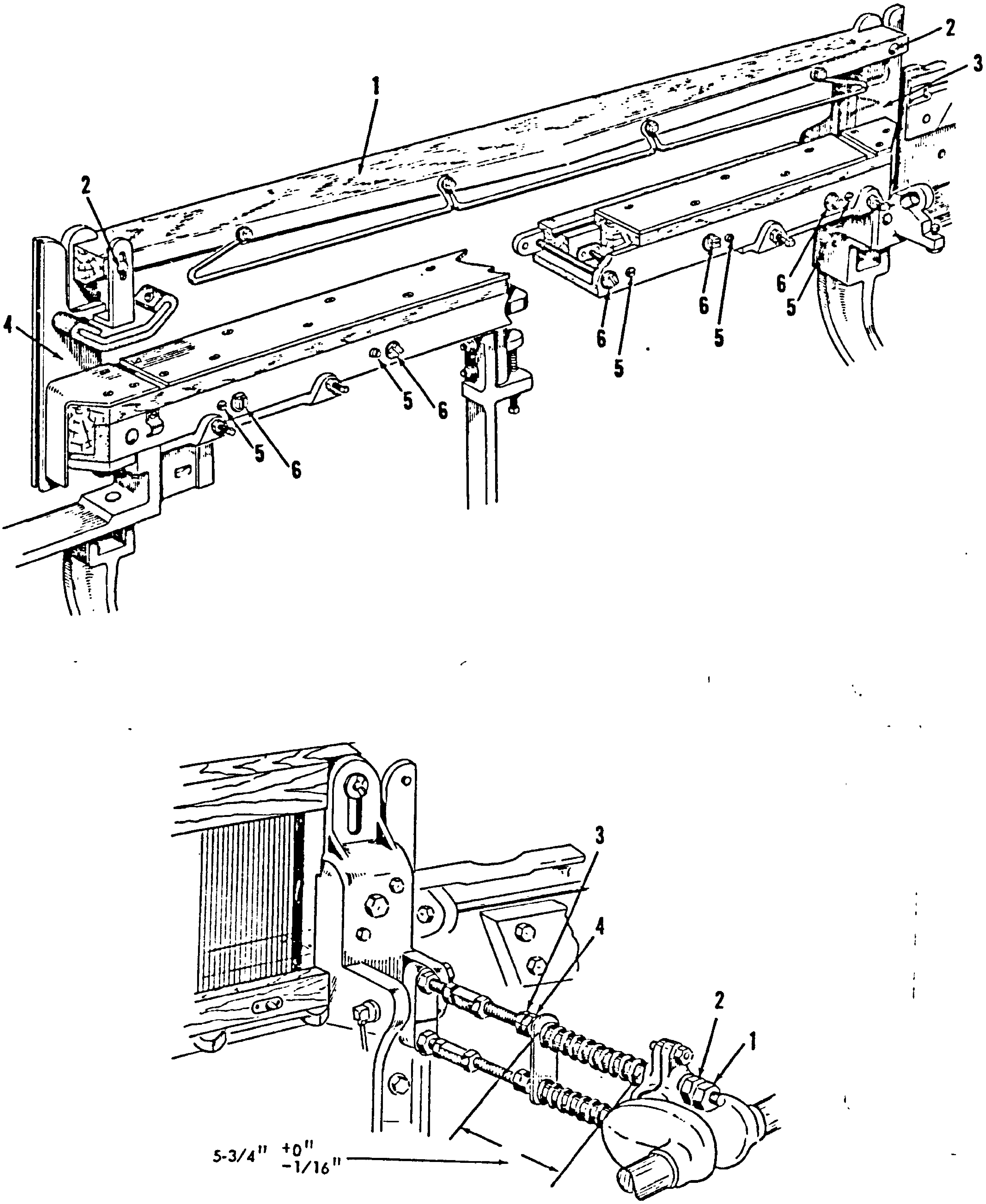


Figure 17. Sley construction and connecting arms

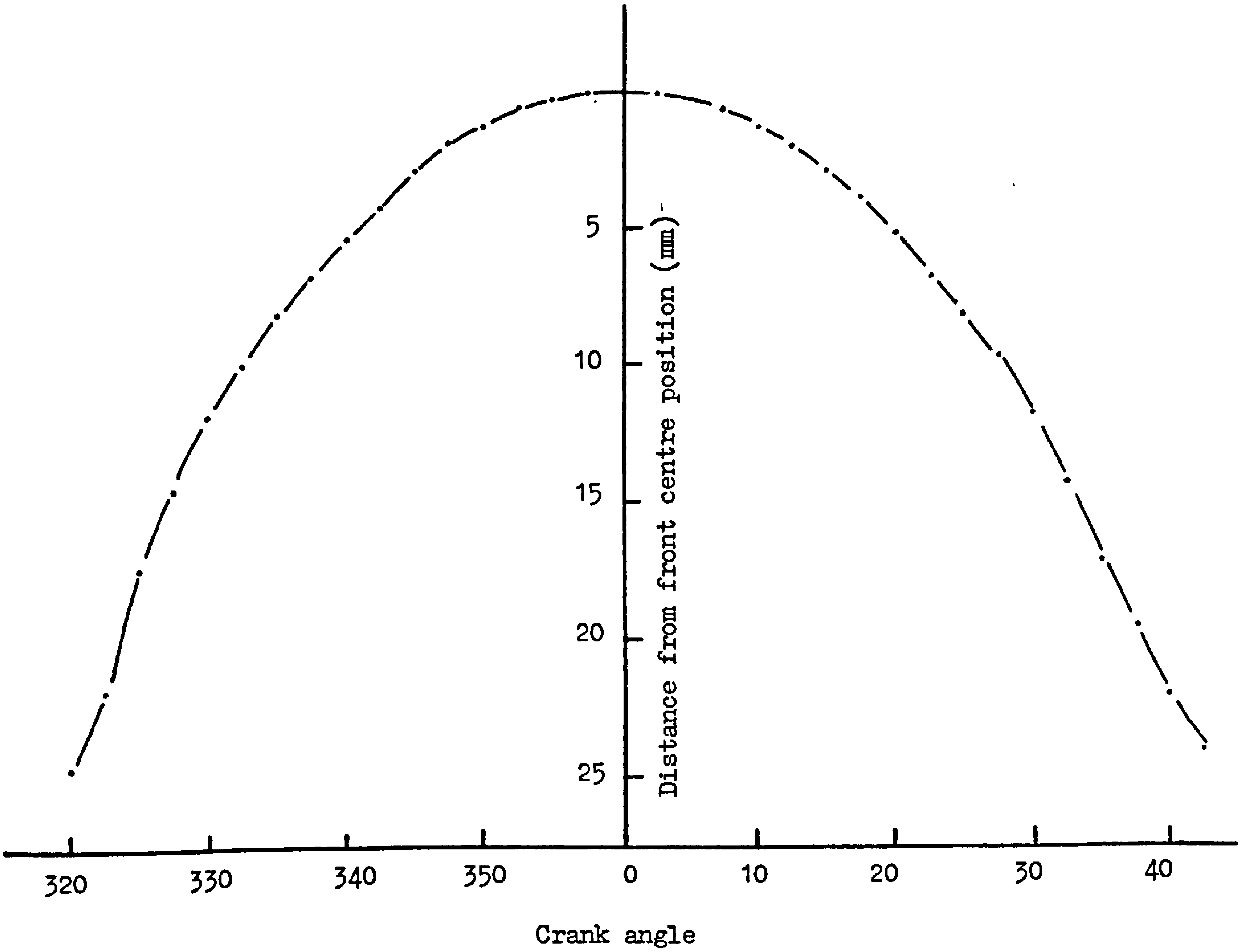


Figure 18. Front portion of sley displacement curve

dwell positions. Two cycles of shedding are covered in the measured displacement/crank angle curve of Fig 19, measured in heald shafts Nos. 1 and 2. Note the small "kink" in the curve just before the dwell associated with the locking action obtained by turning the crank wheel rather more than 180^o in the Knowles dobby.

This curve is, of course, a static curve. Under dynamic conditions some variation might occur.

3.5 The take-up

It is known from Greenwood's work that beat up force depends primarily on cloth fell position and hence is influenced by variations in either take up rate or warp tension. The take up on this loom is by means of a roller of 130 mm diameter situated so that it begins to grip the cloth at a distance of about 32 cm from the fell. The exact point of gripping is not easy to establish. The roller is driven from the crankshaft via the dobby drive shaft by a gear train as shown in Fig 20. Gear A has 50 teeth, B 88 T, C 13 T, D is a change wheel, E 13 T, F is 100 T worm wheel and G a single-start worm. Wheel D is 23 T for plain weave and 40 T for 2/2 twill in this work. Take up irregularity is frequently caused by eccentricity of gears or roller. In this case the likely wavelengths (in picks) of such regular variations would be as follows:

Plain weave:

Eccentricity arising in:	Factor	Wavelength (No. of picks)
drive shaft	1	1
E or F	x 100	100
C or D	x 23/13	177
B	x 88/13	1197
A	x 50/88	680

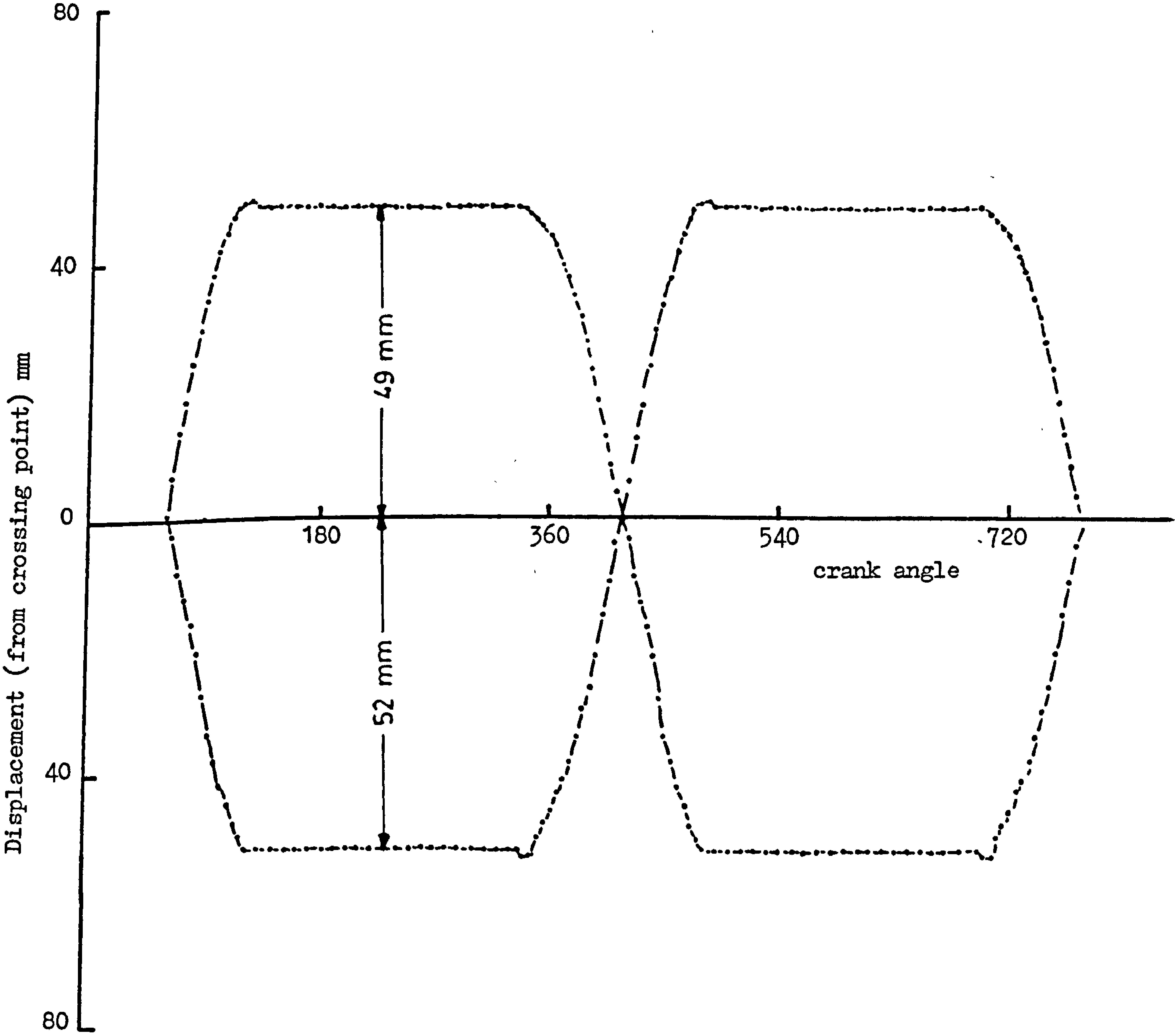


Figure 19. Heald displacement curves (front two shafts)

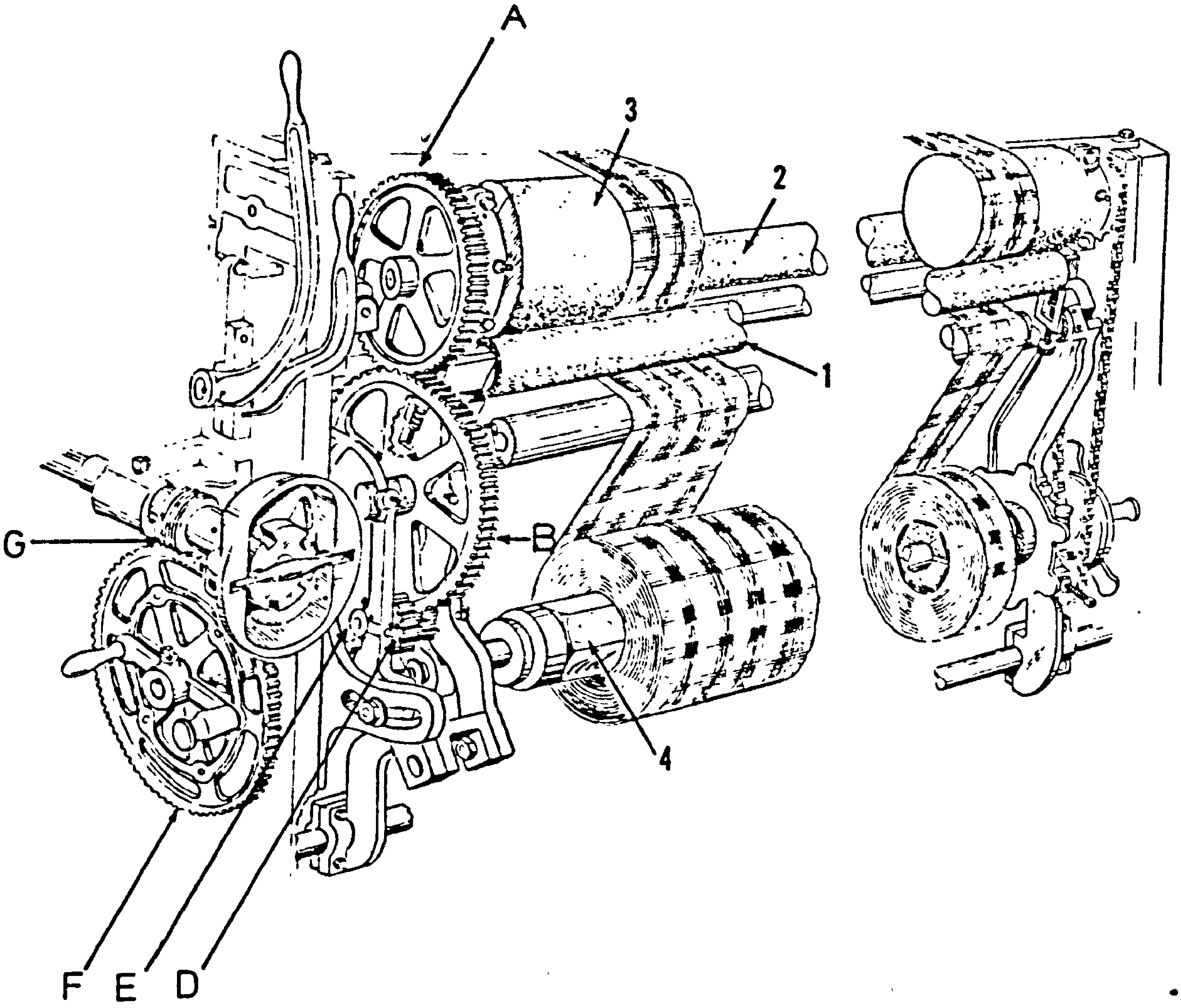


Figure 20. Cloth take-up mechanism

2/2 Twill:

Eccentricity arising in:	Factor	Wavelength (No. of picks)
drive shaft	1	1
E or F	x 100	100
C or D	x 40/13	307
B	x 88/13	2082
A	x 50/88	1183

3.6 The let-off

The let off system is a "negative" one - that is, the warp beam is not driven from one of the loom shafts but relies upon the warp tension to rotate it. There is thus a lower limit to the warp tension that can be used - it must be such that its moment about the beam axis is sufficient to overcome the friction of the beam bearings, together with any additional friction couple that might be applied. However, this arrangement makes use of a sensing roller in the same way as do the class of "positive" (sometimes referred to, confusingly and incorrectly, as semi-positive) let-off mechanisms. The sensing roller has two functions (a), it presses against the warp and changes its position if the rate of supply of warp does not equal the rate of consumption, and by changing its position, through a link to the warp beam aims to correct the rate of supply; (b) by pressing with a controlled and nearly constant force, applies tension to the warp sheet. The applied tension is determined by the weight or spring that counterbalances the sensing roller and presses it to the warp, and is influenced by the geometry of the system. It is no longer controlled by the friction couple on the warp beam (except that the applied tension must be large enough to overcome the friction or else the sensing roller will simply be moved indefinitely by the warp until the mechanism becomes essentially an ordinary simple negative one).

The arrangement used is shown in detail in Fig 21 and diagrammatically in Fig 22. A negative let off usually has the disadvantage that when the friction is overcome, the beam turns and in the usual "stick-slip" manner lets off more than is needed and decreases the tension suddenly. With a sensing-roller, the sudden slip does not directly reduce the tension by a large amount, but it allows the roller to move to a new position and the change in moment may cause a change in the applied tension. Therefore, it is important to restrict the amount by which the beam can suddenly turn. This is arranged by a clock-type escapement mechanism, the wheel of which is positively connected, by a chain drive, to the warp beam. It ensures that the beam must stop rotating after each small movement, while the escapement operates. Even so, there may be sufficient time to let off several small amounts during one swing of the back rail under some conditions of weaving; therefore there is provision to add a weight to increase the inertia of the escapement lever and so reduce the number of small units of let off during any one loom cycle. As the mechanism only restrains one end of the warp beam, to help to prevent twisting of the beam an ordinary "negative" type friction brake is applied at the other end. This simply applies a braking couple, reducing that which has to be applied by the chain from the escapement wheel. Care must be taken that the tension applied through the sensing roller is not less than that caused by the friction brake, otherwise the roller will be drawn in until it reaches a stop, and then the system will act as an ordinary negative let-off.

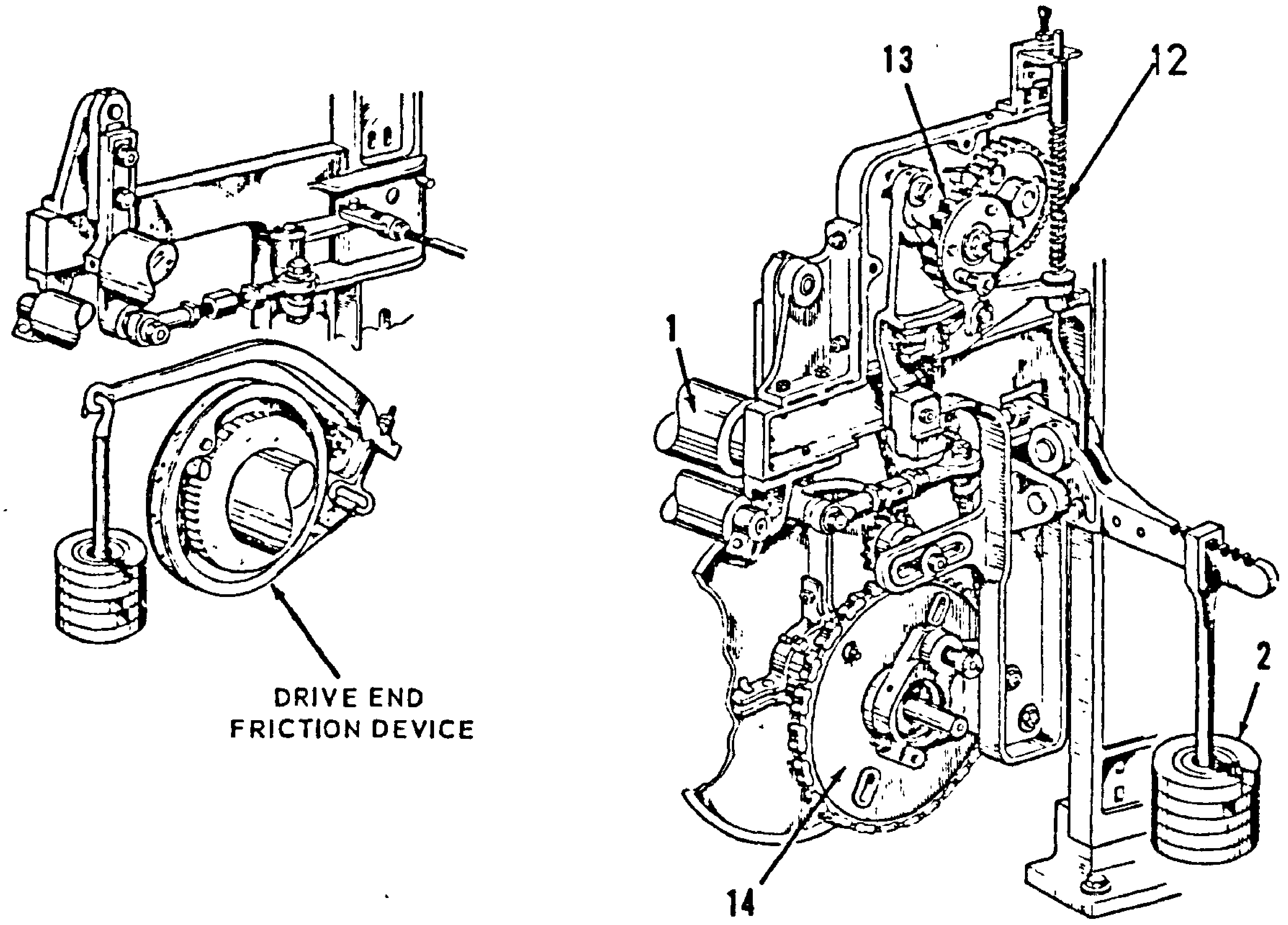


Figure 21. Warp let-off mechanism

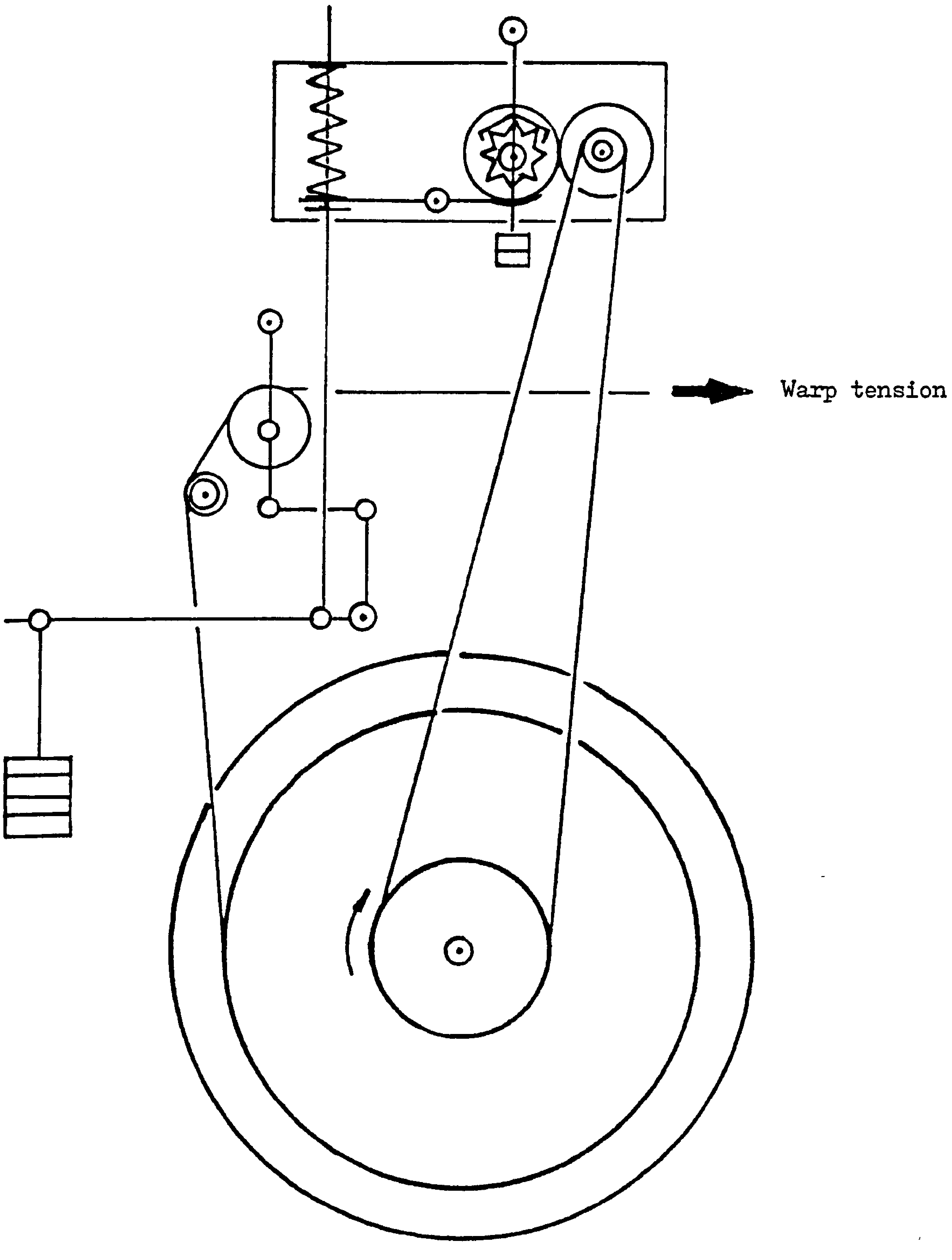


Figure 22. Schematic diagram of let-off mechanism

3.7 The fabric

Because it was intended to weave under a wide range of loom settings, it was decided to limit the cloth to a particular yarn and sett, and to use just two weaves - plain weave and 2/2 twill. These are the commonest weaves, but they are of interest because they produce two quite different beat up situations. In plain weave, because all threads interchange, at some time in the loom cycle the crossed-shed angle behind the new pick is almost zero. For the 2/2 twill, there are always half the threads not changing and, therefore, in an "open" shedding system remaining fully crossed to help to hold the pick in place. Because of the wide range of settings to be used, it was necessary to have yarn that was not too difficult to weave. Similarly the fabric should be not too far from maximum sett to reduce the effects of loom settings, but not near enough to it to cause real difficulty.

Badve[13] had used 55 tex (2/22s cotton) sett at 44 ends/inch and found that his maximum possible weft sett was 46 to 48 p.p.i. depending on shed timing. In the present work, the warp sett was again 44 ends per inch, but the yarn was now 59 tex (2/20s) cotton/vincel, 50/50 blend with a ply twist of 10.5 t.p.i. This yarn has been adopted as standard for weaving research because it is cheaper than cotton. The weft was 55 tex 2/22s American carded cotton. Preliminary experiments showed that pick wheels giving a nominal 43 p.p.i. for plain weave gave a reasonable level of weaving resistance. In the case of the 2/2 twill, a wheel for 75 p.p.i. was used giving a generally somewhat higher resistance.

Fabric specifications:

Warp set in reed:	44 ends/inch throughout (4 per dent in 11s reed)
Width in reed:	60 inches

Weft sett: plain weave - 43 p.p.i. nominal
2/2 twill - 75 p.p.i. nominal

Warp yarn: 59 tex (2/20s) cotton/vincel

Weft: 53.6 tex (2/22s) carded cotton

Maximum sett

In order that these fabrics and their variations under different weaving conditions may be considered in the context of normal weaving practice, the maximum setts of plain weave and 2/2 twill, as indicated by the various known formulae, are given below.

Maximum weft sett, plain weave

Because the sett at plain weave is almost square, square sett formulae are used and the results slightly adjusted.

Method	Formula	Maximum square sett threads/ inch	Maximum weft sett with warp at 44
Ashenhurst	$T = D\frac{F}{F + 0.732}$	48.8	52
Armitage	$T = 9G\,(4.75)$	46	48
Law	$T = NC\frac{F}{F + 1}$	45.8	47
Brierley	$T = \sqrt{200C}$	45.8	47
Peirce	$T = \frac{16}{28d}$ [illegible]	51.8 51.0	58

Maximum weft sett, 2/2 twill

For 2/2 twill the sett is far from square and separate rules must be used. Brierly gives $\frac{P}{P\ \text{square}} = \left(\frac{E\ \text{square}}{E}\right)^{\frac{2}{3}}$. For 2/2 twill, the square sett value is 60 ± 1 by all the common formulae; hence the sett for 44 ends/inch is 75, P and E being pick and end spacings.

Thus the setts chosen were, for plain weave, 10 - 15% below theoretical maximum, according to the theory used, while that for the twill was less than 5% below maximum.

3.8 Yarn and fabric elastic moduli

In order to understand the relationship between the various measured parameters in the main experiments, it is useful to know something of yarn and fabric elastic moduli. The yarn modulus was measured in the standard way on the Instron tensile tester and results are given here. It is also convenient to give, at the same time, similar data for each of the fabrics, although these were measured at a late stage of the experiments. Only typical values for the fabric are given here because small variations with conditions under which the fabric was woven are to be expected and because, on the loom the elastic deformation of the fabric at beat up will be restrained by the temples.

In the case of both yarn and fabric, it should be noted that the speed of extension during these tests is considerably slower than will often occur on the loom during the earlier part of the beat up. For example, for a 1 cm fell displacement, occupying about 30° of crank rotation, the time taken is about 40 ms, indicating an average speed of extension of the warp or relaxation of the cloth of about 25 cm/s and a maximum speed much higher than that in the test which was 1.7 cm/s.

The load extension curve of the warp yarn and a typical curve for the fabric (plain weave) are given in Fig 23, 24. In each case the extension scales have been adjusted to represent the behaviour of the actual free lengths of yarn and fabric on the loom.

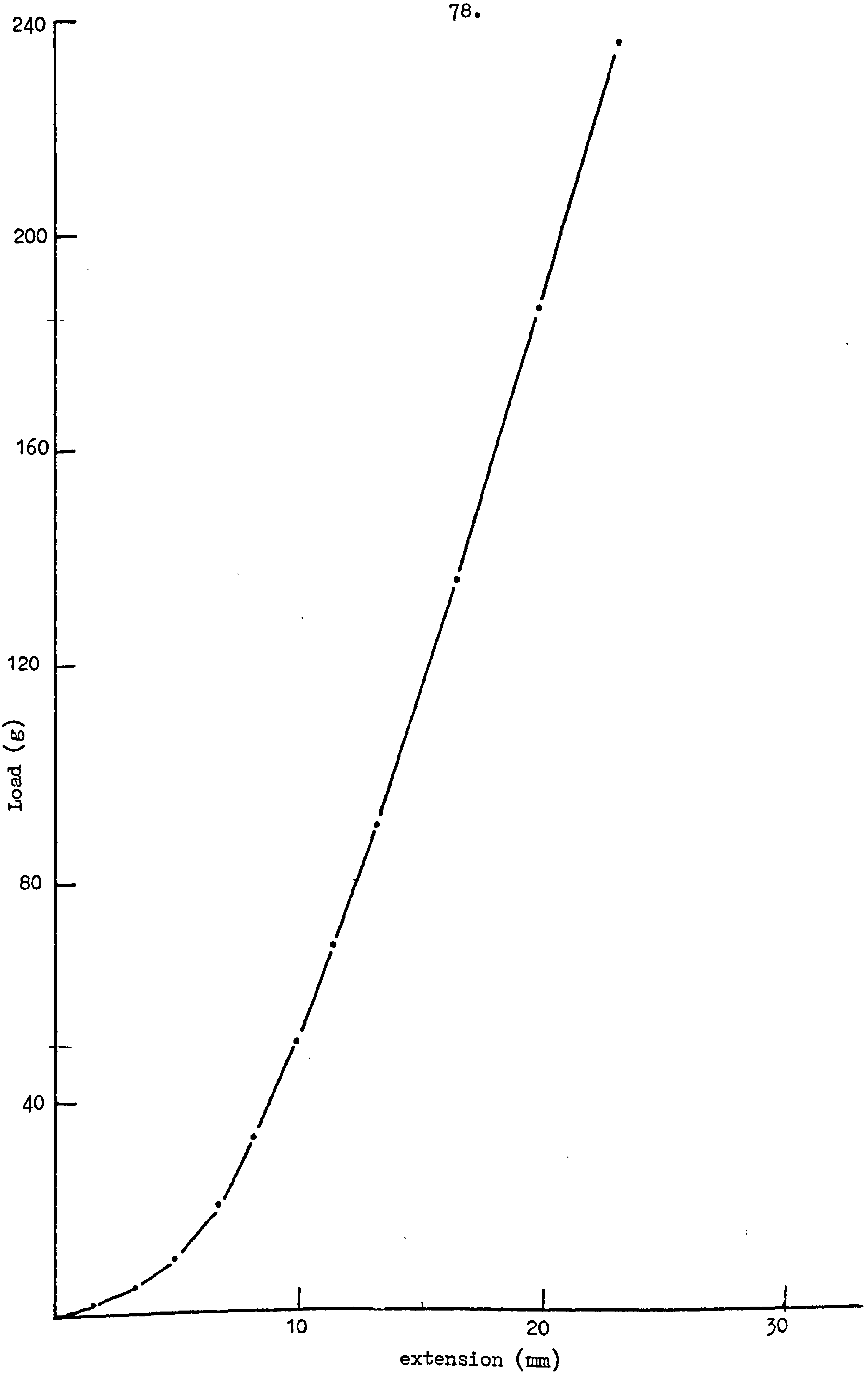


Figure 23. Load extension curve scaled for free length of warp on loom

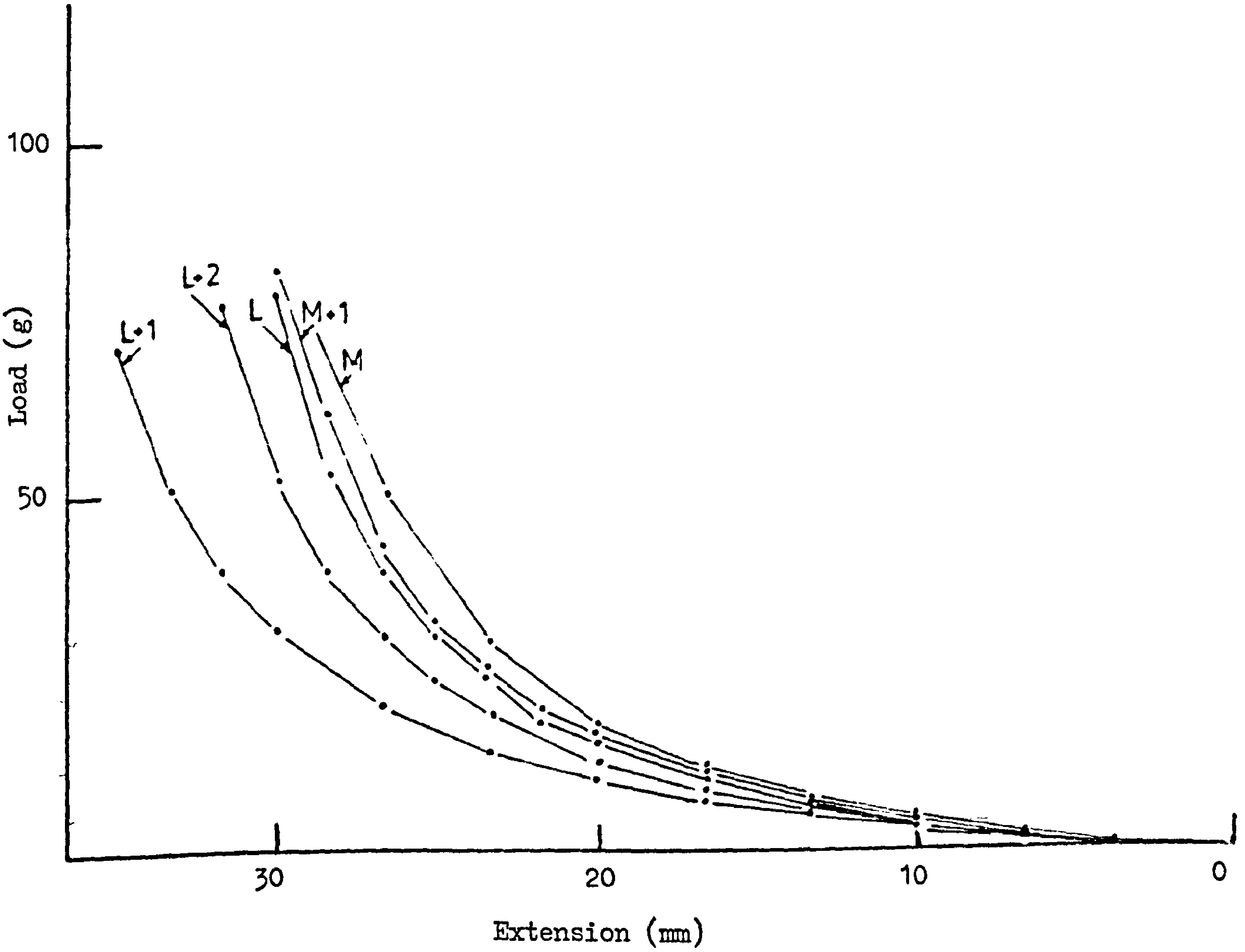


Figure 24. Fabric load-extension reversed, and based on unloading

CHAPTER IV

4. EXPERIMENTAL PROCEDURE

CHAPTER IV

Experimental Procedure

4.1 Introduction

Methods of measuring B.U.F., warp tension and, possibly, C.F.D. have been described, and the range of loom settings that could be used have also been explained. In this chapter, the design and procedure of the experiments will be explained. To give a sufficiently fine coverage of the available range of variables, it was considered that seven shed timings, eleven back rail (extra rollers) positions and about six warp tensions would be needed. The range of shed timings to be attempted was as follows:

Healds level, i.e. crossing, at crank angles of 0°, 15°, 30°, 45°, 60°, 75° and 90°, i.e. from front centre to 90° before front centre, coded as L (late), L + 1, L + 2, M (medium) M + 1, M + 2 and E (early), respectively.

The shed balance was set by raising or lowering the extra rollers, to produce effects similar to those obtained by raising or lowering the back rail, in units of one inch. The positions are coded as "BR + 1", "BR + 2", "BR + 3" etc., from BR - 5 to BR + 5, including N, the normal position (BR ± 0), to give altogether eleven positions. A range of tension values produced by having zero to 20 units of added weight was thought necessary to cover the practicable range.

Combinations of these values would have required 7 x 11 x 6 experiments. Consequently it was decided to limit the fabrics to one pick-spacing each of plain weave, and 2/2 twill, apart from observing the "build up" of the cloth fell in each experiment. The specifications of these fabrics have been given in Chapter III

In addition, it was decided to try to reduce the number of experiments by first testing two hypotheses formed from a study of previous theoretical work. One was that the weaving resistance would vary nearly linearly with warp tension except perhaps at very low values. The other was that raising the back rail would have almost the same effect as lowering it.

4.2 Group I experiments

The first set of experiments used six values of static warp tension combined with seven shed timings. The shed was the "normal" one previously used in the loom; it actually gave a ratio of 1.2 between the tensions in the two warp sheets. As a result of these experiments, it was decided that only two tension levels need be used, although actually that was increased to three.

4.3 Group II experiments

For these a range of 11 extra rail positions (BR-5 to BR + 5) was used with two warp tensions and two shed timings. As a result, it was eventually decided that only positive, i.e. upward shifts need be used.

4.4 Group III experiments

Group I experiments suggested that one of the extreme shed timings could be discarded and the major group of experiments used 6 back rail positions, 6 shed timings and 2 or sometimes 3 tensions.

4.5 Group IV experiments

Here the weave was 2/2 twill instead of plain weave; the range of variables was the same as Group III except that only one warp tension was used.

4.6 Procedure for each experiment

It was necessary to establish a procedure for recording as efficiently as possible the large amount of data required. The main requirement was the measurement of beat up force - not a single beat up force because there might be variations within the weave repeat, or due to take up or yarn irregularities, but an average value over many cycles. It is well known that because of the inherent feedback in pickspacing control, the required value of spacing is approached exponentially. Therefore, it is necessary to weave a considerable length of fabric before stability is obtained. In order to ensure that stable conditions had been reached, the beat up force was recorded on a slow timebase on the storage oscilloscope, so that about 50 successive cycles were stored on the screen. These were then cleared and the next 50 stored and so on until it was evident that the value had stabilized. Then the latest display was photographed.

Because it seemed that useful information could be obtained from the curve showing the decay of beat up force when the loom ran without weft, this was also recorded. Similarly the build up of beat up force as the fell was formed at the start of weaving was recorded, because this might give information about the way B.U.F. varies with pickspacing.

In order to reveal any peculiar behaviour of the loom or instrumentation, it was thought desirable to record at least one single beat up force/time curve on a faster timebase (20 ms). A standard test, therefore, involved the following recordings:

(1) The build up of B.U.F. from no fell;

(2) A sample succession of B.U.F. during normal running;

(3) The decay of B.U.F., loom running without weft;

(4) A sample succession of B.U.F. when fully stable conditions had been reached;

(5) A single expanded trace of B.U.F. during stable weaving conditions;

(6) Two tension traces, one for each warp sheet, recorded together;

(7) A final photograph of a card with basic settings written on it, described by the codes previously explained, inserted in front of the oscilloscope screen.

The camera was Cossor model 1428 adapted to fit the Telequipment, Type OM 35A, storage oscilloscope and Ilford FP 4 film was used.

This standard procedure was gradually introduced during preliminary experiments and used for most of the Group III experiments, but for some of the later ones, "filling in" the map of results, an abbreviated set consisting of (3), (4) and sometimes (6) was used.

Before each set of readings was begun, the bridge and amplifier calibrations were checked by holding a standard high value resistor across each arm of each bridge in turn and confirming that the movements on the screen were of the normal amount. Both B.U.F. measuring systems and warp tension measuring systems were prepared in this way so that between recordings (5) and (6) it was merely necessary to plug a different signal lead into the oscilloscope. Both channels were used for warp tension records, but for the B.U.F. recordings, only one channel was in use and it would probably have been wise to put a timing trace on the other channel. Because of the already complicated procedure, this was not done. The time scale can be deduced from a knowledge of loom speed and, on the expanded traces, from a knowledge of carrier frequency, i.e. oscillator frequency. It would have been useful also to have a front-centre indicator for those traces and because it was not done some supplementary experiments were later needed.

These standard procedures were used for most of the recordings for Groups II, III and IV. For Group I, during the evolution of these methods, a slightly different procedure had been used. That, together with the results and discussion for Group I will now be introduced.

CHAPTER V

5. GROUP I EXPERIMENTS

Effect of shed timing and warp tension on weaving resistance

CHAPTER V

Group I Experiments - Effect of shed timing and warp tension on weaving resistance

5.1 Introduction

For this group of experiments the warp tension and shed timing were varied over the following ranges: L, L + 1, L + 2, M, M + 1, M + 2 and E, for shed timings; and 20, 16, 12, 8, 4 and 0 weight units on the let-off weight lever. The shed balance was not varied, being kept at the level which had previously been used on the loom with the warp line horizontal. This was expected to give a balanced shed but in fact the tension ratio T/S was 1.2 under the original tension setting.

Most of the 42 different combinations of settings could be woven without much difficulty, but the combination of late shed timings with low warp tensions (no weights added to the weight lever) gave large fell displacements and violent movement of the back rail that threatened to damage the mechanism. The order of recording was a little different from that of the later experiments and consists of (1) tension trace, average of sheet 1 and sheet 2, no weft inserted, (2) tension trace with weft being beaten up, (3) single beat up trace on 10 ms/cm time-base, (4) B.U.F. during fell build up, (5) stable weaving B.U.F., (6) decay of B.U.F. after deliberate breaking of the weft, (7) label, giving shed timing code, warp tension code, picks per inch and shed balance code. The warp tension code indicates the number of standard weights added to the weight lever (see calibration, Chapter 2).

5.2 Warp tension

Sample results are presented in Figures 25, 26, 27, and

Figure 25

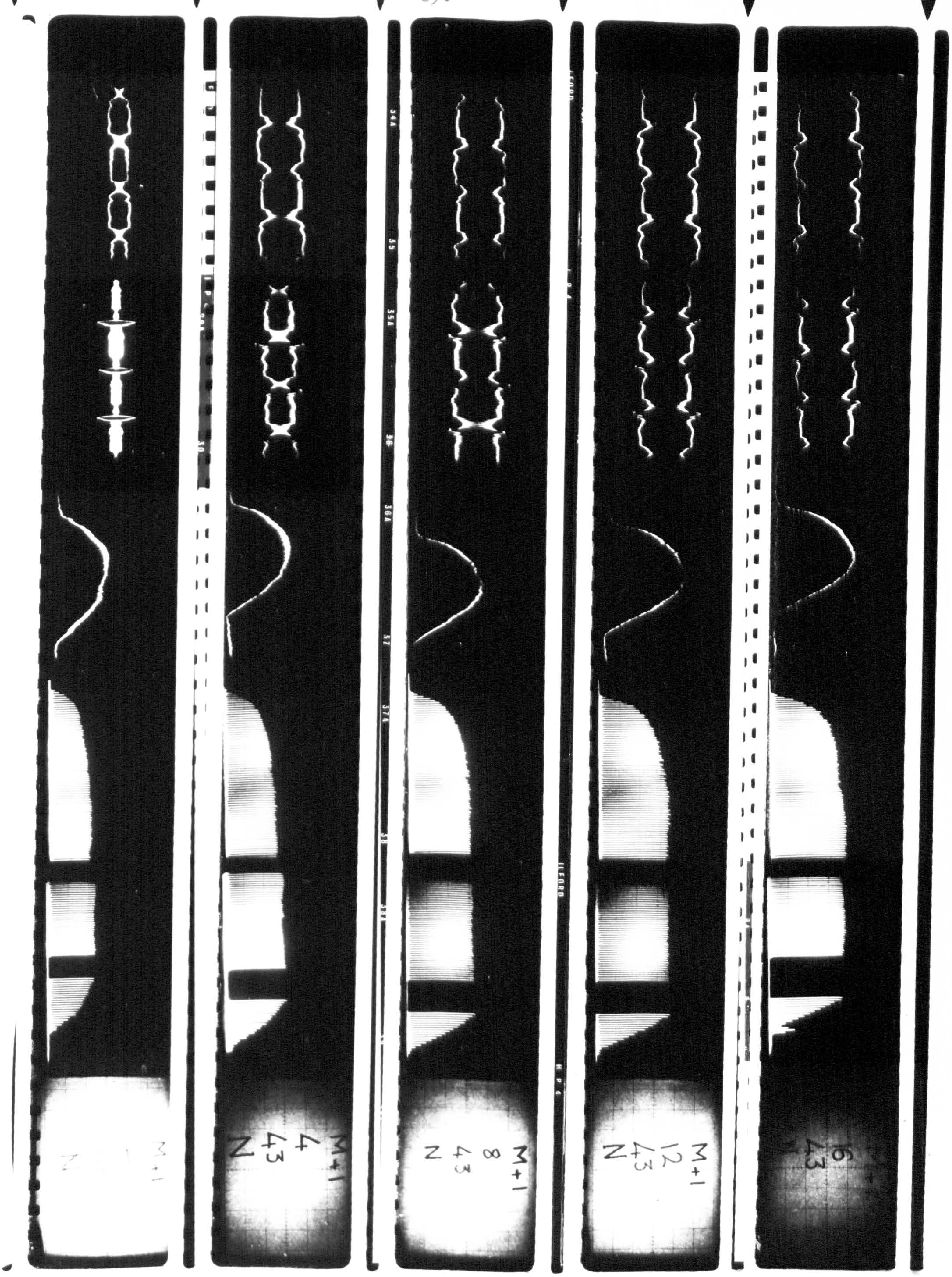


Figure 26

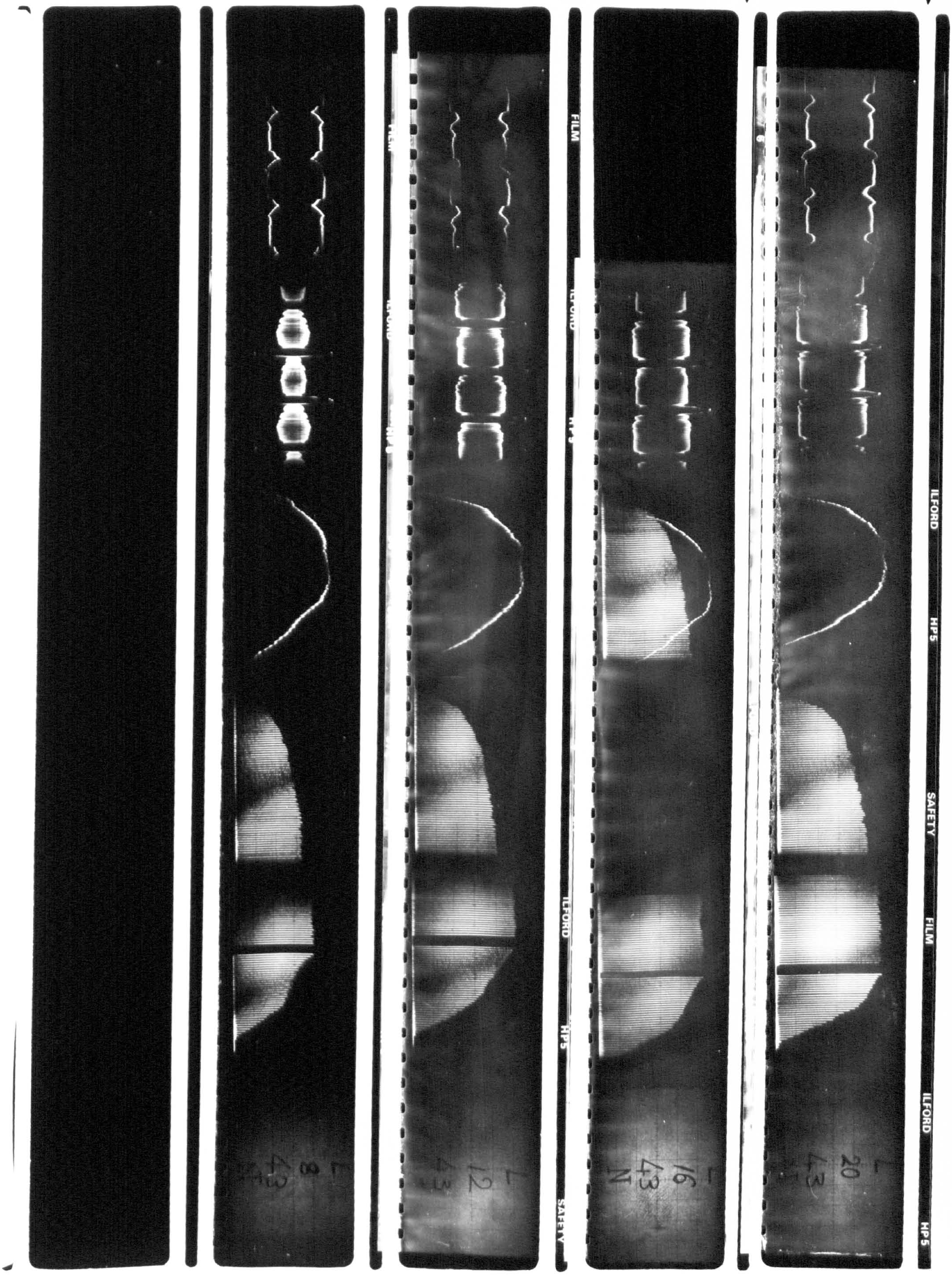


Figure 27

comprehensive values are in Tables 4, 5, 6. Some features are immediately obvious. As expected, the warp tension average or "basic" levels decrease as the number of weight units on the weight lever is reduced. It is clear from the B.U.F. traces that they reduce also as tension is reduced, yet the cloth fell displacement, as indicated by the decay curves, increases as tension reduces. The establishment of stable conditions always takes more than the 50 picks or so recorded during the "build up" period and for the very low warp tensions it appears that stable conditions may never be reached for this pickspacing. The slight differences in force that are seen on alternate picks are probably due to small shed imbalance variations due to heald shafts being at slightly different heights and producing a slightly imperfect shed-line repeating on a 2-pick cycle.

These points are noted but will not all, at this stage, be discussed in detail. The particular purpose of the Group I experiments is to observe the effect of warp tension on weaving resistance. Therefore, special attention has been paid to the value of warp tension which is recorded, both when no weft is being inserted and during normal weaving. The first trace shows a broadly constant tension during the open shed period with a reduction as the shed closes and a small peak as it opens, which may be partly due to the slight overlifting of the healds before the dobby locks them in the open shed position, but is more likely to be due to the back rail moving outwards as the shed closes and taking a small time (dependent on its inertia and the elasticity of the warp) to reverse its movement.

The second trace of the set shows the tension when weft is being inserted and beaten up. Again there is a steady region during the open shed period with a peak due to the beat up and, for some timings, a minimum for the closed shed when the beat up does not cover it. Surprisingly this steady level is lower than that in the first trace in every case, by an amount that varies with tension level and shed timings, although the weights on the weight lever are the same for each of the two traces. These values T_o^* and T_o, the open-shed tensions with and without weft insertion respectively, together with T_b the tension just prior to the beat up peak and T_b^*, the closed shed tension or perhaps, more accurately, the minimum tension, in the first trace are listed in Table 4 and plotted against applied weights in Fig 28. T_b is used as an approximation to the base tension from which the beat up force is developed. The value below the beat up peak is really required, but this cannot easily be estimated; interpolation between the values before and after beat up cannot be used because the value after beat up has been affected by beat up.

The reason for T_o being less than T_o^* is apparently because this design of let off is such that tension is considerably dependent on back rail position. Under normal conditions back rail movement is relatively small and tension is not much affected by it. The fact that the resultant of the tensions in the warp sheets either side of the back rail passes close to the back rail pivot means that fairly small weights can be used to apply warp tension, which may be the reason for the arrangement. However, when at low tensions or late timings, the beat up is in phase with the effects of shedding, resulting in large back rail movements and a fairly large proportion of the cycle when the brake is released, excessive let off of warp could result. Indeed the loom makers have provided the spring (12 in Fig 21) and an extra weight to increase the inertia of the escapement lever in order to try to control the let off under these conditions. The effect

TABLE 4

Warp tension (g/end) for different let-off weight units
and shed timings

Type of measurement	Shed timing code / No. of weight units \ Crank angle	L 0	L+1 15	L+2 30	M 45	M+1 60	M+2 75	E 90	Mean value	g/mm
T_o^*	20	73	78	81	84	78	78	78	79	1.32
	16	70	67	64	76	67	73	73	70	1.20
	12	59	53	53	64	62	59	59	58	0.98
	8	59	48	50	48	48	42	50	49	0.83
	4	48	-	45	45	46	42	45	45	0.76
	-	-	-	33	32	22	22	22	26	0.44
T_o	20	73	64	73	76	73	73	73	73	1.24
	16	59	59	56	70	62	-	66	62	
	12	48	50	48	56	53	56	53	52	
	8	25	37	28	42	45	39	42	37	
	4	17	-	14	31	34	36	-	28	
	-	-	-	11	17	11	17	17	15	0.25
T_b^*	20	59	59	67	70	62	62	62	63	1.07
	16	53	50	53	56	50	56	56	53	
	12	45	42	39	45	45	45	45	43	
	8	39	36	36	34	34	28	34	34	
	4	31	-	31	28	28	25	28	28	
	-	-	-	-	17	10	10	10	12	0.20
T_b	20	59	53	59	56	56	56	56	56	0.95
	16	48	45	45	50	45	-	48	47	
	12	36	36	36	39	36	39	36	36	
	8	22	25	20	28	28	25	25	24	
	4	8	-	5	12	17	20	-	12	
	-	-	-	5	5	5	5	5	5	0.08

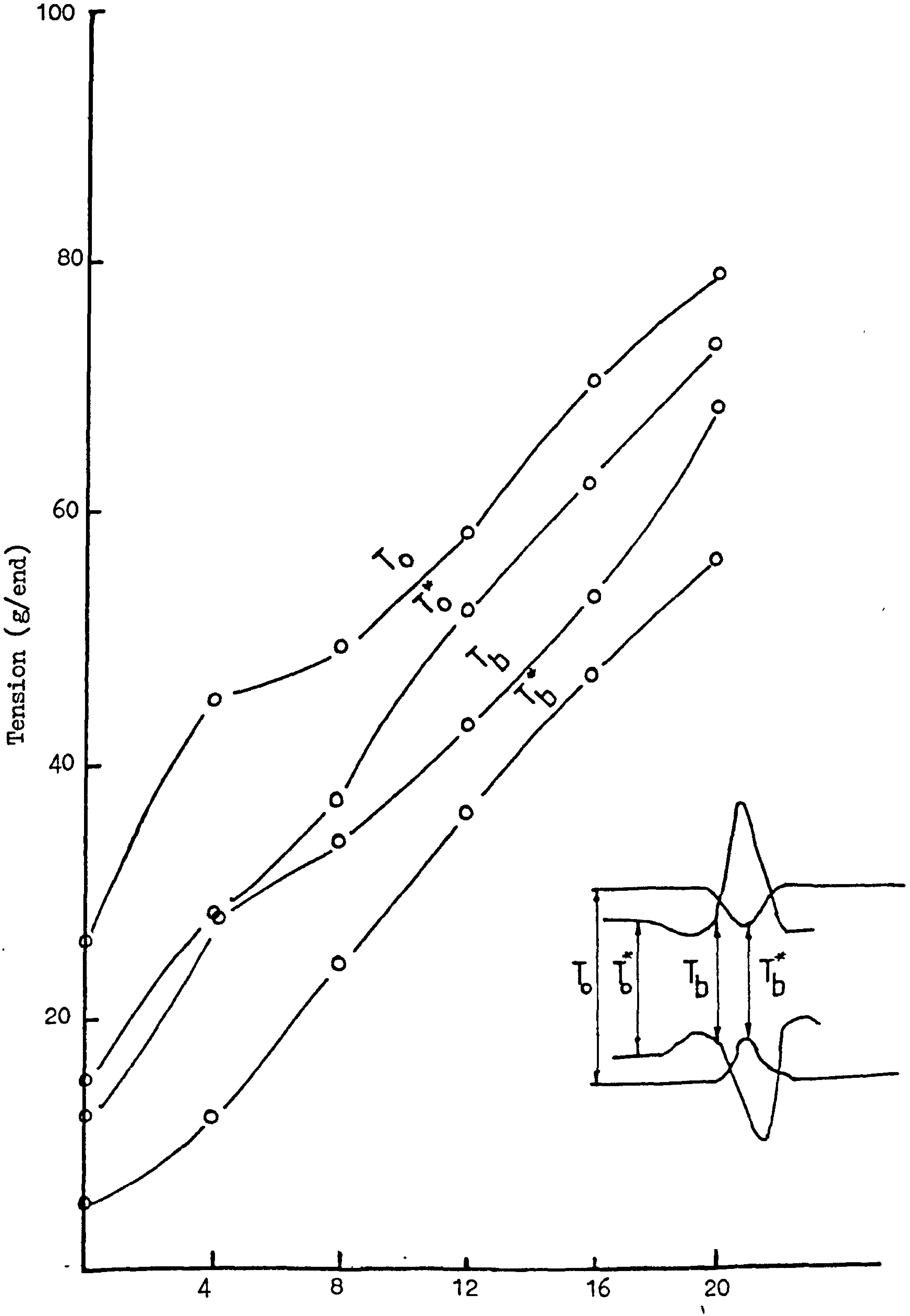


Figure 28. Relationship between warp tensions during loom cycle and applied weights

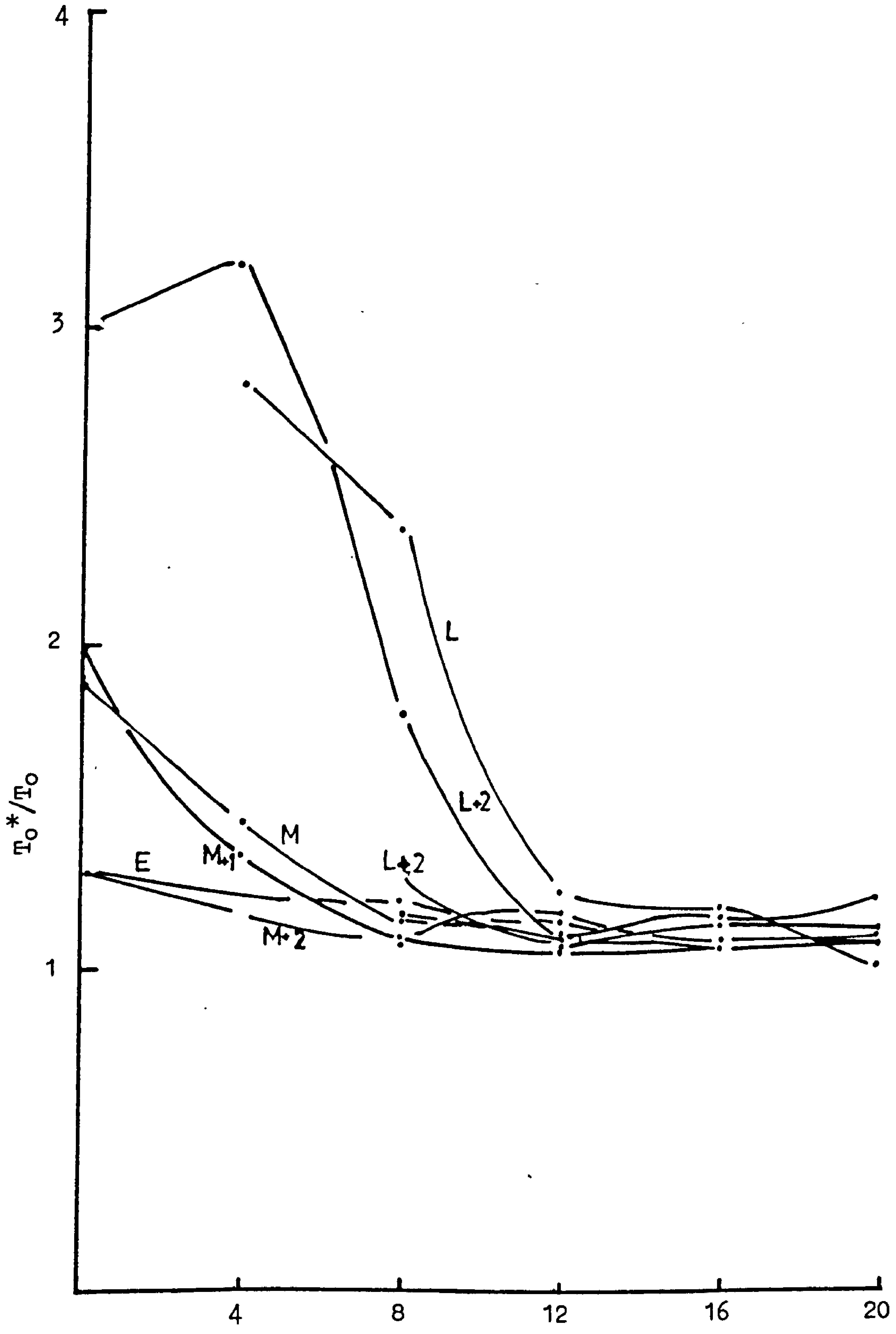


Figure 29. Ratio of open shed warp tensions without and with weft insertion

of the tendency to excessive let off means that the back rail will adopt an average position further back, so that the let off will be the required amount in spite of the large swing; being further back it applies a lower tension. The effect of the spring may help to cause the centre of the oscillation to be even further back when the amplitude is larger.

The ratio of the open-shed tensions with and without weft insertion is shown as a function of applied weight in Fig 29 for a range of shed timings identified by the usual codes. The curves show the effects of both very clearly. The applied weights probably have the effect of increasing elastic moduli of yarn and fabric and so decreasing fell displacement and hence the ratio T_o^*/T_o.

In spite of these variations, the values of T_b and T_o are more or less linearly related to the applied weight.

5.3 Beat up force

The values of beat up force recorded under stable conditions are shown as functions of base tension T_b and shed timing in Table 5 and Fig 30. They show the influence of shed timing and a broadly linear variation with base tension for each timing, which suggests that it would be reasonable to use fewer levels of tension. Fig 31 shows that at all tension levels there is, broadly, the same sort of variation with shed angle at beat up, θ_o. One peculiarity of these curves requires comment. The angle θ_o in the fully open shed is 22° and is reached at beat up (front centre) for the timing denoted by M + 2. The earlier timing, E, has the shed fully open just before front centre and shows a slightly higher beat up force for virtually the same angle $\theta_o = 22.2^\circ$ possibly because the crossed shed makes the pressure between the warp

TABLE 5

Beat up force (g/end) for different basic warp tensions and shed timings

Shed timing code		L	L + 1	L + 2	M	M + 1	M + 2	E
Warp tension code	Crank angle	0	15	30	45	60	75	90
	Aver. (Tb) g/end / θ_o	0	4.4	9.2	14	19	22	22.2
20	56	163	160	147	147	141	144	147
16	47	160	152	144	138	127	123	133
12	36	157	149	141	127	120	117	122
8	24	133	136	127	123	107	100	113
4	12	-	-	123	110	97	90	100
-	5	-	-	110	83	77	73	78

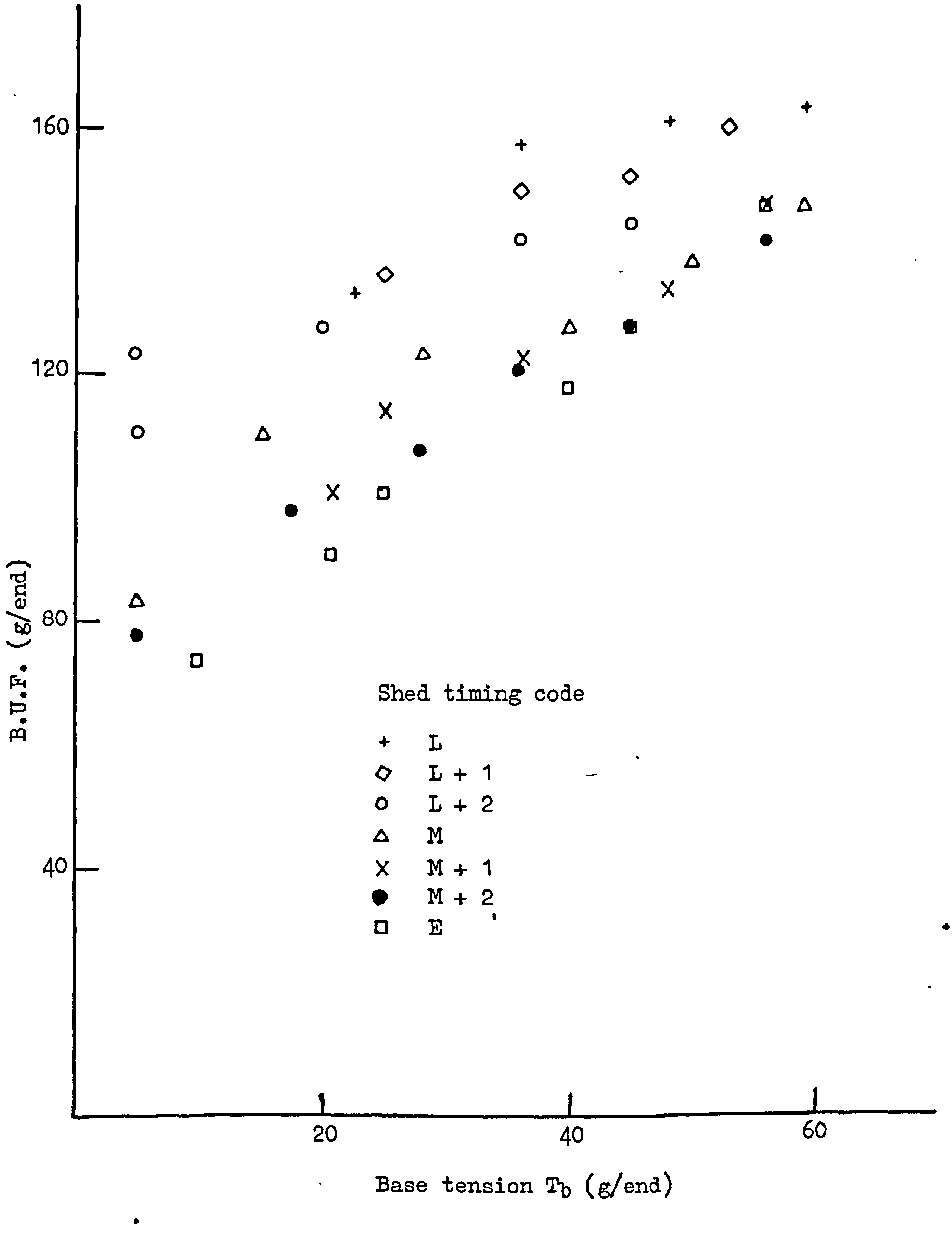


Figure 30. Effect of base tension on B.U.F.

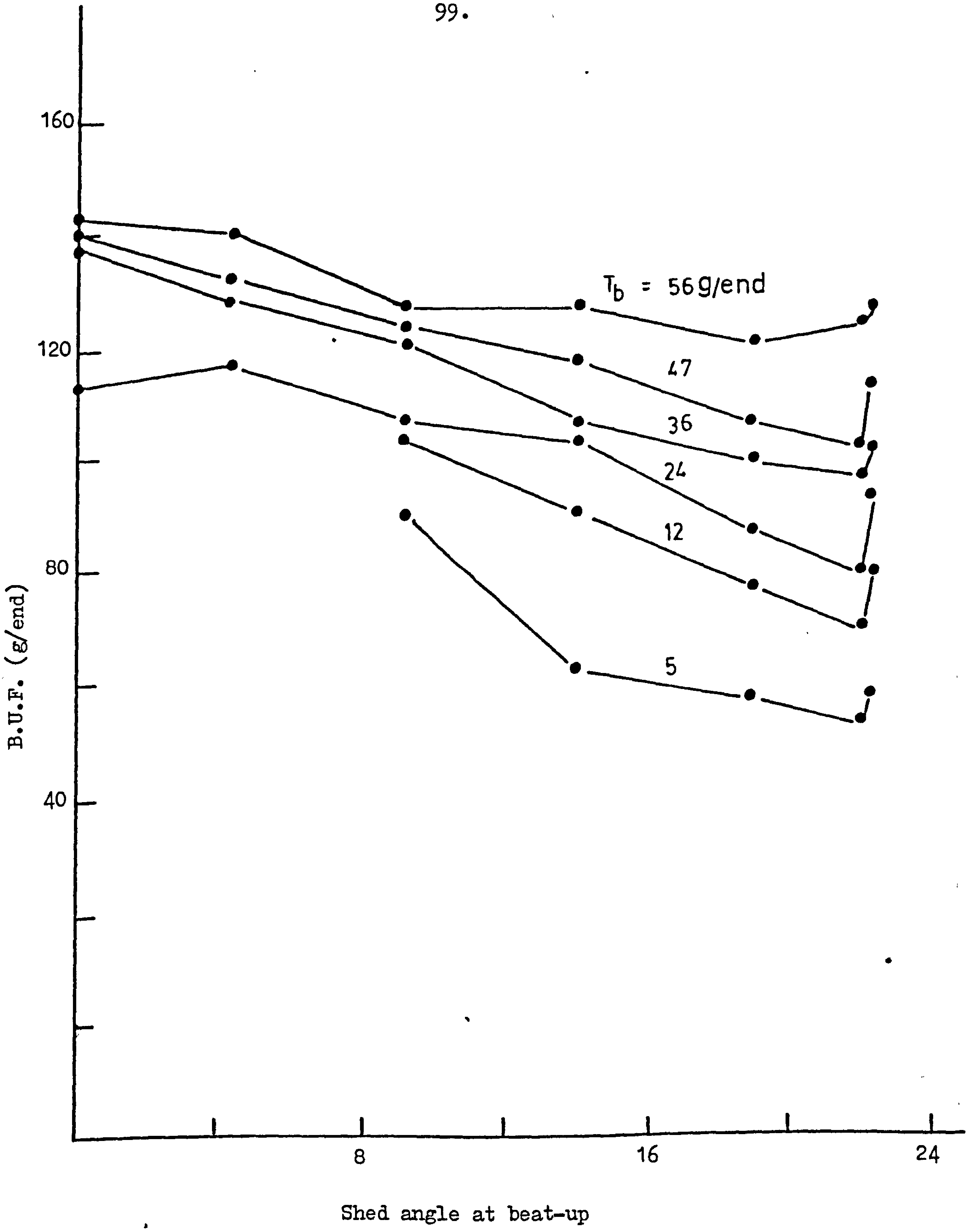


Figure 31. Effect of shed angle at beat-up on B.U.F.

and weft greater during the last stages of beating in, possibly because of a very briefly increased θ_0 due to the locking action of the dobby. To discover if these results indicated an upward trend of weaving resistance for earlier shed timings, three such timings were employed for one typical tension value with shed crossing at 105°, 120°, and 135°, i.e. what might have been termed E + 1, E + 2, E + 3. These were extremely difficult and rather dangerous experiments to conduct and when they indicated an almost constant value of weaving resistance equal to that of M + 2, $\theta_0 = 22^\circ$, it was decided to limit the range for all future experiments at M + 2.

5.4 Cloth fell distance

This preliminary set of experiments gives some information on cloth fell distance as deduced from the series of beat up traces when the weft has been cut. It must be remembered that this represents the distance over which the reed is in contact with the fell. Badve had pointed out that beat up force was to be expected to be proportional not to the disturbance of the fell from its original position the "cloth fell distance" defined by Greenwood for a simplified model of the process, but what Badve called the "cloth fell interference", the disturbance of the fell from where it would have been if, without beat up, the shedding and back rail movements had influenced it in the way they do. What is being indicated here is the distance of reed sweep over which reed and fell are in contact. So, if the fell is moving to meet the reed, because the shed is opening, the C.F.D. will be short, while if the fell is running away from the reed, the distance they are in contact will be larger. The tension level will be expected to have an additional effect because of its effect on elastic moduli. Table 6 and Figs 32, 33 show

TABLE 6

Cloth fell distance (mm) for different basic warp tensions and shed timings

Shed timing code		L	L + 1	L + 2	M	M + 1	M + 2	E
	Crank angle	0	15	30	45	60	75	90
Warp tension code	θ_o Aver. Tb (g/end)	0	4.4	9.2	14	19	22	22.2
20	56	17	17	13	12	8.5	7	8.5
16	47	20.5	19.5	15	12	8	7	8.5
12	36	22.5	20	15	12	8.5	7	7
8	24	21	22	18	14	9	7	8.5
4	12	-	-	15.5	17	12	7	9
-	5	-	-	-	21	13	8.5	10

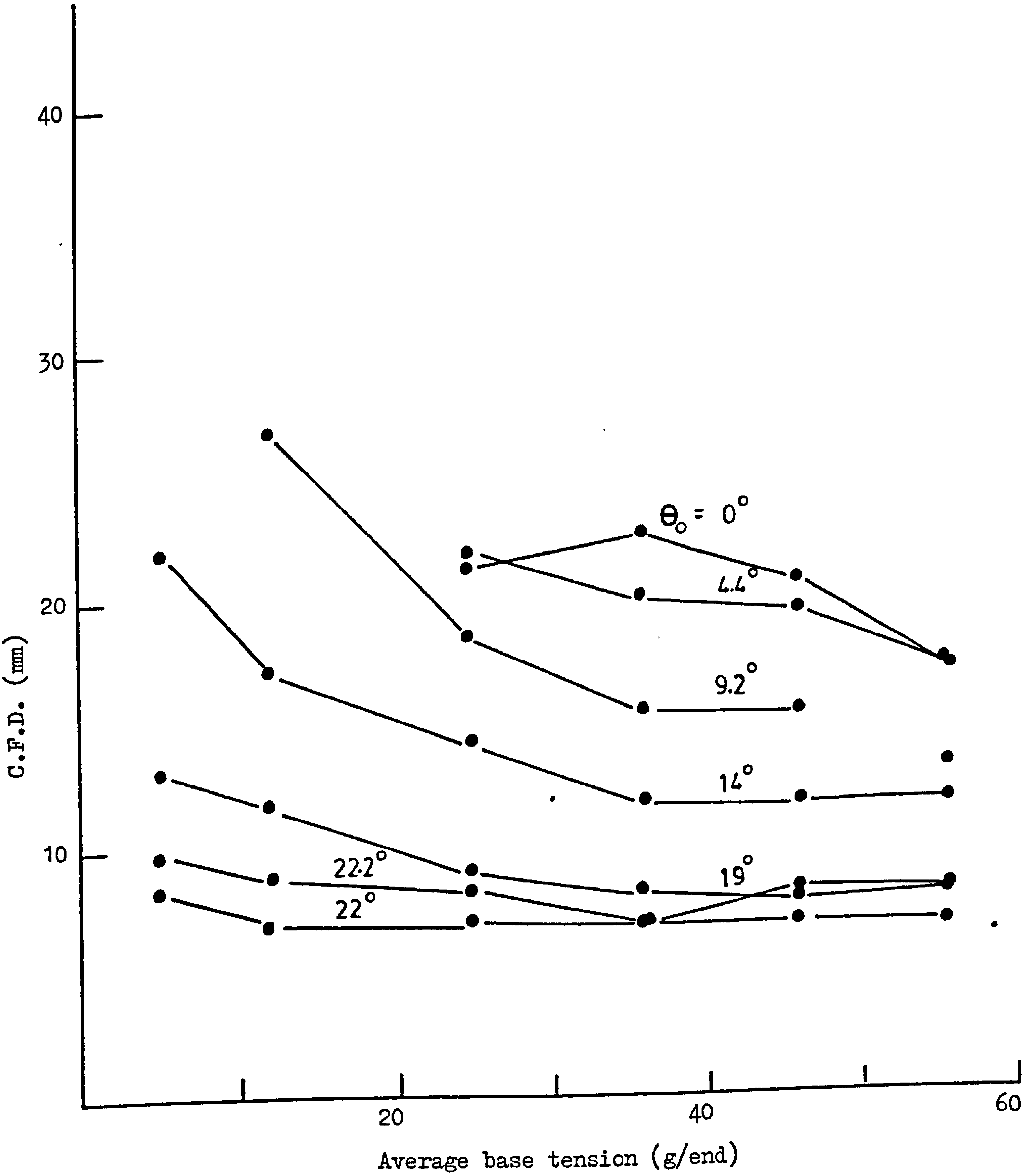


Figure 32. Effect of base tension on C.F.D.

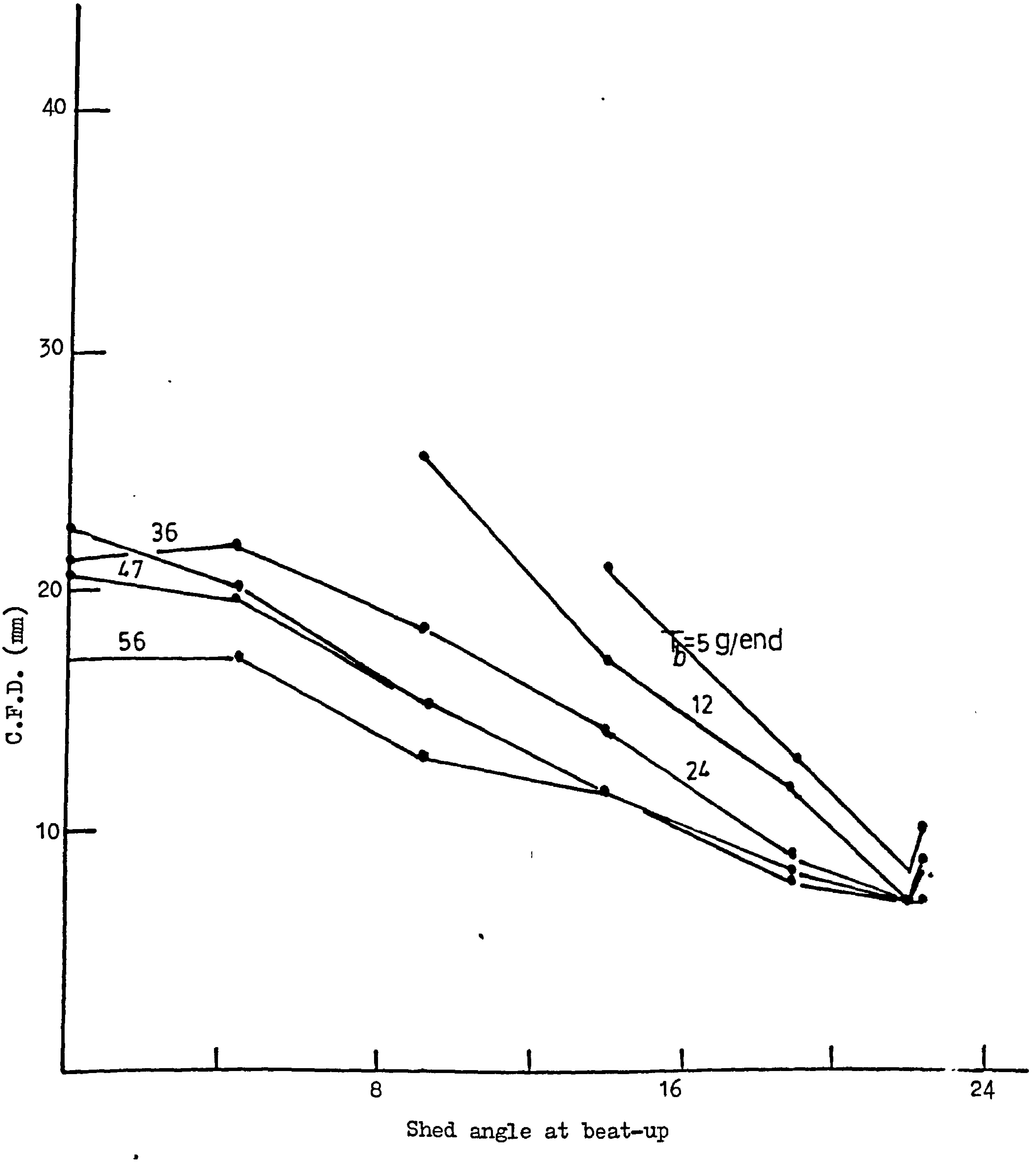


Figure 33. Effect of shed angle at beat-up on C.F.D.

how C.F.D. varies with tension level and shed timing and suggests that tension level only has no significant effect with early timing. In spite of these dynamic effects, Fig 34 in which B.U.F. is plotted against C.F.D. suggests that the two are approximately linearly related for a given base tension.

The form of the decay curve is worth some comment at this stage, although it will be discussed in more detail later. There are three possible influences on it. The basic form represents a reversed load/extension curve for the warp/cloth combination, its slope representing the combined elastic constant $\left(\frac{E_1}{L_1} + \frac{E_2}{L_2}\right)$. At high warp tension, that is almost linear.

When the warp tension is reduced, "bumping" conditions are reached in which the cloth tension falls to zero and the upper part of the decay curves have a shallower slope representing $\frac{E_1}{L_1}$ only. When the shed timing is made later, this effect is magnified because, as has already been seen, the warp tension, at least on this loom, is reduced by making the shed later. For really low tension and late timing, the change of slope seems to occur at a tension level which is on the curved part of the warp's load/extension curve so that, moving from right to left on the decay curve, the slope, having fairly suddenly reduced, begins to increase again. Finally, superimposed on these effects, the whole curve is increased in length if there is fell movement in phase with that of the reed.

5.5 Conclusions, Group I

From this first set of experiments, two basic facts emerge; (a) weaving resistance is approximately linearly related to warp tension so that the number of warp tension levels used in the main experiments

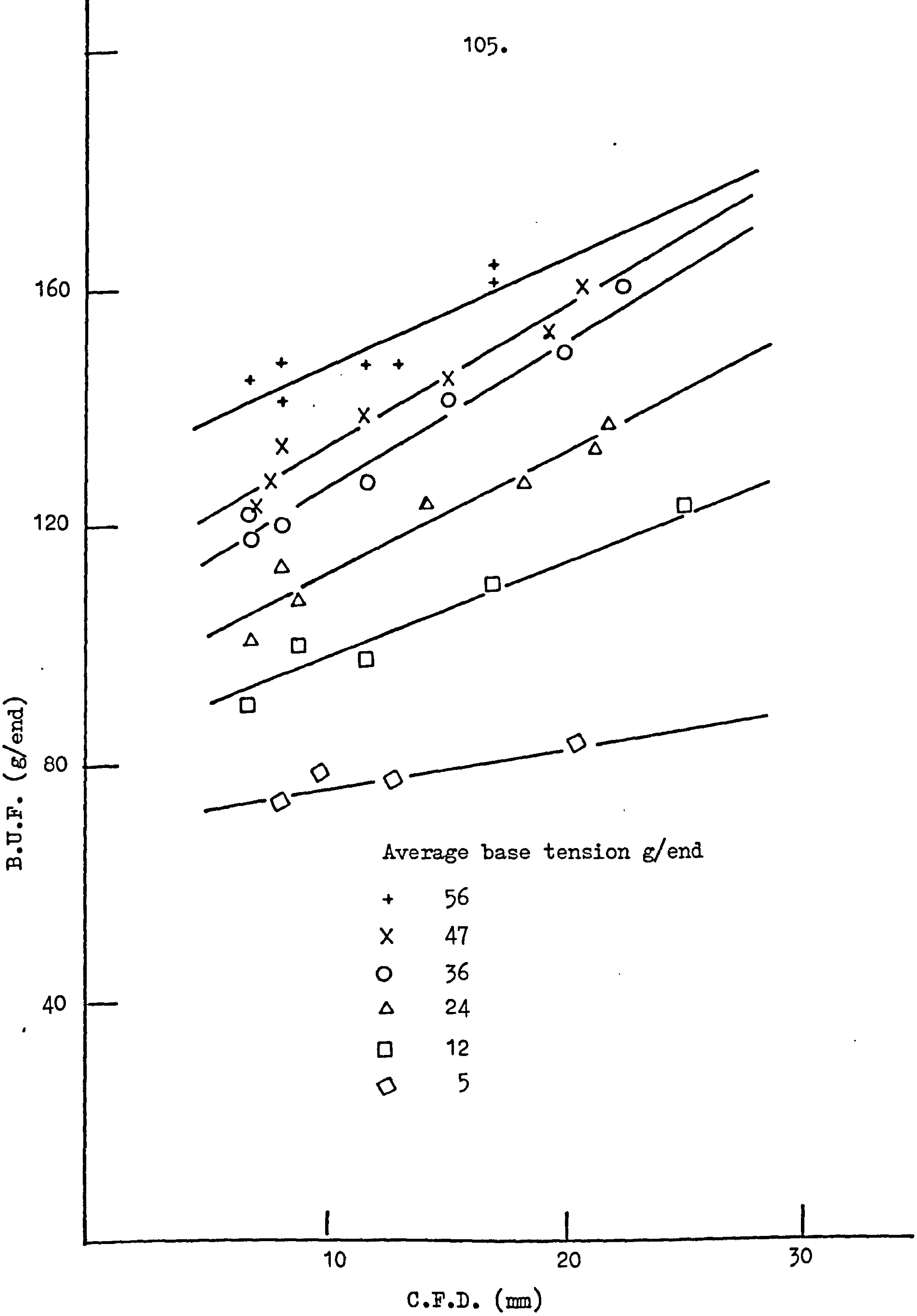


Figure 34. B.U.F. plotted against C.F.D.

may be reduced; (b) that actual average warp tension and the base tension depend not only on the applied weights, but on back rail position and hence on shed timing.

CHAPTER VI

6. GROUP II EXPERIMENTS

Effect of shed unbalance

CHAPTER VI

Group II Experiments - Effect of shed unbalance

The purpose of this set of experiments is to establish whether it is necessary, in weaving with an unbalanced shed, to unbalance it by both raising and lowering the back rail (extra rail) or to rely upon only one of these methods.

The original warp line was set by the back rail of the loom in its normal working position. This was taken as the centre of the range. The extra rail was arranged so as to raise the warp sheet by + 5, + 4, + 3 .... - 4, - 5 inches from that level. These settings were combined with two warp tensions ("high", 56 gm/end (WT5) and "low" 24 gm/end (WT2)) and two shed timings L and M + 2 of the set previously defined.

The procedure was similar to that used in Group I except that, on recording the results, the tension traces recorded are for the slacker and tighter sheets of the unbalanced shed; they are only recorded during actual weaving, and they are arranged one above the other on the film strip; also the single B.U.F. traces are recorded on 20 ms/cm.

Samples of these traces are shown as Figs 35 - 39. Examination of these traces shows very clearly the influence of shed imbalance on weaving resistance and, of course, on the warp tension in the two sheets. It is also obvious that the variation is not symmetrical about BR zero - the traces for BR + 1, for example, being noticeably smaller than those for BR - 1.

The values extracted from these traces (by measuring the images projected by an enlarger and applying the calibration curves, including those for cloth-fell height) are given in Table 7. The beat up force

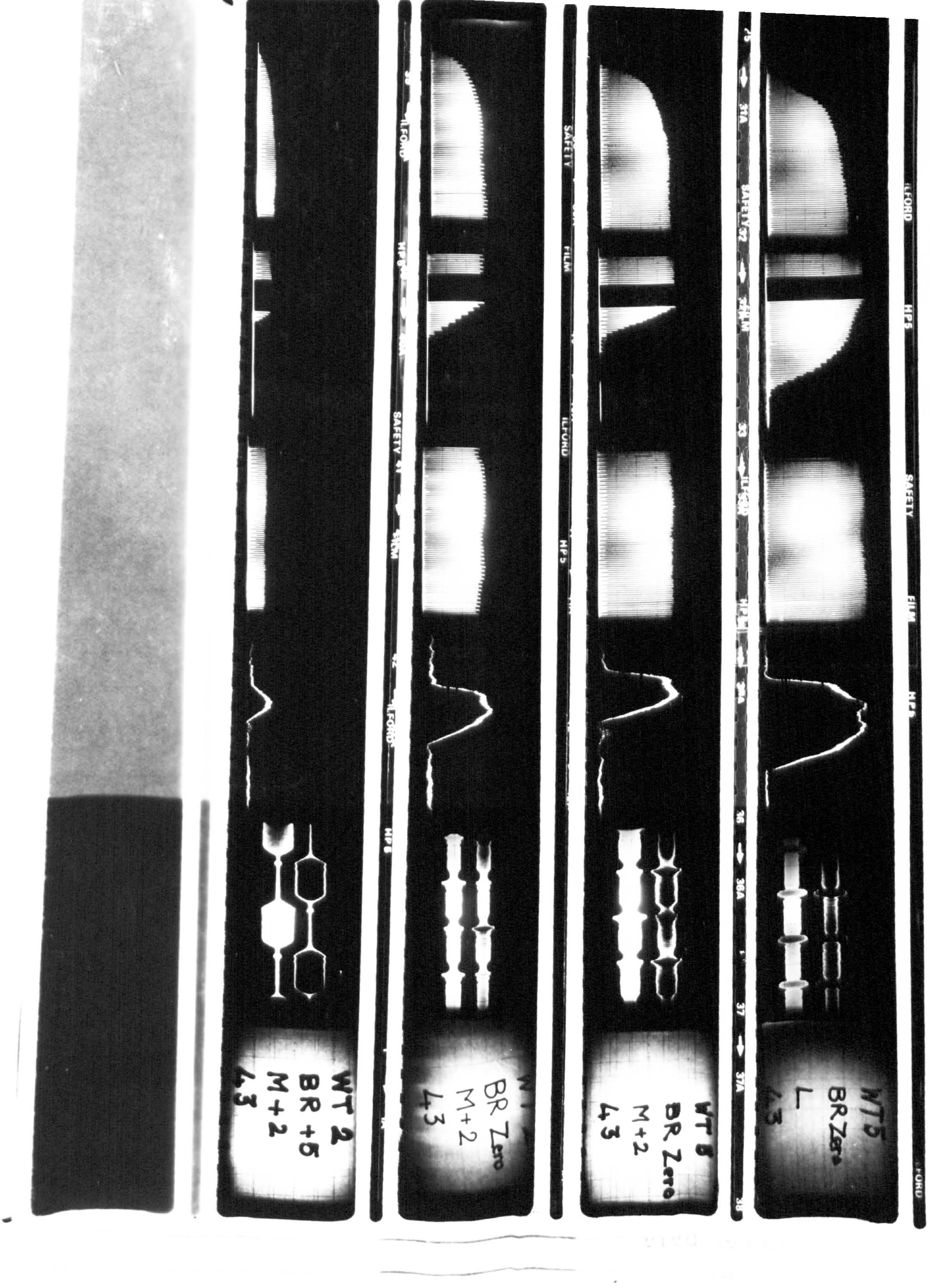

WT 2
BR +5
M+2
43
BR Zero
M+2
43
WT 8
BR Zero
M+2
43
WT 5
BR Zero
L
43
ILFORD
HP5
SAFETY
FILM

Figure 35

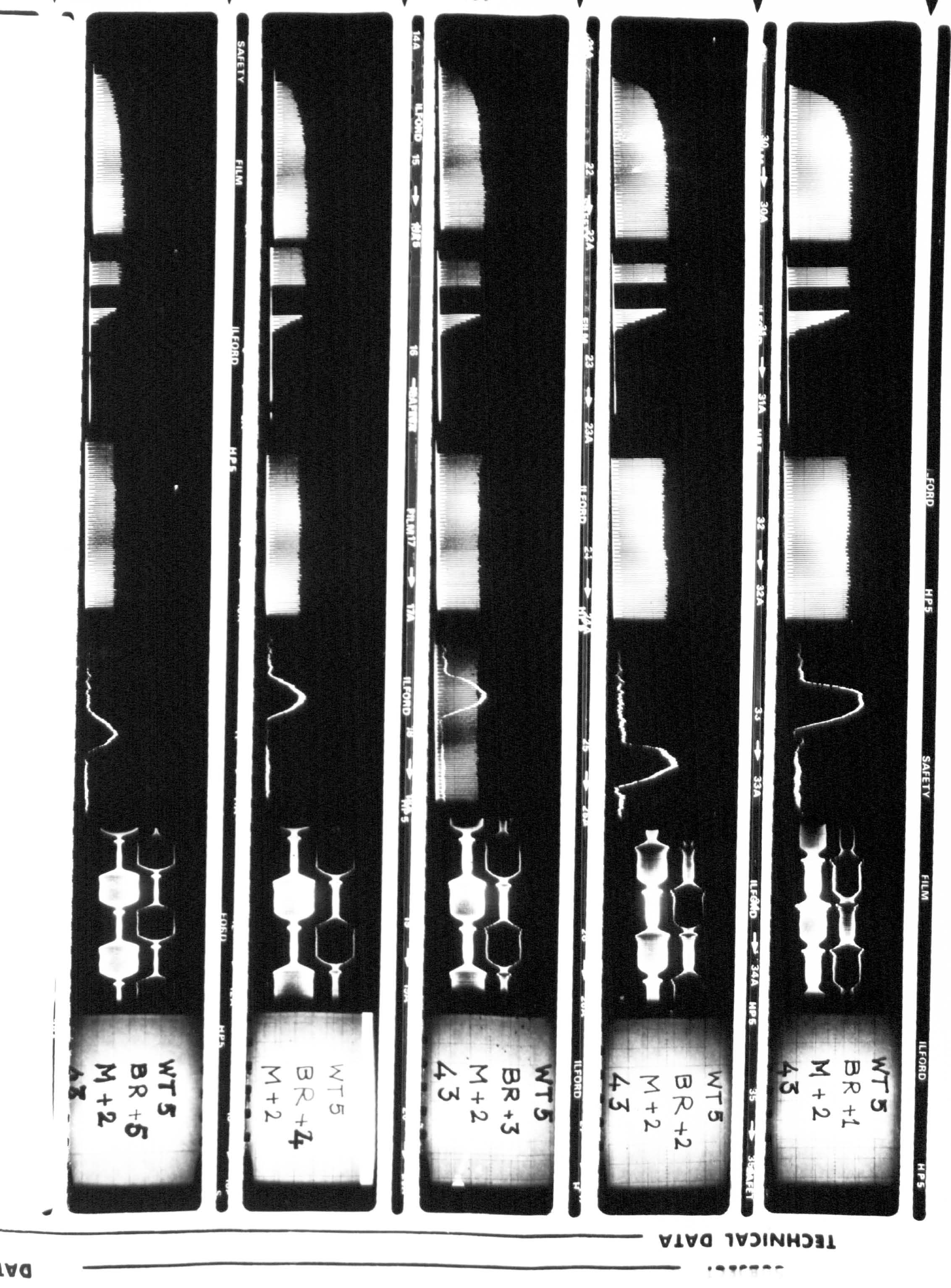

WT5
BR+5
M+2
43
WT5
BR+4
M+2
WT5
BR+3
M+2
43
WT5
BR+2
M+2
43
WT5
BR+1
M+2
43
ILFORD
HP5
SAFETY FILM
TECHNICAL DATA

Figure 36

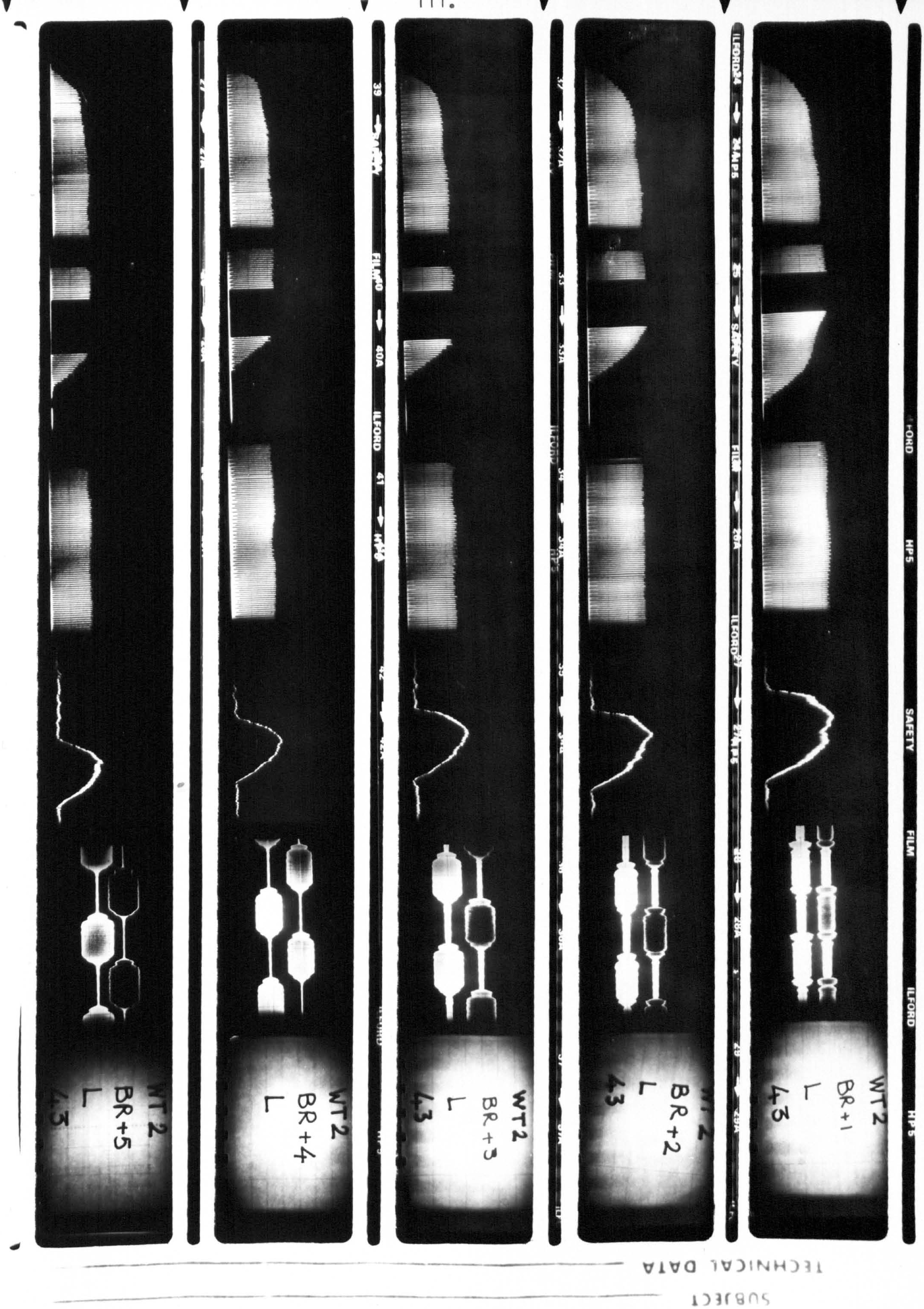

WT 2
BR+5
L
43
WT 2
BR+4
L
WT 2
BR+3
L
43
WT 2
BR+2
L
43
WT 2
BR+1
L
43
ILFORD
HP5
SAFETY
FILM

Figure 37


WT 5 BR-5 L.43
WT5 BR+4 L 43
WT 5 BR-3 L 43
WT 5 BR-2 L
WT5 BR-1 L
SAFETY
FILM
ILFORD
HP5

Figure 38

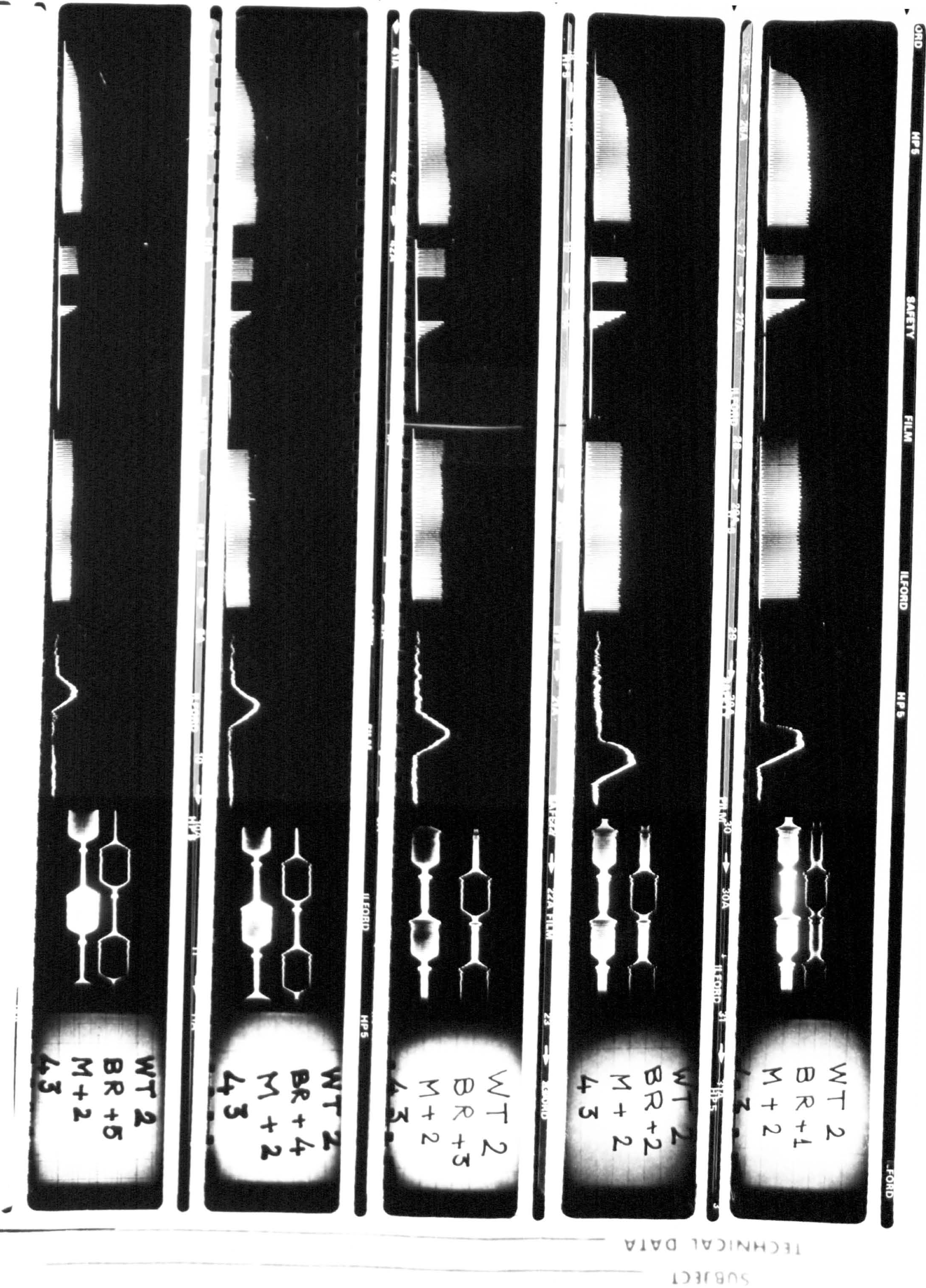

WT 2
BR +5
M+2
43
WT 2
BR +4
M+2
43
WT 2
BR +3
M+2
43
WT 2
BR +2
M+2
43
WT 2
BR +1
M+2
43
ILFORD
HP5
SAFETY
FILM
TECHNICAL DATA
SUBJECT

Figure 39

TABLE 7

Beat up force (g/end) for different extra rail positions (inches) at two different shed timings and two warp tensions

Type of measurement.		Extra rail position (in.)	+ 5	+ 4	+ 3	+ 2	+ 1	"N"	- 1	- 2	- 3	- 4	- 5
High warp tension (WT5)	Late shed timing (L) 0	B.U.F. trace (mm)	-	33	34	37	41	52	47	43	42	36	33
		C.F.H.(mm)	-	-8	-8	-6	0	0	+3	+5	+6	+6	+10
		Correction factor	-	1.09	1.09	1.07	1	1	0.98	0.96	0.95	0.95	0.93
		Actual BUF (g/end)	-	119	121	128	133	165	149	138	133	118	105
	Early shed timing (M + 2) 30°	BUF trace (mm)	13	16	20	27	32	38	47	43	37	31	24
		C.F.H.(mm)	-16	-12	-10	-6	0	0	+2	+4	+6	+8	+10
		Correction factor	1.19	1.15	1.12	1.07	1	1	0.98	0.97	0.95	0.94	0.93
		Actual BUF (g/end)	53	63	73	96	107	127	150	137	123	102	75
Low warp tension (WT2)	Late shed timing (L) 0°	BUF trace (mm)	20	22	24	27	33	34	33	30	28	26	24
		C.F.H.(mm)	-3	-6	-6	-6	0	0	+1	+5	+6	+6	+5
		Correction factor	1.04	1.07	1.07	1.07	1	1	0.99	.96	0.95	0.95	0.96
		Actual BUF (g/end)	70	81	89	97	110	115	111	98	91	84	77
	Early shed timing (M + 2) 30°	BUF trace (mm)	9	11	14	17	20	30	38	25	23	19	15
		C.F.H.(mm)	-13	-12	-10	-8	-3	+1	+2	+6	+8	+10	+10
		Correction factor	1.16	1.15	1.12	1.09	1.03	0.99	0.98	0.95	0.94	0.93	0.93
		Actual BUF (g/end)	39	43	53	60	70	101	126	86	76	59	43

values are plotted in Fig 40 against the extra rail position for the various shed timings and tensions. They show, over the range of imbalance, a variation by a factor of three in B.U.F. The curves showing that variation are broadly symmetrical but not about the position "BR zero", but more nearly about "BR - 1" or between the two. This is due, at least in part, to the fact that with a dobby based on a crank, the raised and lowered healds are not quite equally displaced from the position at which they cross. Confirmation is provided by the graph of T_t/T_s (the ratio of open-shed tensions in tighter and slacker sheets) plotted against extra rail position, which shows a minimum at about "BR - ½" (Fig 41). Note that the discontinuity of slope in this graph is due to a change of identity of T_t and T_s at this point as the tighter sheet becomes the slacker and vice versa. Symmetry about "BR - ½" is not perfect because shifting the height of the extra rail does not only change shed balance, it influences the total warp tension and there are possible dynamic effects and friction effects, some of which may have a greater influence at the front of the heald shafts than at the back where tension measuring takes place. The effect on total warp tension of the extra rail is shown in Fig 42. The values result from addition of the measured slacker and tighter shed values.

The general levels of total tension vary with applied weights in the way that would be expected from the Group I experiments - the tensions designated "low" being in fact lower than those nominally "high" and the late timings giving significantly lower tension values than the early timings. There is also some variation of tension with shed imbalance that may be attributable to dynamic effects or might indicate measuring errors. Raising the warp sheet will alter the direction of the resultant force exerted on the sensing roller, increasing its moment about the

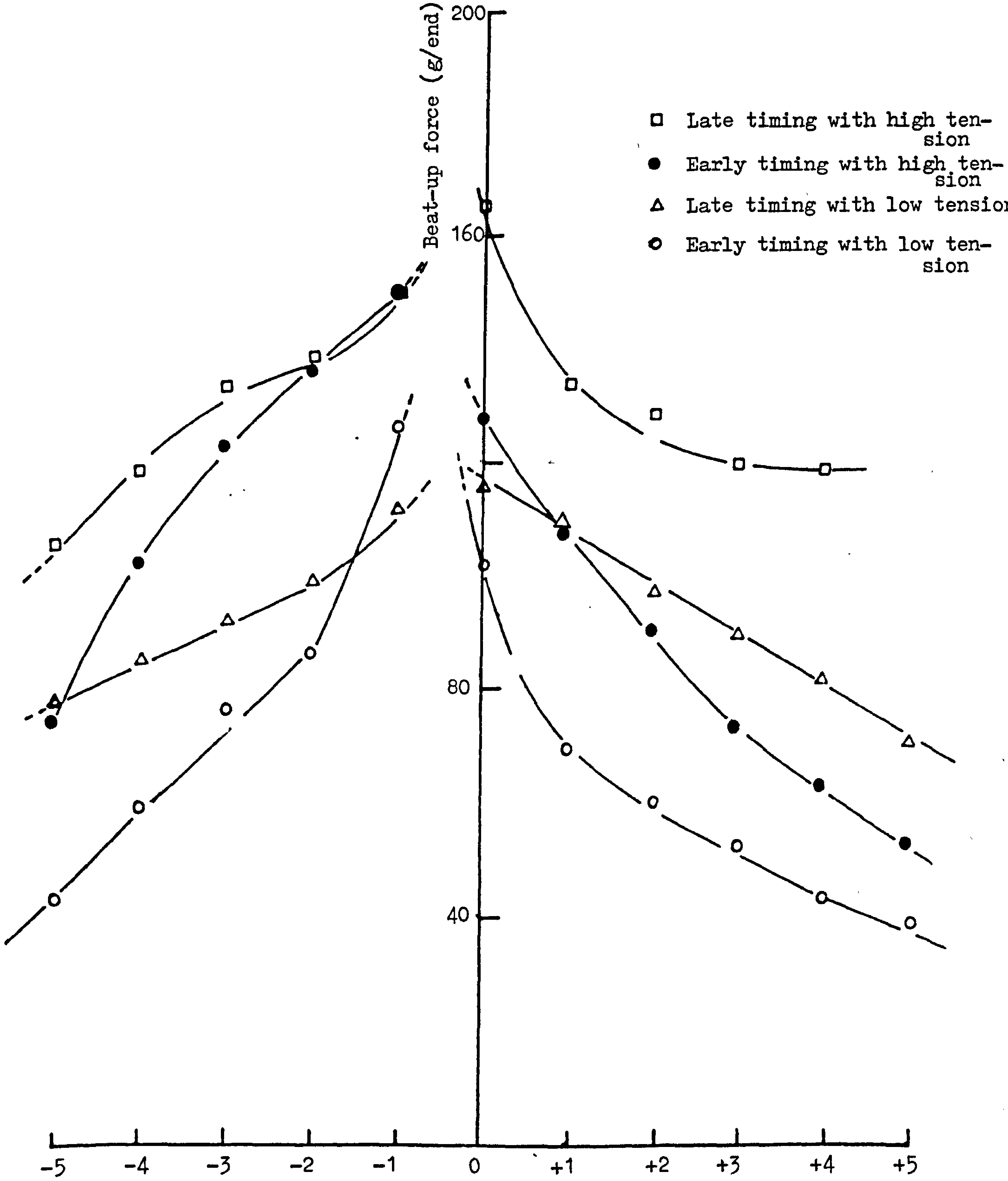


Figure 40. Beat-up force against extra rail position

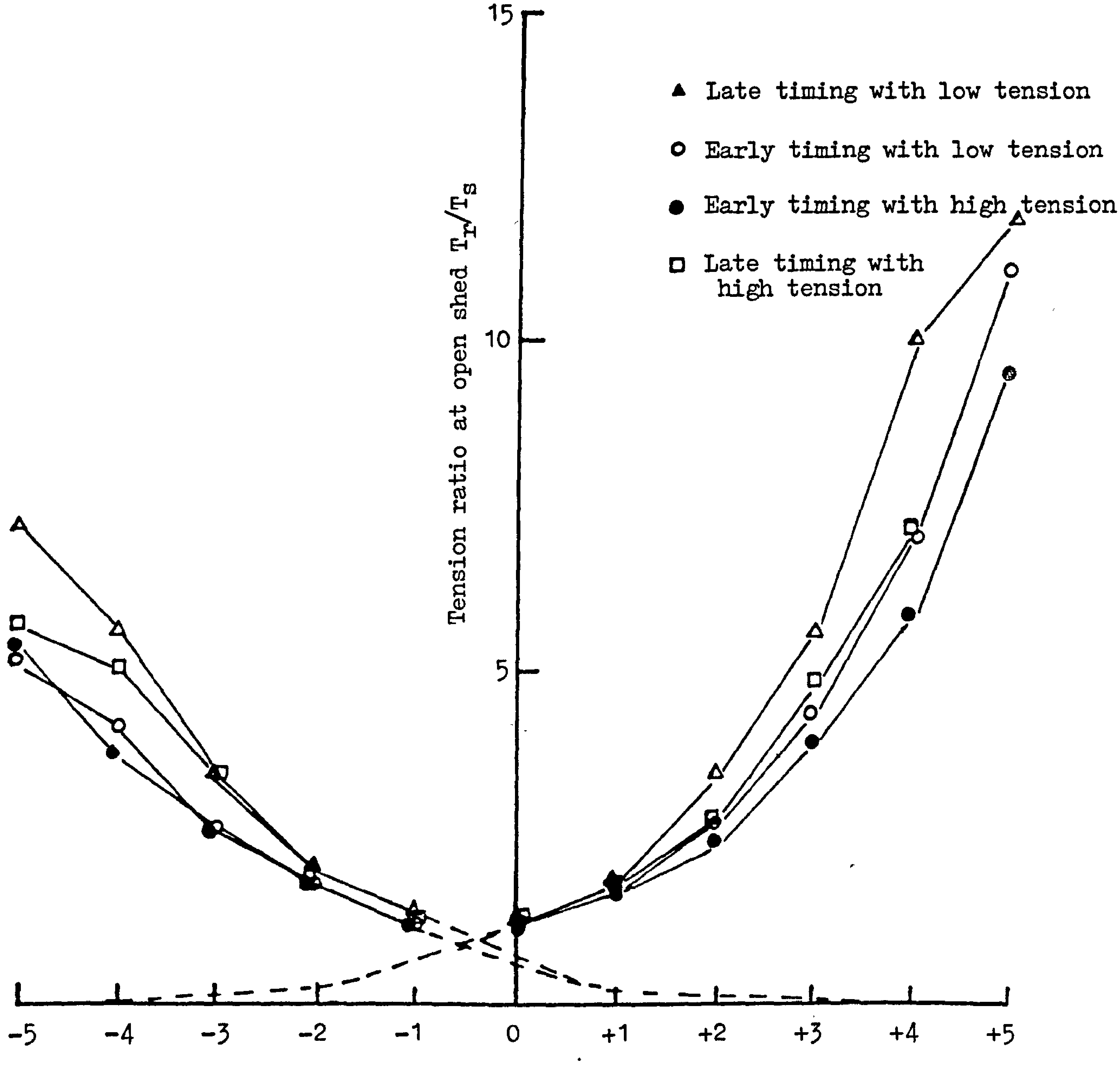


Figure 41. Tension ratio at open shed at different extra rail positions

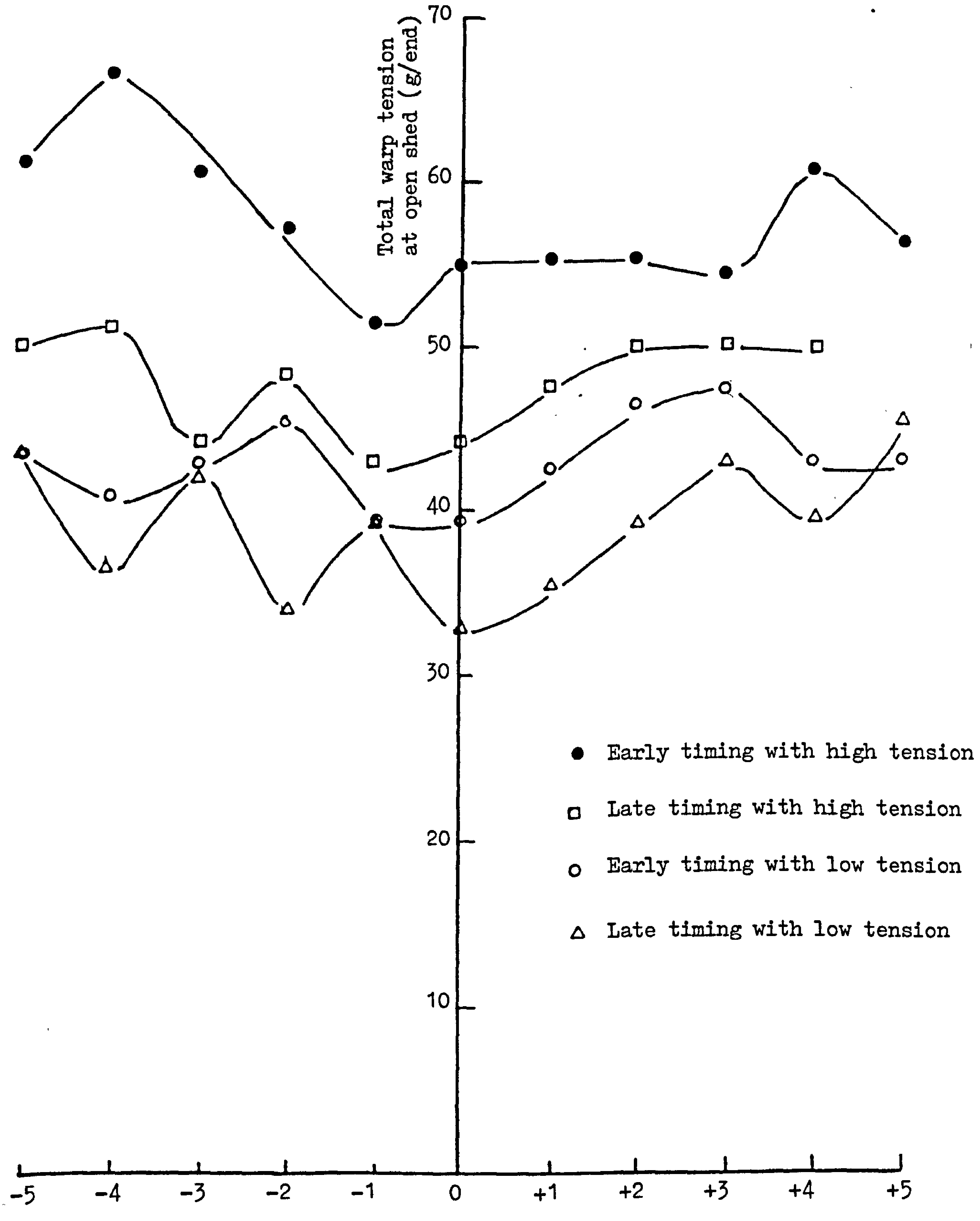


Figure 42. Total warp tension at open shed against extra rail position

pivot of that roller and so reducing the tension. But, as has already been mentioned, the reduction of cloth-fell displacement would decrease the amount let off due to the swinging of the back rail from its mean position, which would cause it to adopt a more forward mean position and lead in turn to a higher average tension. In view of these complex interactions, such variations will not be examined in detail at this stage, but will be referred to later when more results are available. The effect of shed imbalance on cloth fell distance is roughly what would be expected - a similar effect to that on B.U.F. but distorted probably by dynamic effects. Again a more detailed examination will be delayed.

From the basic data, three areas will be selected for further comment. Firstly, the near-symmetry of Fig 41, although not about the "level" value, suggests that experiments in which the warp sheet is deflected only in one way will be sufficient for the present purpose. As, in practice, it is always the lower warp sheet that is made tighter (as the alternative would tend to lift the warp off the shuttle race), it was decided to adopt that method - so that just positive values in the B.R. code will be used.

Secondly, although some of the effects of shed unbalance are not very clear, that which is of major interest is Fig 43 showing the B.U.F. plotted against tension ratio T_t/T_s. It confirms the suggestions by Yehia[14] and Leung,[15] as a result of their limited experiments, that a significant reduction in B.U.F. can be achieved. Comparison with Ito's results extracted from Fig 2 (Page 7) and superimposed on the present results in Fig 43, suggests that the effects are of a similar magnitude to those that he predicted over the range T_t/T_s 1 to 4 (but do not remain as great over higher ranges) provided that shed

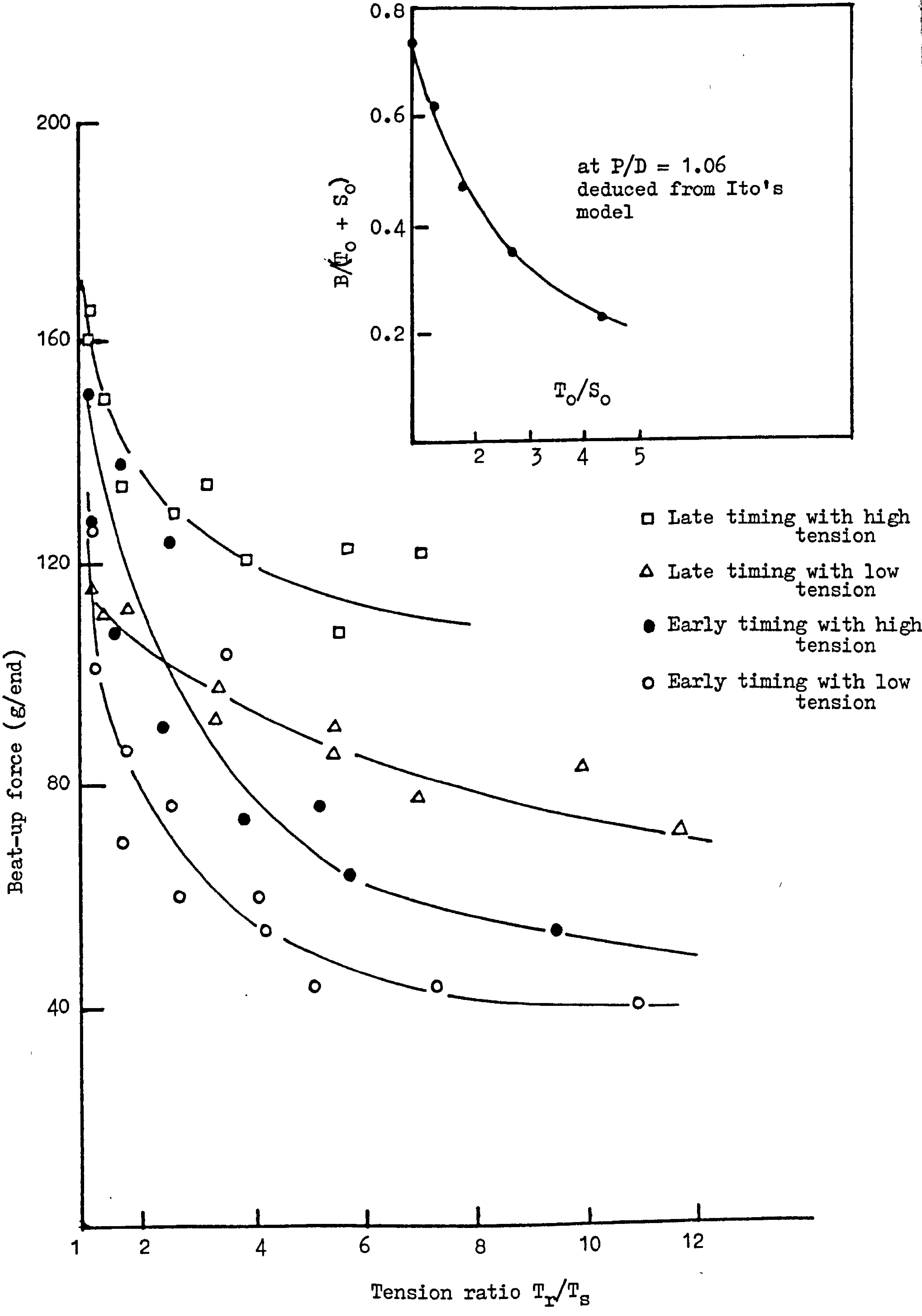


Figure 43. Beat-up force against tension ratio of open shed

timing is early so that open-shed values of T_t/T_s remain effective during beat up. Fig 44 shows the corresponding effect on C.F.D.

Thirdly, some comment on the effect of shed settings on tension ratio are relevant. When the shed is unbalanced by adjusting the extra rail, the effect is to extend one set of yarns more than the other, i.e. to cause a strain difference that depends on the unbalance but hardly at all on the general tension level. The given strain difference is converted to a tension difference via the elastic moduli. If the moduli are constant, then a given shed setting will produce a given tension difference regardless of general level of tension - i.e. at high tensions the tension-ratio will be less than at low levels. In fact the moduli do increase with tension, but they would have to be proportional to tension if a given setting were always to give the same ratio. It is doubtful if they increase so much; consequently it would be expected that the tension ratio produced by a given unbalance will reduce as the tension level increases and Fig 41 seems to confirm this.

The results suggest that the comprehensive set of experiments planned will provide results that are of practical interest and, in their inter-relationships, of theoretical interest. Those Group III experiments will now be introduced.

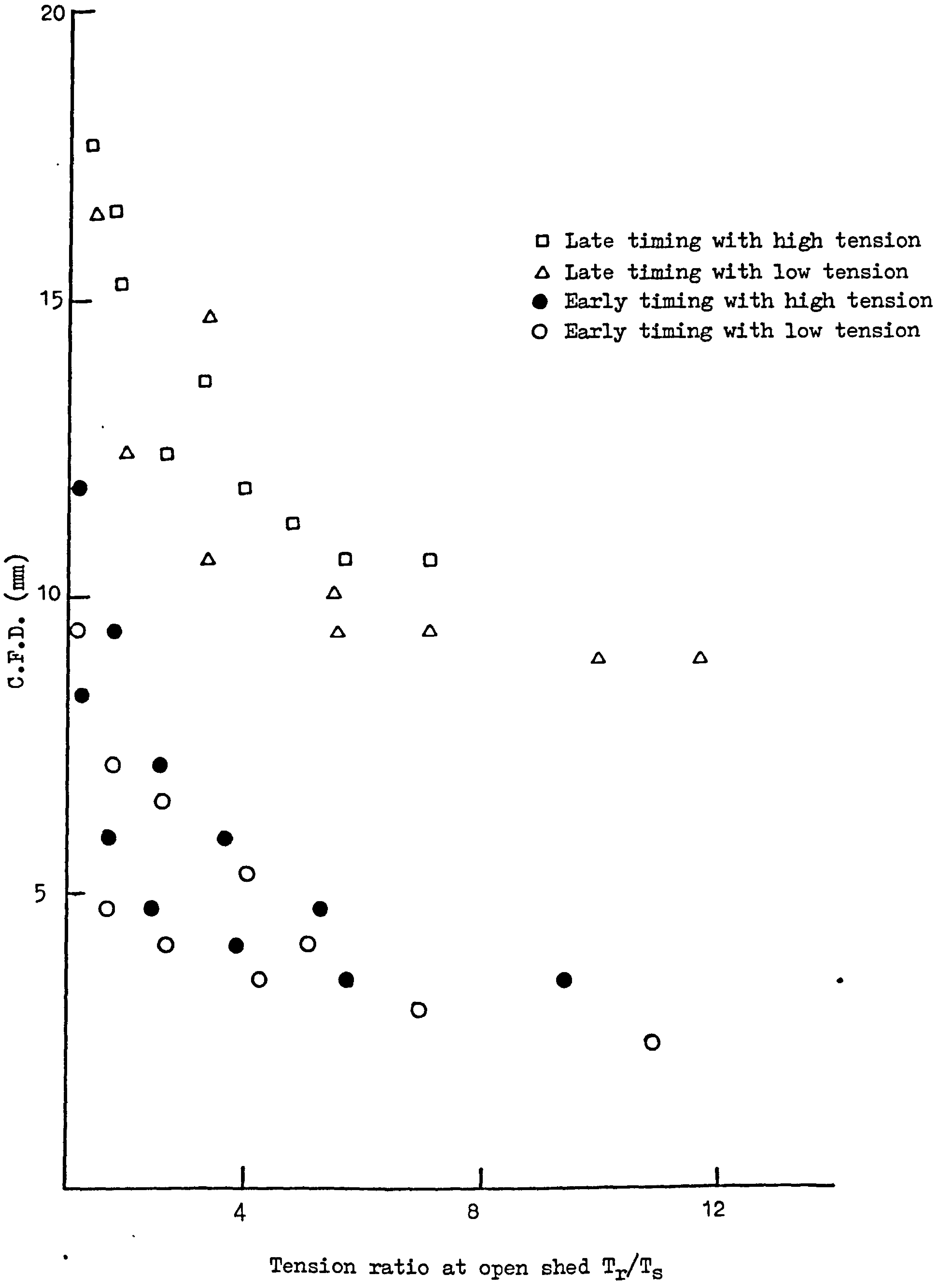


Figure 44. Cloth fell distance against tension ratio at open shed

CHAPTER VII

7. GROUP III EXPERIMENTS

The effect of shed unbalance, shed timing and warp tension on weaving resistance

CHAPTER VII

Group III experiments - The effect of shed unbalance, shed timing and warp tension on weaving resistance

7.1 Introduction

The two previously described sets of experiments suggested that weaving resistance had an almost linear dependence on warp tension when other factors were unchanged, and that raising the warp sheet to give an unbalanced shed produced a similar effect to that produced by lowering it, although not exactly the same. Thus it was decided to work with six levels of extra back rail positions (BR N to BR + 5), six shed timings, (L, L + 1, L + 2, M, M + 1, M + 2) which would be expected to give tension ratios T_t/T_s ranging from about 1.2 to 10, and three levels of warp tensions corresponding to 20, 14, and 8 weights on the weight lever, a total of 108 combinations. To cut the labour of recording and the cost of materials, the fell build up, the single beat-up trace and the tension traces were omitted from some recordings, but only from those for which reasonable interpolation from neighbouring settings could be made if necessary.

The results are presented in terms of the independent variables, the actual loom settings listed above; but it has already been seen that it will be necessary to look at relationships between dependent variables, e.g. between BUE and tension ratio. Because the recorded traces contain a great deal of information, not all of which may be obvious at first and not all of which may be extracted in this work, it was thought advisable to print copies of the original traces for all the Group III experiments. There are problems of arranging them because five full film strips or ten abbreviated ones can be fitted on a page, while there is a 6 x 6 x 3 set of experiments. The arrangement used for the first (highest) tension level is as follows, Table 8, where the numbers refer to the

Figure numbers on the pages that follow. For example, on Figure 49 are collected eight short strips covering combinations of M + 1 and M + 2 with BR + 1 to + 4 together with a full strip for M + 2, BR + 5. Before each set of traces is a key table giving the locations of the traces, and after each set is a table giving the original measurements of the B.UF traces, the measured fell height, the correction to the first on account of the second, the corrected trace value and the B.U.F. value obtained by using the calibration data. The values from this final section are shown on a three-dimensional representation (Figures 61, 62, 63) in which BUF is represented by the height of a surface above a base on which the axes represent shed timing (crank angle at crossing) and upward shift of the extra "back-rail". No attempt has been made to smooth the measured values and so the points on the surface are joined by straight lines. It should be remembered that those values are themselves the average of a series of beat-up peaks, so it is not surprising that the surfaces appear reasonably smooth.

7.2 Results - B.U.F.

The results show, as did the earlier ones, a very considerable variation in B.UF ranging from 159 g/end for late shedding with a near-balanced shed to 35 g/end for an early shed (almost, but not quite, fully open at beat-up) and a tension ratio of about 7 (as measured at the back of the loom).

Similar sets of traces for the two other tension levels follow, each preceded by a key (Pages 133 and 141) and followed by tables of extracted values. In each case, graphs (Figures 45 - 60) showing the variation in B.UF follow and each shows a variation very similar to that of the first one, but with slightly reduced values of B.UF as basic

TABLE 8

Key to location of traces
high warp tension (WT5)

<table>
<tr><th>Shed timing code
Extra rail position (in.)</th><th>L</th><th>L + 1</th><th>L + 2</th><th>M</th><th>M + 1</th><th>M + 2</th></tr>
<tr><td>0 (N)</td><td colspan="5">FIG.46</td><td>FIG. 47</td></tr>
<tr><td>+ 1</td><td colspan="2" rowspan="4">FIG.47</td><td colspan="2" rowspan="4">FIG.48</td><td colspan="2" rowspan="4">FIG.49</td></tr>
<tr><td>+ 2</td></tr>
<tr><td>+ 3</td></tr>
<tr><td>+ 4</td></tr>
<tr><td>+ 5</td><td colspan="5">FIG.45</td><td>FIG. 49</td></tr>
</table>


WT6
BR+5
M+1
4-3
WT5
BR5
M
WT5
BR+5
L+2
WT5
BR+5
L+1
4-3
WT6
BR+5
L
4-3
TECHNICAL DATA
SUBJECT

Figure 45

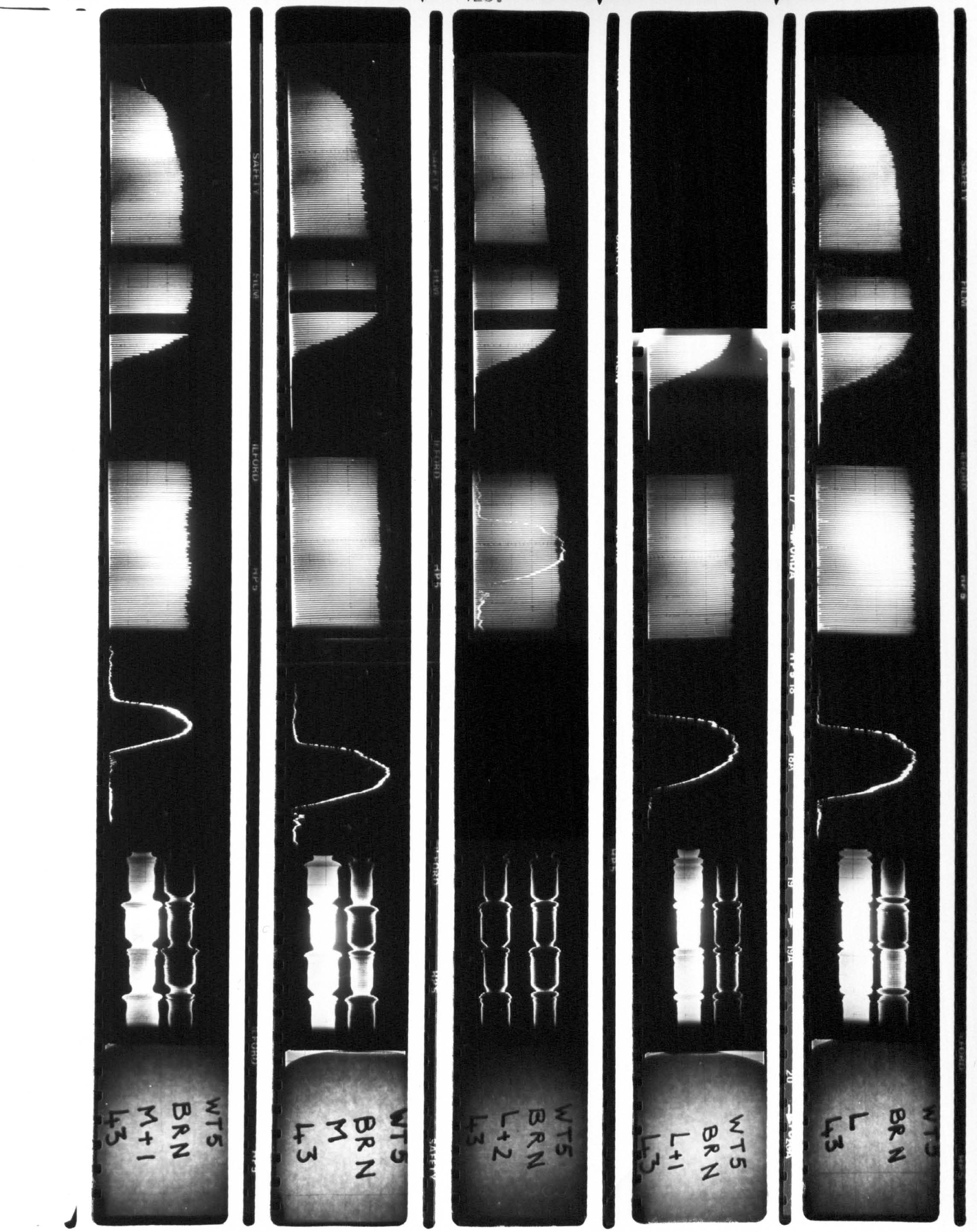

WT5
BRN
M+1
43
WT5
BRN
M
43
WT5
BRN
L+2
43
WT5
BRN
L+1
43
WT5
BRN
L
43
SAFETY FILM
ILFORD HP5
TECHNICAL DATA
SUBJECT
DAT

Figure 46

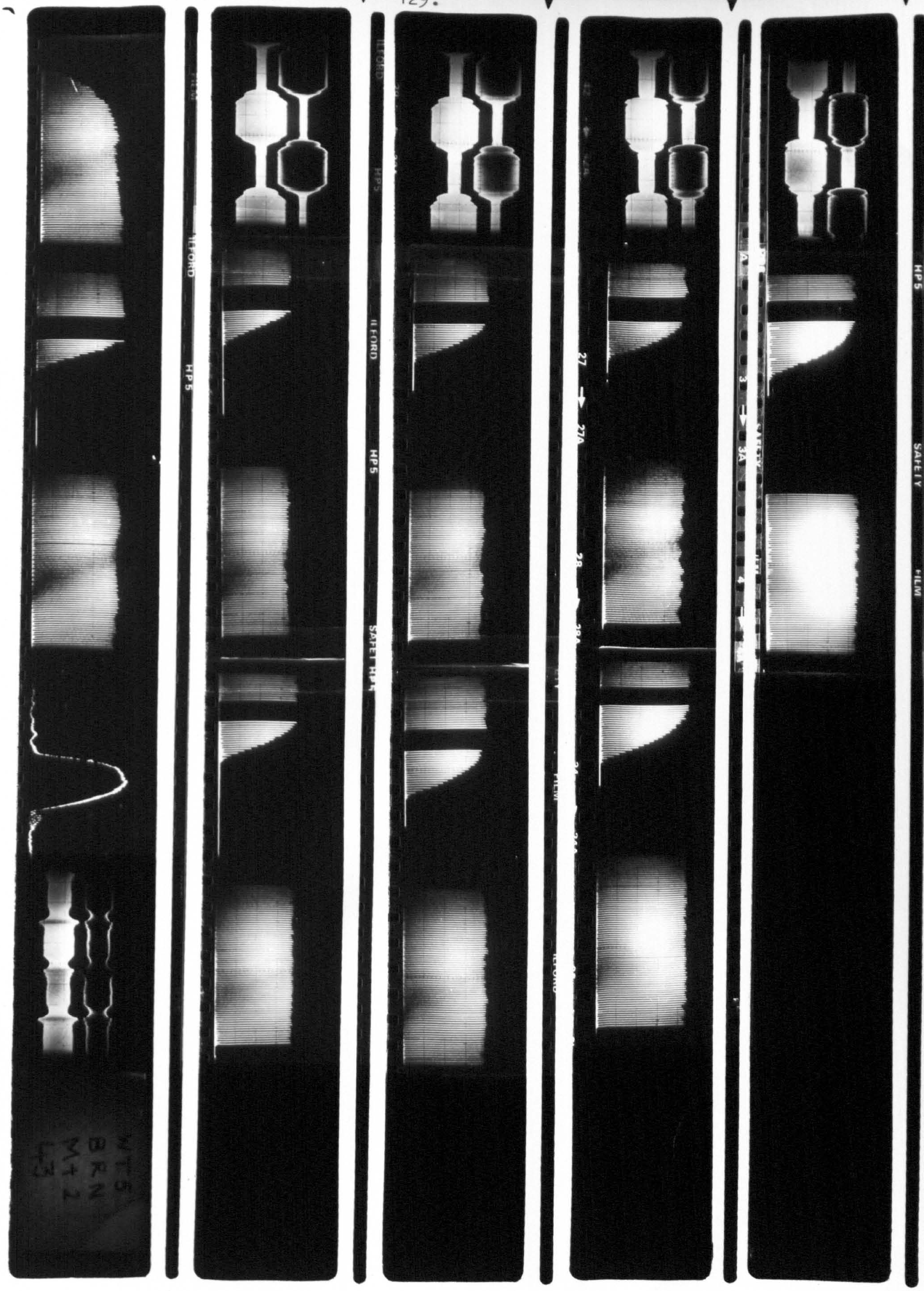


Figure 47

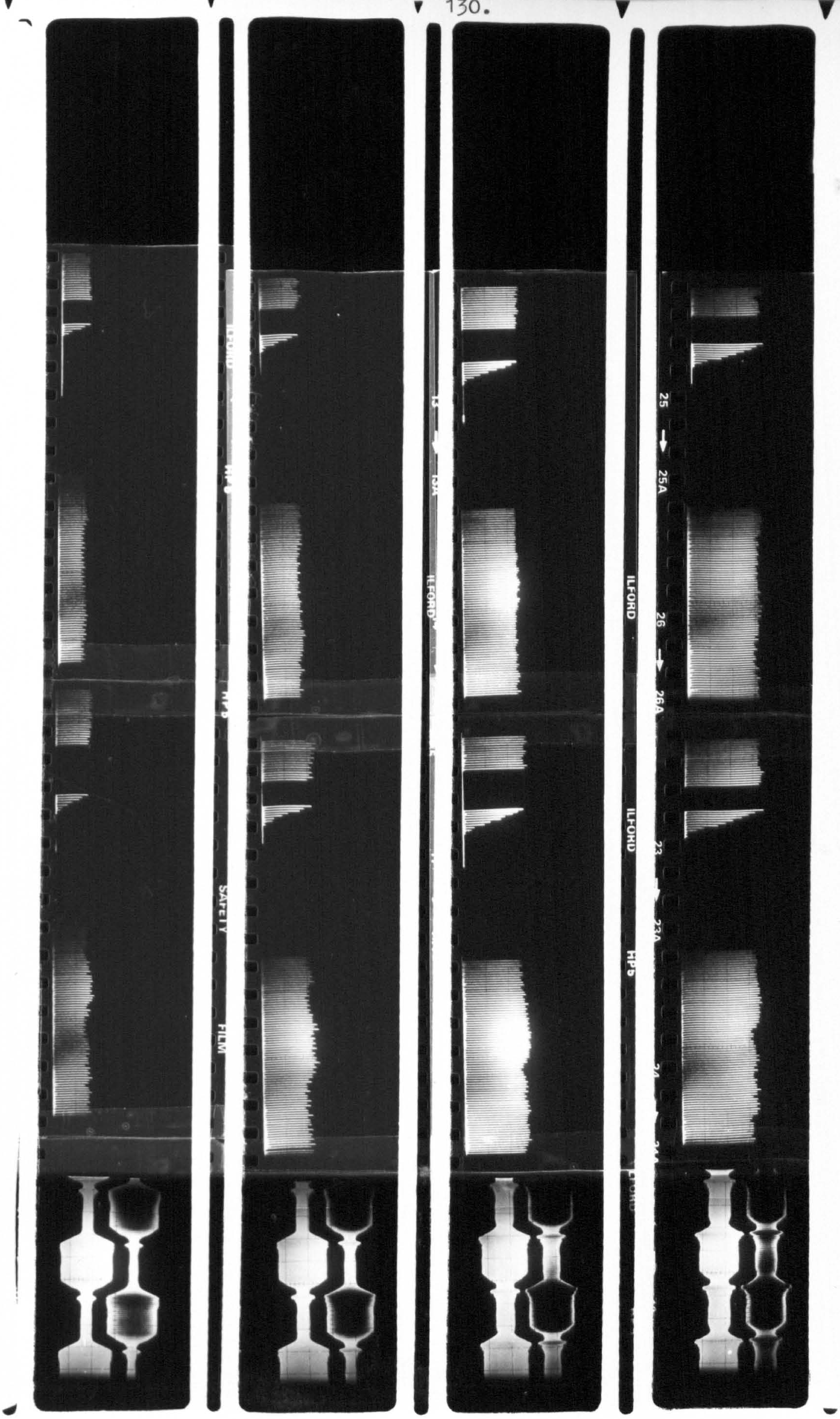

ILFORD
HP5
SAFETY
FILM
13
13A
ILFORD
ILFORD
HP5
25
25A
26
26A
23
23A

Figure 48

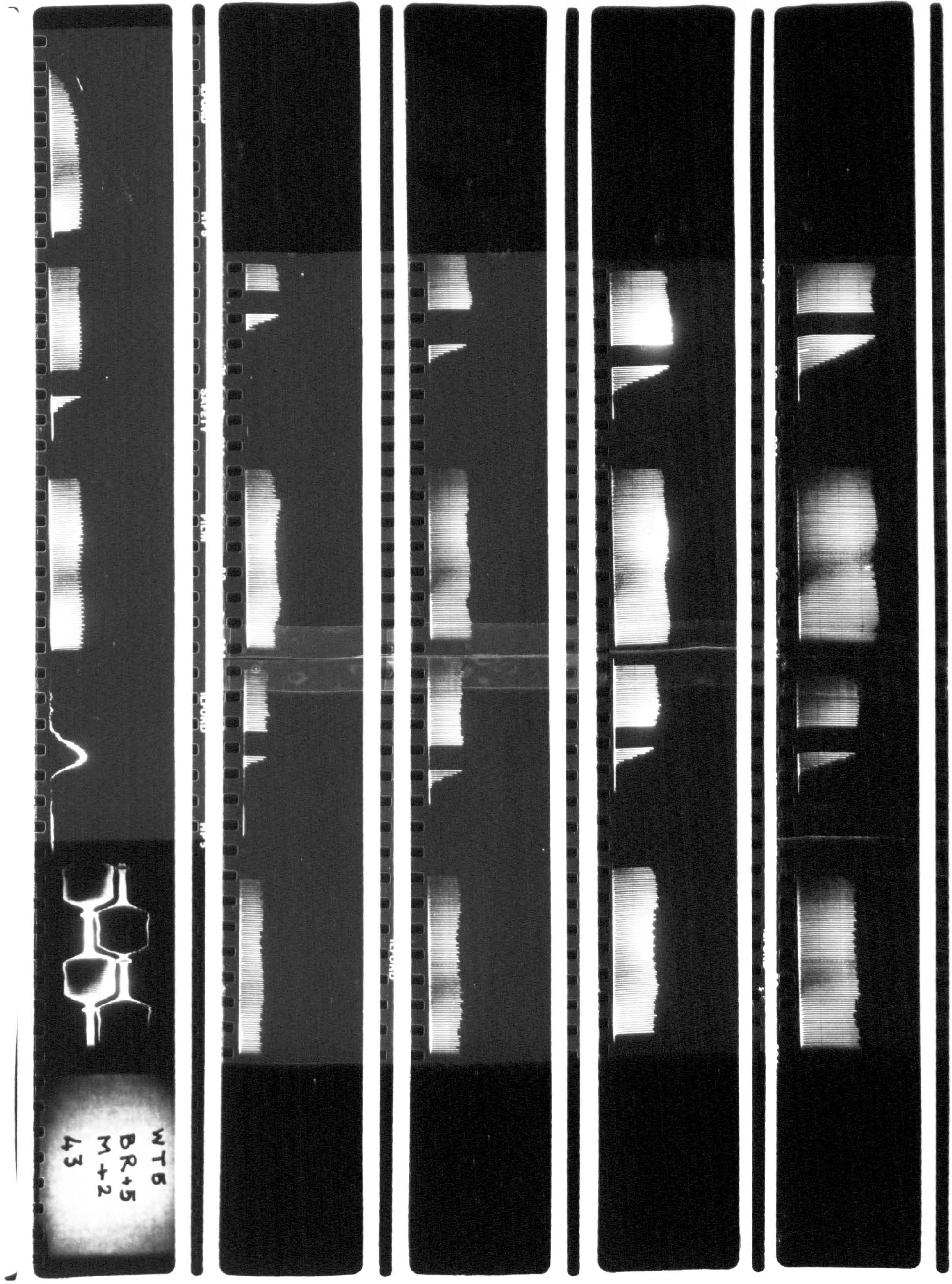


Figure 49

TABLE 9

Beat-up force for different shed timings
and extra rail positions under high warp tension level

Type of measurement	Extra rail position (in) / Shed timing code	0 (N)	+ 1	+ 2	+ 3	+ 4	+ 5
B.U.F. traces (mm)	L	49	45	38	36	33	32
	L + 1	44	42	42	40	38	40
	L + 2	42	37	26	19	15	16
	M	45	27	21	14	11	10
	M + 1	41	30	24	17	12	9
	M + 2	40	32	28	22	16	14
C.F.H.(mm)	L	0	0	-6	-4	-3	-3
	L + 1	0	-2	-3	0	-1	-3
	L + 2	0	+2	+2	0	+2	-1
	M	0	0	0	-4	-4	-8
	M + 1	0	-1	-5	-8	-8	-11
	M + 2	0	-4	-6	-10	-12	-16
Correction factor	L	1	1	1.07	1.04	1.03	1.03
	L + 1	1	1.02	1.03	1	1.01	1.03
	L + 2	1	0.98	0.98	1	0.98	1.01
	M	1	1	1	1.04	1.04	1.09
	M + 1	1	1.01	1.05	1.09	1.09	1.14
	M + 2	1	1.04	1.07	1.12	1.16	1.19
Actual B.U.F. (g/end)	L	159	147	134	126	115	112
	L + 1	144	140	143	132	127	136
	L + 2	138	121	86	64	50	55
	M	147	91	71	49	39	37
	M + 1	135	104	85	63	44	35
	M + 2	132	114	100	83	63	56

TABLE 10

Key to location of traces
medium warp tension (WT 3.5)

<table>
<tr><th>Shed timing code
Extra rail position (in.)</th><th>L</th><th>L + 1</th><th>L + 2</th><th>M</th><th>M + 1</th><th>M + 2</th></tr>
<tr><td>0 (N)</td><td rowspan="5">FIG. 51</td><td colspan="5">FIG.52</td></tr>
<tr><td>+ 1</td><td colspan="2" rowspan="4">FIG.54</td><td colspan="2" rowspan="4">FIG.55</td><td rowspan="5">FIG. 53</td></tr>
<tr><td>+ 2</td></tr>
<tr><td>+ 3</td></tr>
<tr><td>+ 4</td></tr>
<tr><td>+ 5</td><td colspan="5">FIG.50</td></tr>
</table>

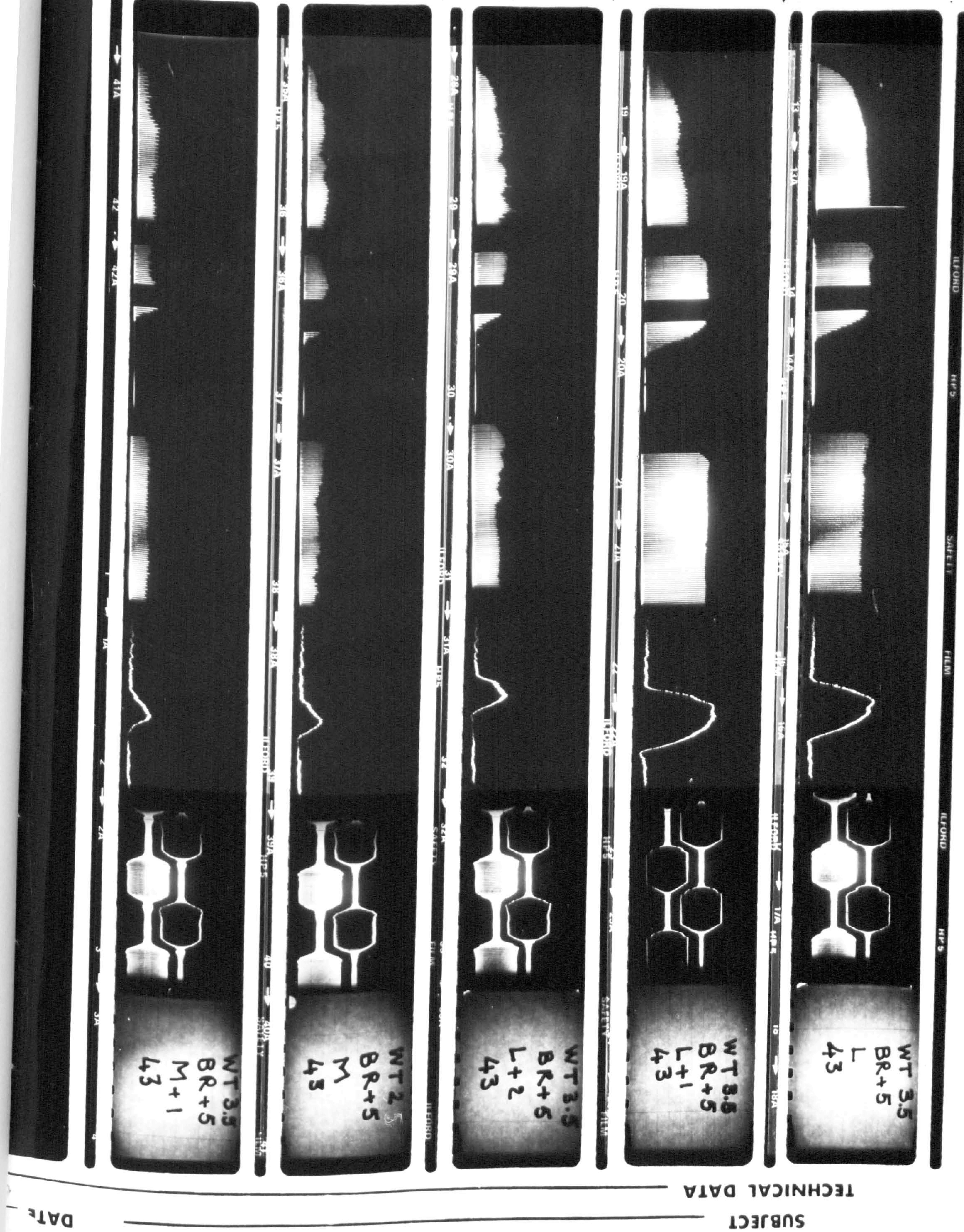

WT 3.5
BR+5
M+1
43
WT 2.5
BR+5
M
43
WT 3.5
BR+5
L+2
43
WT 3.5
BR+5
L+1
43
WT 3.5
BR+5
L
43
TECHNICAL DATA
SUBJECT
DATE

Figure 50

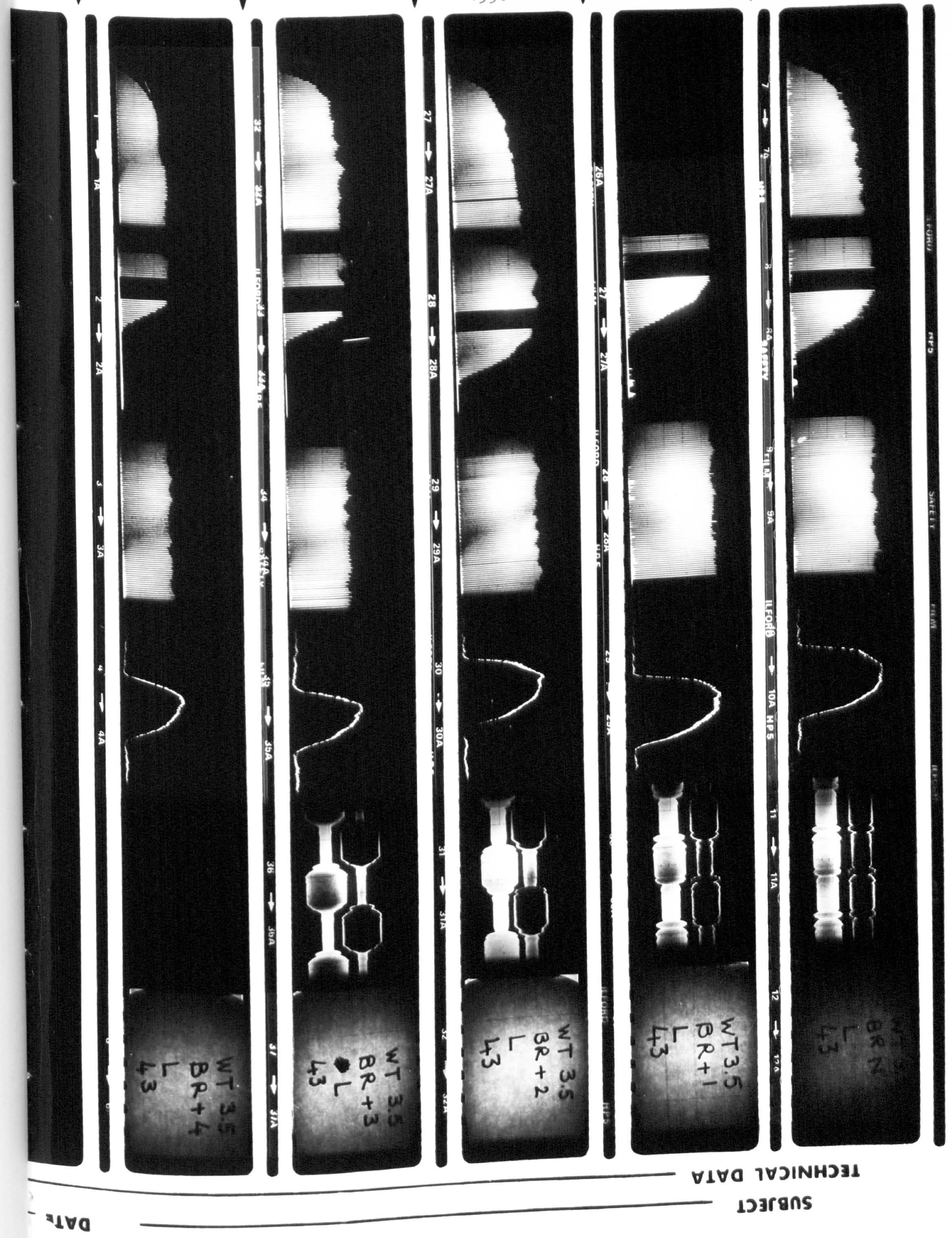

WT 3.5
BR+4
L
43
WT 3.5
BR+3
L
43
WT 3.5
BR+2
L
43
WT 3.5
BR+1
L
43
BR N
L
43
TECHNICAL DATA
SUBJECT
DATE

Figure 51

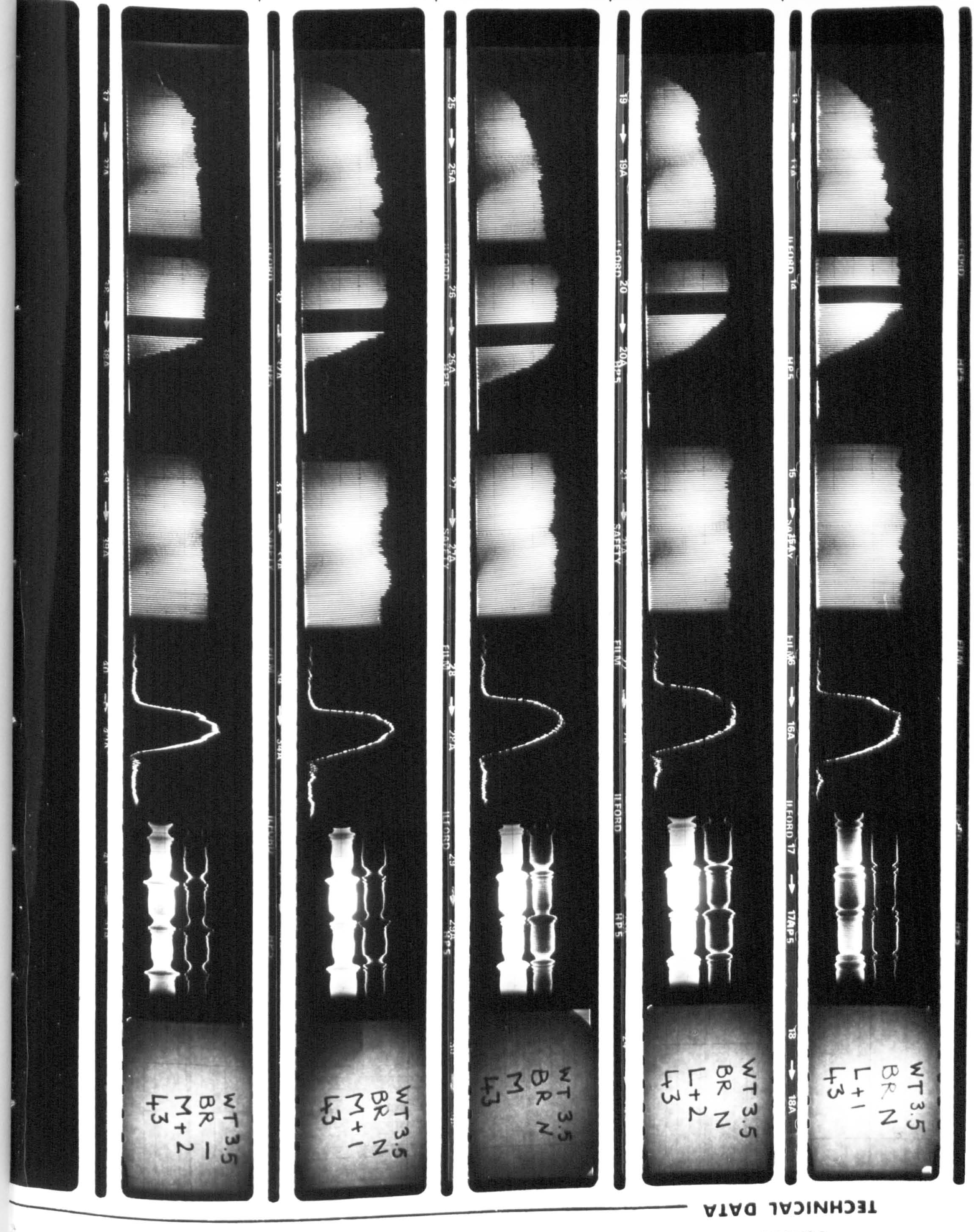

WT 3.5
BR —
M+2
43
WT 3.5
BR N
M+1
43
WT 3.5
BR N
M
43
WT 3.5
BR N
L+2
43
WT 3.5
BR N
L+1
43
ILFORD
HP5
SAFETY
FILM
TECHNICAL DATA
SUBJECT
DATE

Figure 52

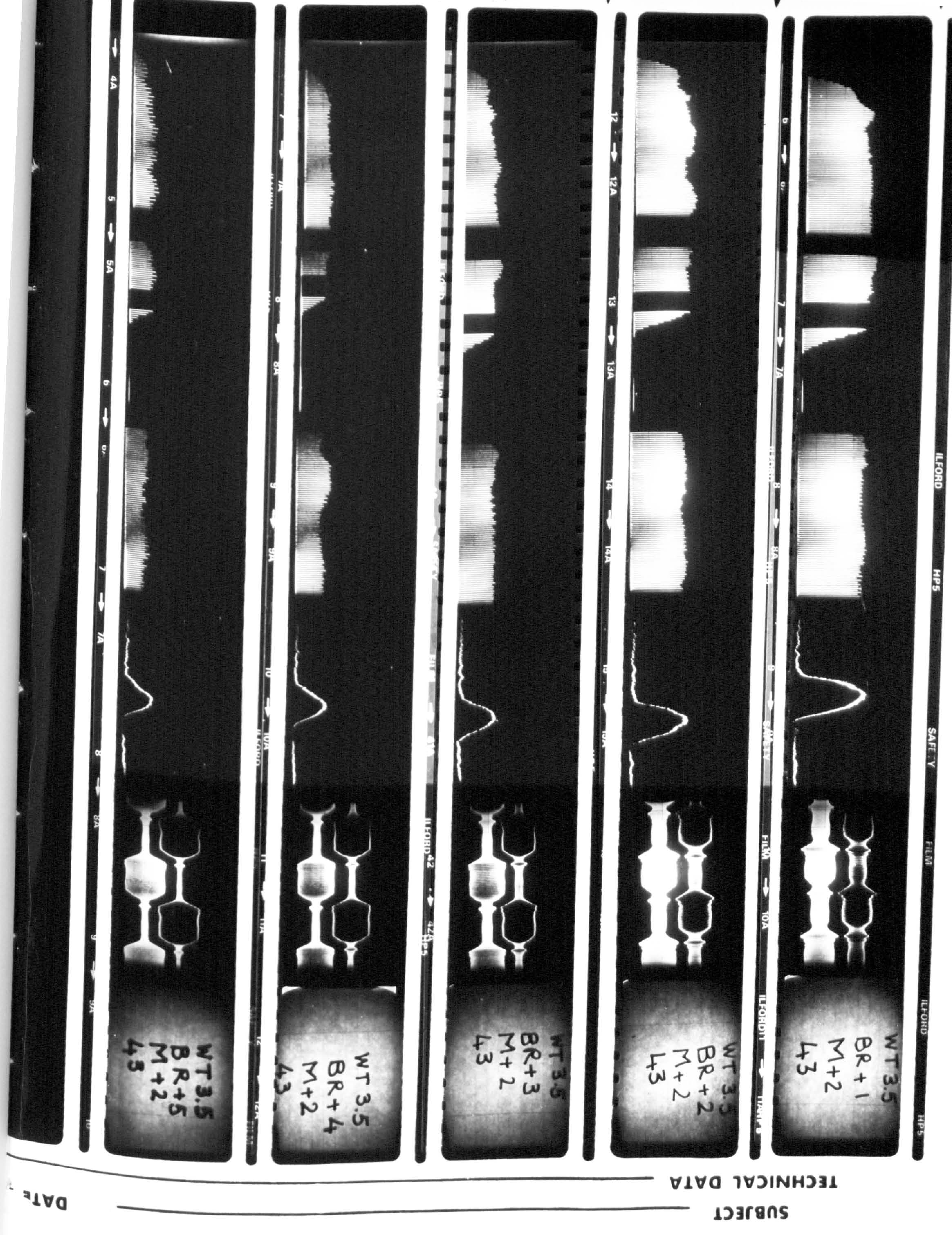

WT 3.5
BR+5
M+2
43
WT 3.5
BR+4
M+2
43
WT 3.5
BR+3
M+2
43
WT 3.5
BR+2
M+2
43
WT 3.5
BR+1
M+2
43
ILFORD HP5 SAFETY FILM
TECHNICAL DATA
SUBJECT
DATE

Figure 53

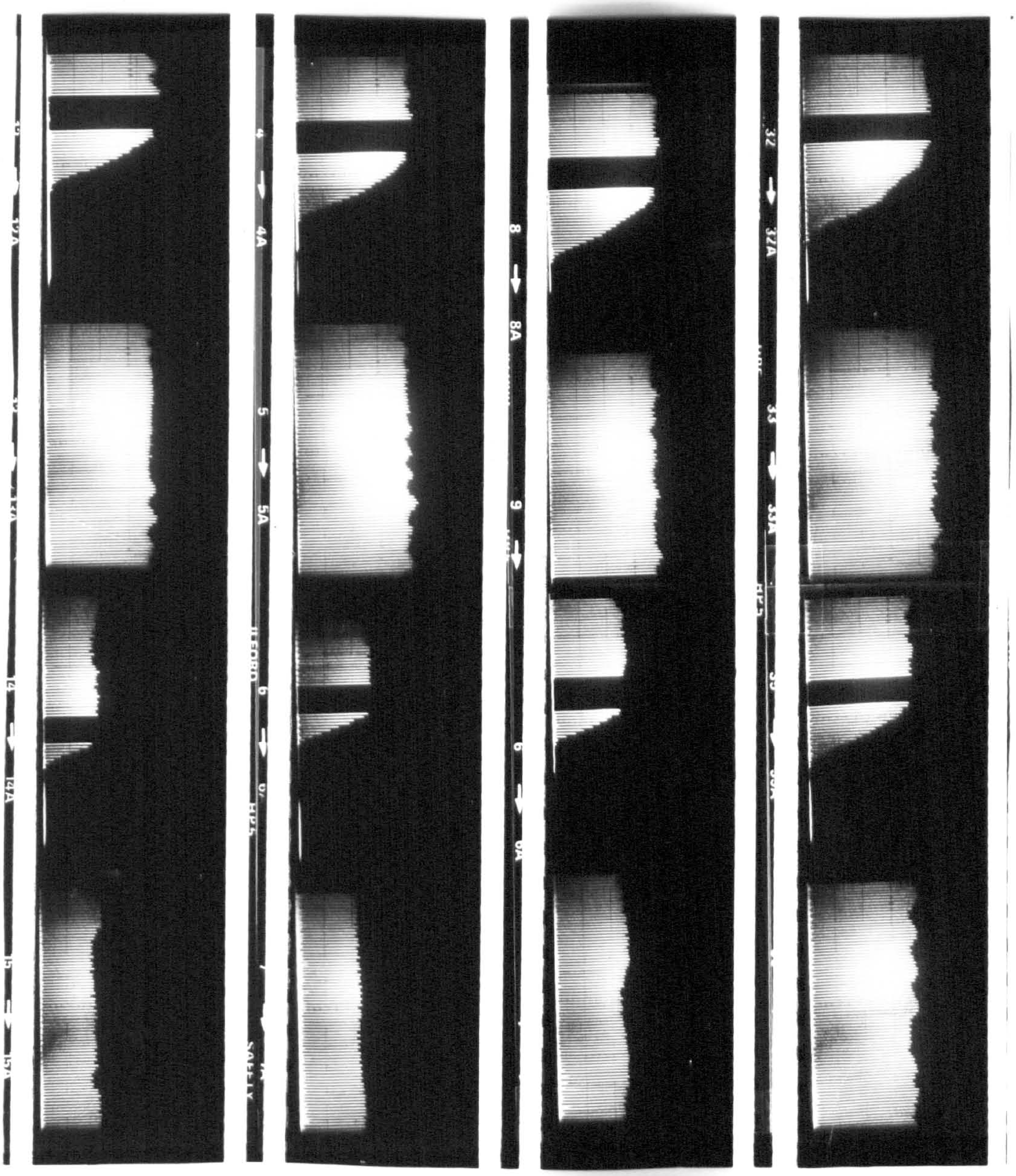


Figure 54

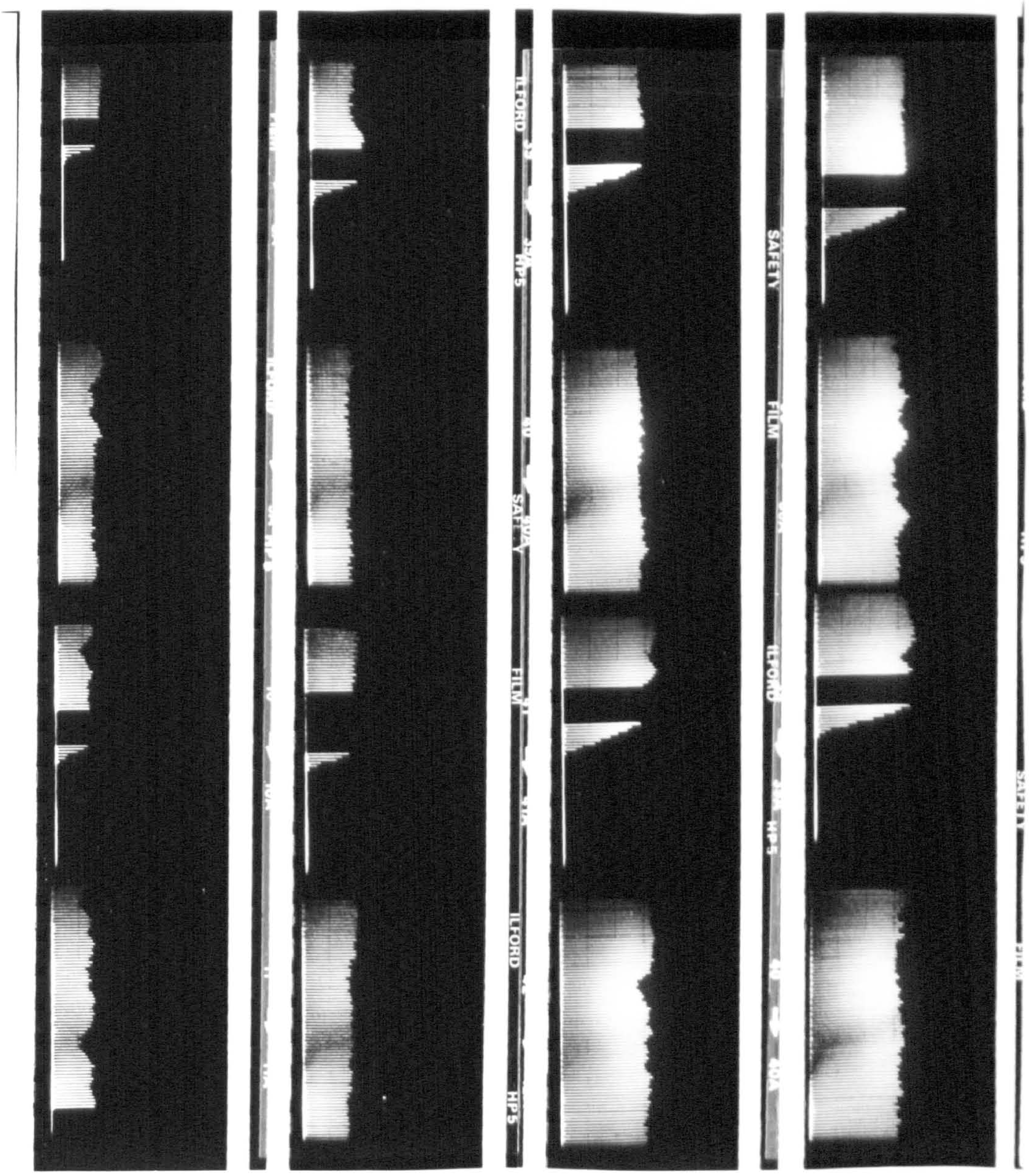

ILFORD
HP5
SAFETY
FILM
ILFORD
HP5
SAFETY
FILM
ILFORD
HP5
40A

Figure 55

TABLE 11

Beat-up force for different shed timings
and extra rail positions under medium warp tension level

Type of measurement	Extra rail position (in) Shed timing code	0 (N)	+ 1	+ 2	+ 3	+ 4	+ 5
B.U.F. traces (mm)	L	45	45	42	34	27	29
	L + 1	43	42	39	40	38	34
	L + 2	42	38	25	22	20	14
	M	41	29	23	15	12	10
	M + 1	41	33	27	18	14	10
	M + 2	39	34	29	21	16	12
C.F.H.(mm)	L	0	0	0	-3	-4	-3
	L + 1	0	-1	+2	0	+2	+4
	L + 2	0	+2	-3	0	0	+5
	M	0	0	-4	-2	0	-8
	M + 1	0	-3	-7	-6	-5	-8
	M + 2	0	-3	-8	-8	-10	-12
Correction factor	L	1	1	1	1.03	1.04	1.03
	L + 1	1	1.01	0.98	1	0.98	0.96
	L + 2	1	0.98	1.03	1	1	0.96
	M	1	1	1.04	1.02	1	1.09
	M + 1	1	1.03	1.08	1.07	1.05	1.09
	M + 2	1	1.03	1.09	1.09	1.12	1.16
Actual B.U.F. (g/end)	L	147	147	138	118	95	101
	L + 1	141	139	126	132	124	110
	L + 2	138	123	87	74	68	46
	M	135	98	81	52	41	37
	M + 1	135	115	99	65	50	37
	M + 2	129	118	107	77	61	47

TABLE 12

Key to location of traces
low warp tension (WT2)

<table>
<tr><th>Shed timing code
Extra rail position (in.)</th><th>L</th><th>L + 1</th><th>L + 2</th><th>M</th><th>M + 1</th><th>M + 2</th></tr>
<tr><td>0 (N)</td><td colspan="5">FIG.57</td><td>FIG. 58</td></tr>
<tr><td>+ 1</td><td colspan="2" rowspan="4">FIG.58</td><td colspan="2" rowspan="4">FIG.59</td><td colspan="2" rowspan="4">FIG.60</td></tr>
<tr><td>+ 2</td></tr>
<tr><td>+ 3</td></tr>
<tr><td>+ 4</td></tr>
<tr><td>+ 5</td><td colspan="5">FIG.56</td><td>FIG. 60</td></tr>
</table>

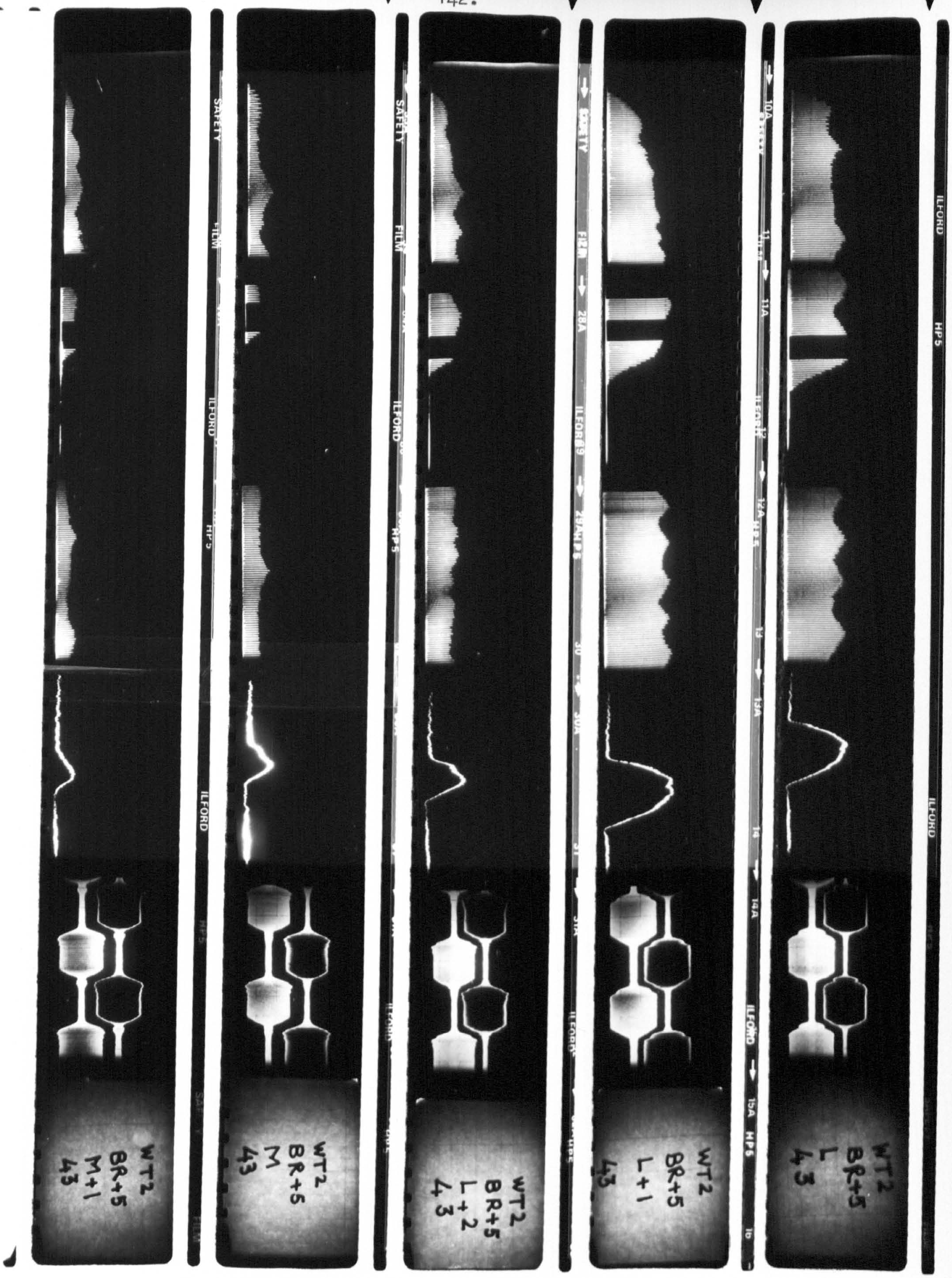

WT2 BR+5 M+1 43
WT2 BR+5 M 43
WT2 BR+5 L+2 4 3
WT2 BR+5 L+1 43
WT2 BR+5 L 4 3
SAFETY FILM
ILFORD HP5

Figure 56

Figure 57

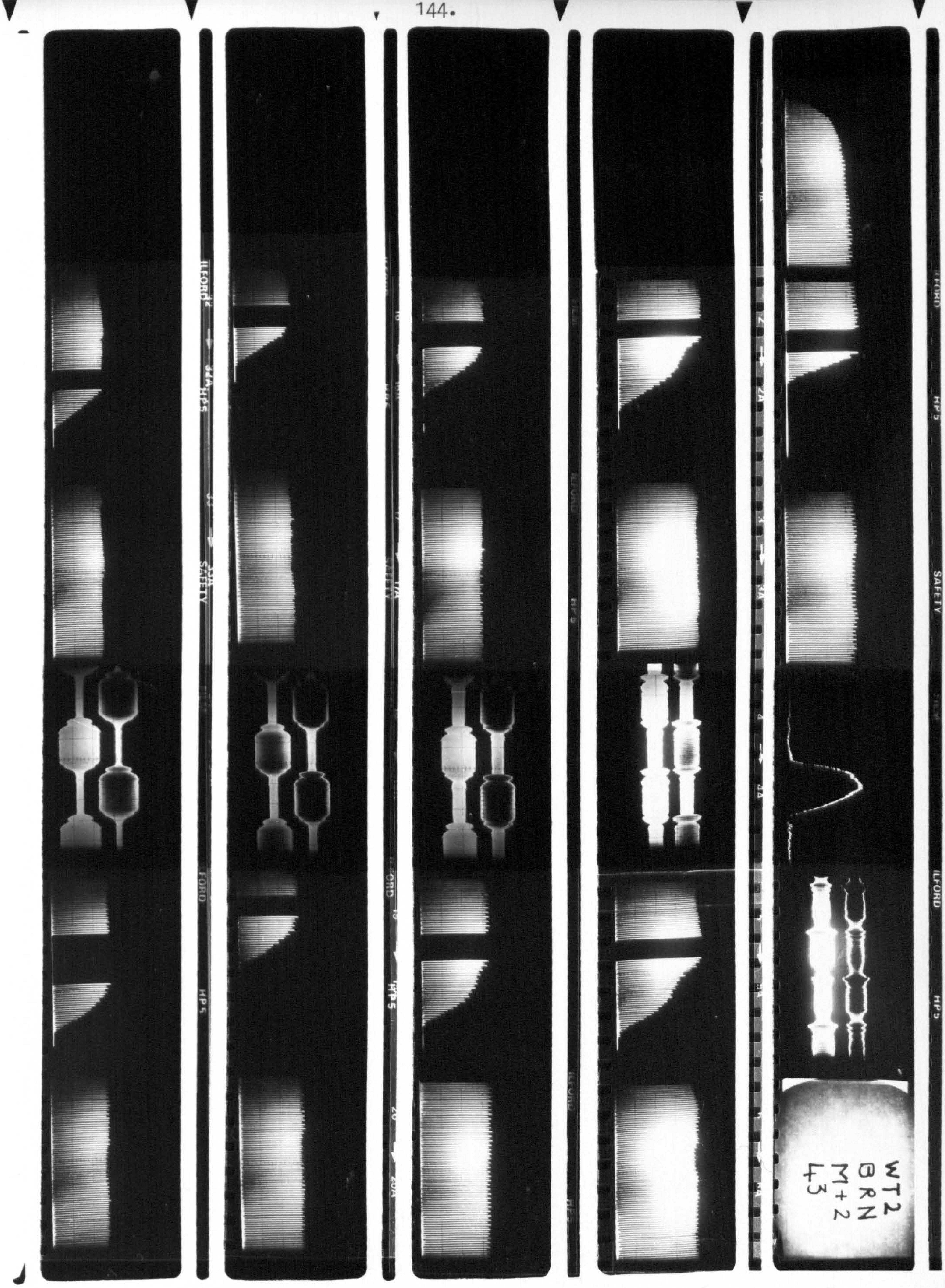


Figure 58

Figure 59

Figure 60

TABLE 13

Beat-up force for different shed timings
and back rail positions under low warp tension level

Type of measurement	Extra rail position (in) / Shed timing code	0 (N)	+ 1	+ 2	+ 3	+ 4	+ 5
B.U.F. traces (mm)	L 0	40	39	29	27	24	25
	L + 1 15	42	30	33	31	27	29
	L + 2 30	40	36	25	18	17	14
	M 0	39	23	14	11	9	8
	M + 1 15	34	21	16	12	8	6
	M + 2 30	34	23	18	14	10	9
C.F.H.(mm)	L	0	-6	-8	-8	-8	-4
	L + 1	0	-3	-4	-3	0	+2
	L + 2	0	0	+2	+4	+4	+1
	M	0	0	0	-4	-4	-2
	M + 1	0	-2	-5	-5	-10	-8
	M + 2	0	-3	-8	-10	-12	-13
Correction factor	L	1	1.07	1.09	1.09	1.09	1.04
	L + 1	1	1.03	1.04	1.03	1	0.98
	L + 2	1	1	0.98	0.96	0.96	0.99
	M	1	1	1	1.04	1.04	1.02
	M + 1	1	1.02	1.05	1.05	1.12	1.09
	M + 2	1	1.03	1.09	1.12	1.16	1.17
Actual B.U.F. (g/end)	L	132	137	107	102	89	88
	L + 1	138	136	116	108	91	98
	L + 2	132	121	83	59	55	47 Lowest
	M	129	80	47	39	32	28
	M + 1	114	72	57	44	30	24
	M + 2	114	82	66	55	37	36

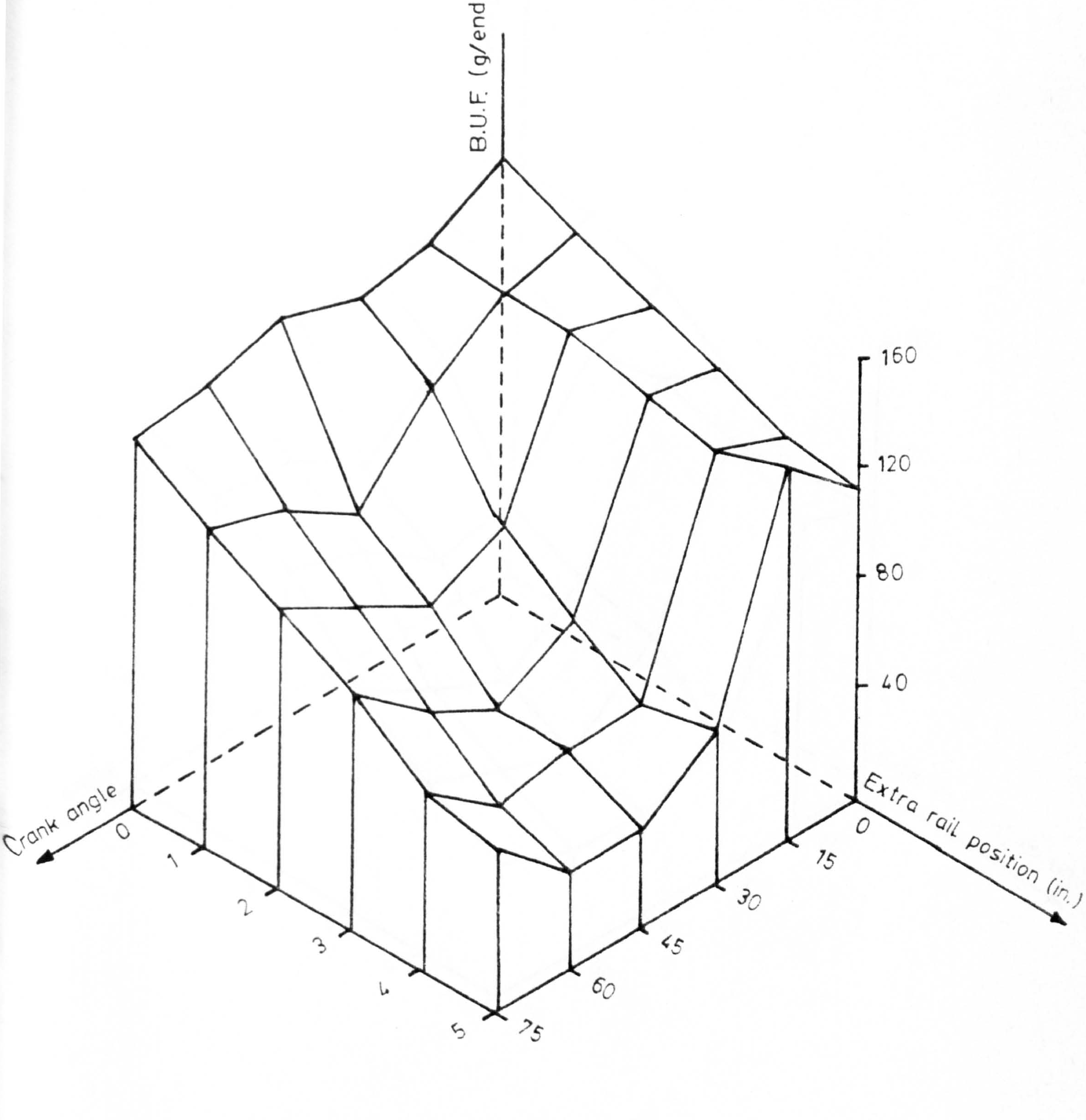


Figure 61. Effect of shed timing and shed unbalance on B.U.F.
(plain weave - high warp tension)

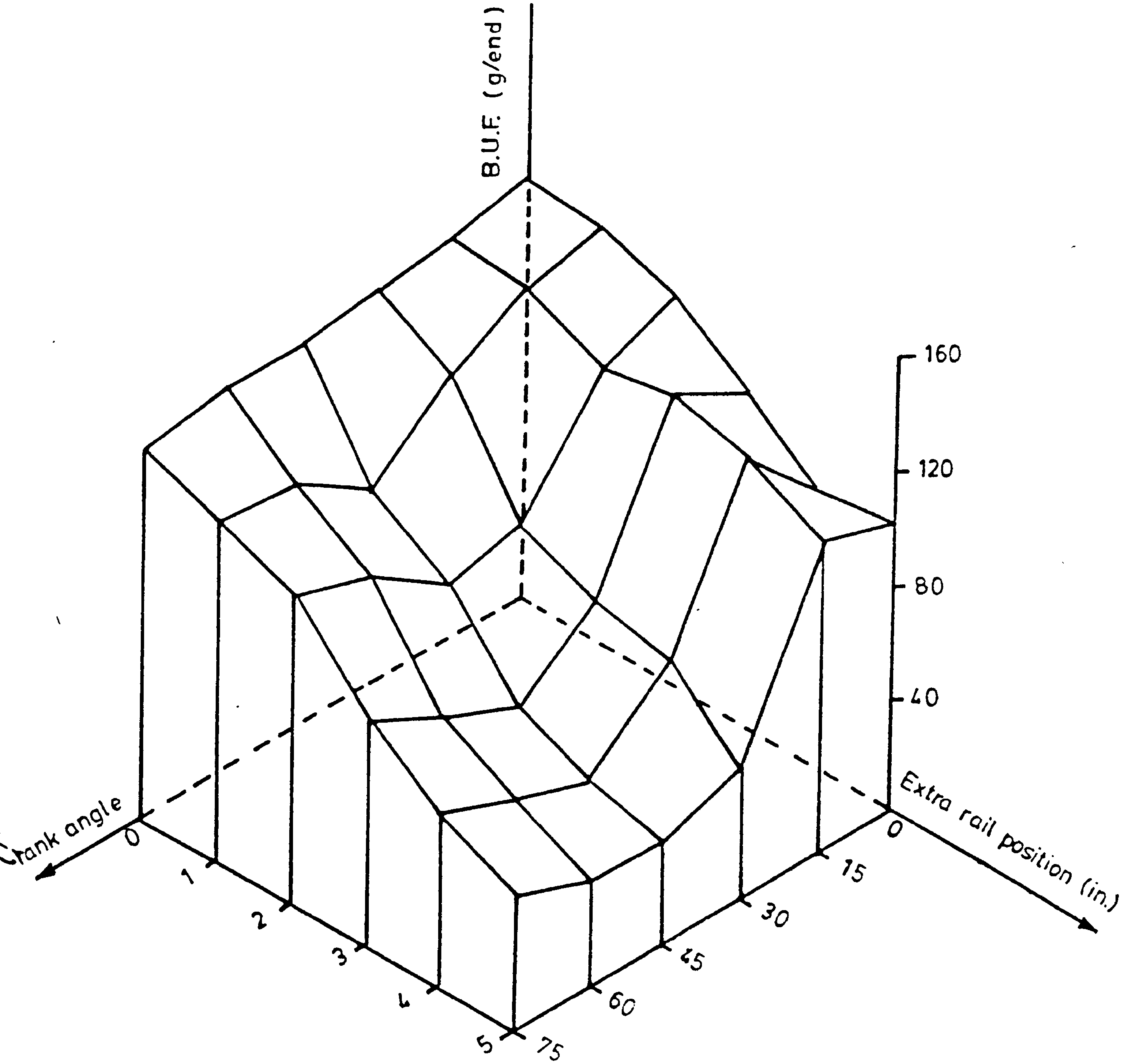


Figure 62. Effect of shed timing and shed unbalance on B.U.F.
(plain weave - medium warp tension)

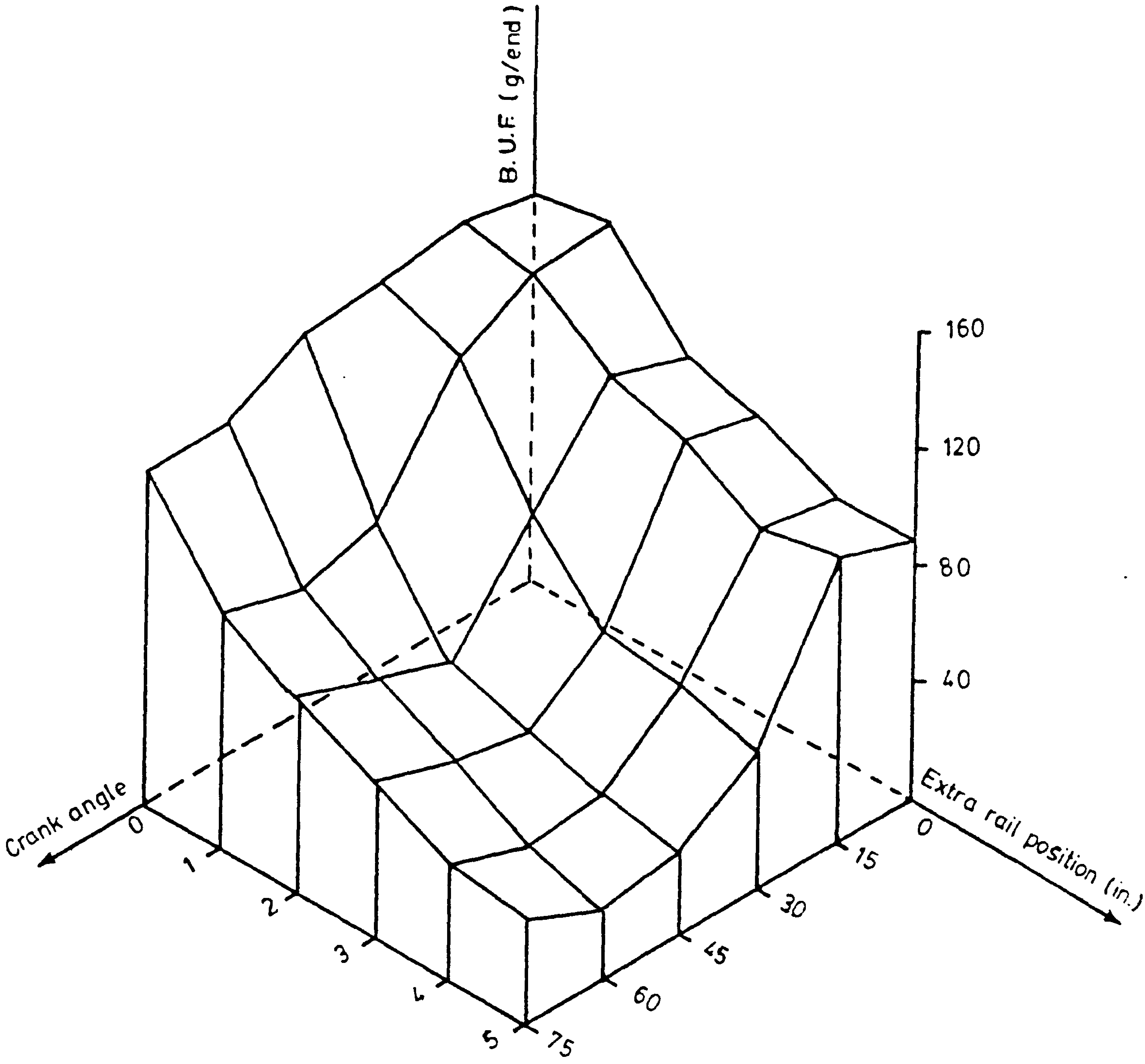


Figure 63. Effect of shed timing and shed unbalance on B.U.F. (plain weave - low warp tension)

tension is reduced. The minimum, for the same timing and back rail settings as before, is 24 g/end. If this study has one most important result it is this; that by moving from settings that might be considered perfectly reasonable, to those that are optimum with respect to reduction of B.U.F. has enabled a reduction of 85% in that force to be achieved. However, the object of this study is not simply to establish facts about B.U.F. but also to establish the reasons for the variations. To assist in this there have been extracted from the results and presented also as functions of the basic variables, data about cloth fell distance, yarn tensions and other dependent factors that might influence B.U.F.

7.3 Cloth-fell distance

Surfaces showing the variation of C.F.D. have been constructed in a similar way to those for B.U.F. In spite of the fact that the relationship between B.U.F. and C.F.D. is not so simple as suggested by Greenwood's equations (largely because the C.F.D. measured here is not merely the displacement caused by the reed alone, but includes effects of shedding and back rail oscillation), there is a general similarity between the shapes of the C.F.D. and B.U.F. surfaces with the maxima and minima in the same regions for the two surfaces for each tension value. However, when C.F.D. and B.U.F. values are compared directly as in Fig 67, the departure from linearity is apparent. When C.F.D. is small there is the expected almost linear relationship between C.F.D. and B.U.F., a given C.F.D. generating a slightly larger B.U.F. at the higher warp tension than at the lower one, consistent with the slightly higher elastic moduli expected when weaving at a higher tension. As C.F.D. increases, however, there is a reduction in slope of this curve because the larger C.F.Ds are associated with the fell running away from the reed, thus increasing the period of contact;

TABLE 14

Cloth fell distance (mm) for different shed timings, extra rail positions and warp tension levels

Warp tension level	Extra rail position (in) / Shed timing code	0 (N)	+ 1	+ 2	+ 3	+ 4	+ 5
High	L	16.5	13.5	9	8	7.5	6.5
	L + 1	14	14	14	11	10	9
	L + 2	11	9.5	6	3.5	3	3
	M	10.5	5	3.5	3	2.5	2.5
	M + 1	7	5	4	3	2.5	2.5
	M + 2	6	5	5	3.5	3.5	3.5
Medium	L	17	155	13.5	8	7.5	7.5
	L + 1	15.5	16	12.5	11	10	9
	L + 2	13	9.5	5.5	5	3.5	3.5
	M	10	5.5	3.5	2.5	2.5	2
	M + 1	8	5	5	2.5	2.5	2.5
	M + 2	6.5	6	5.5	5	4	3.5
Low	L	17	18.5	12	9	9	7
	L + 1	16.5	19.5	16	12.5	12	10.5
	L + 2	16	16	10	6	6	3.5
	M	13.5	6	3.5	2	2	2.5
	M + 1	8	5	3.5	2.5	2	2.5
	M + 2	7.5	5	4	3.5	2.5	3.5

2.5

1.7

1.7

2.4

1.7

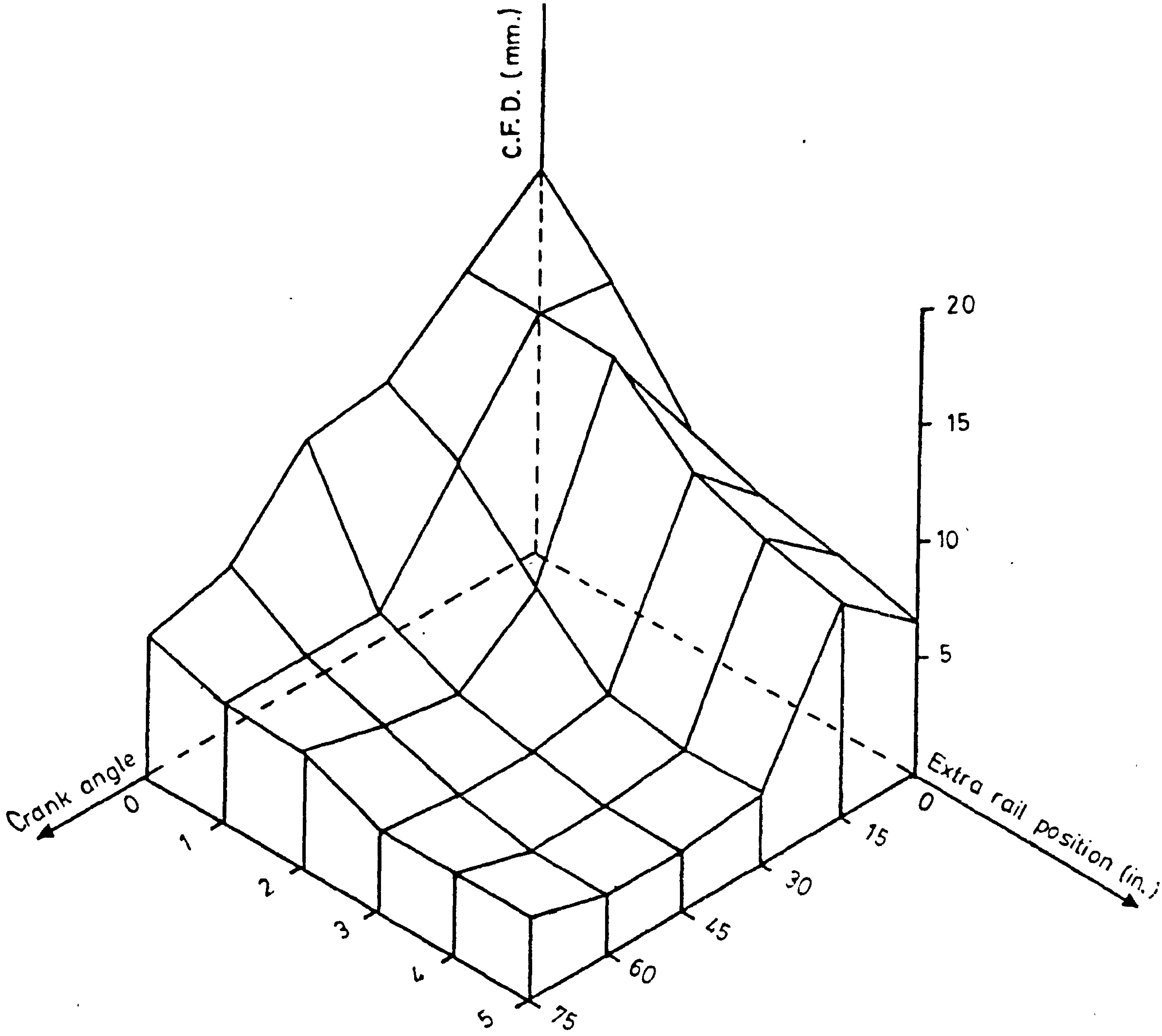


Figure 64. Effect of shed timing and shed unbalance on C.F.D.
(plain weave - high warp tension)

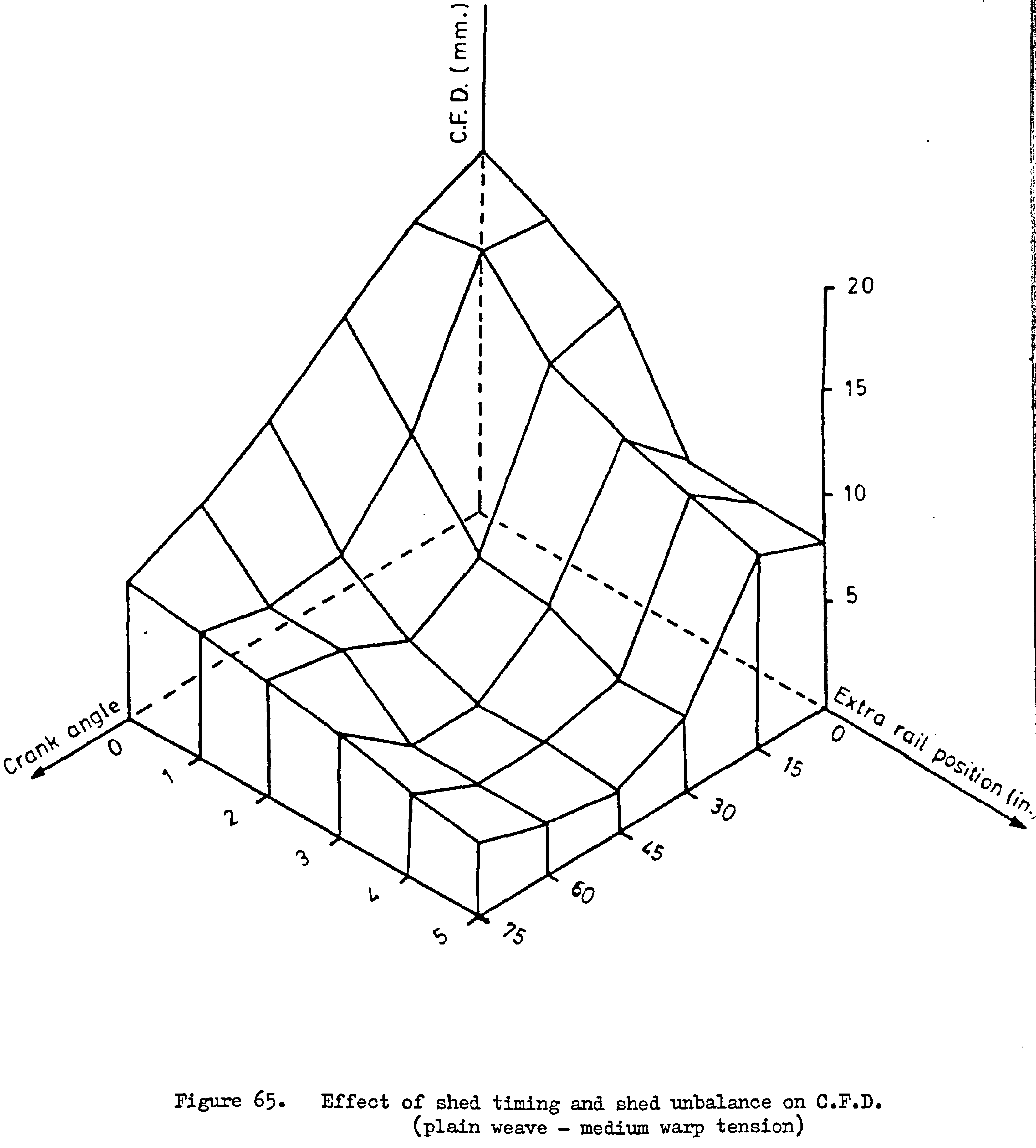


Figure 65. Effect of shed timing and shed unbalance on C.F.D. (plain weave - medium warp tension)

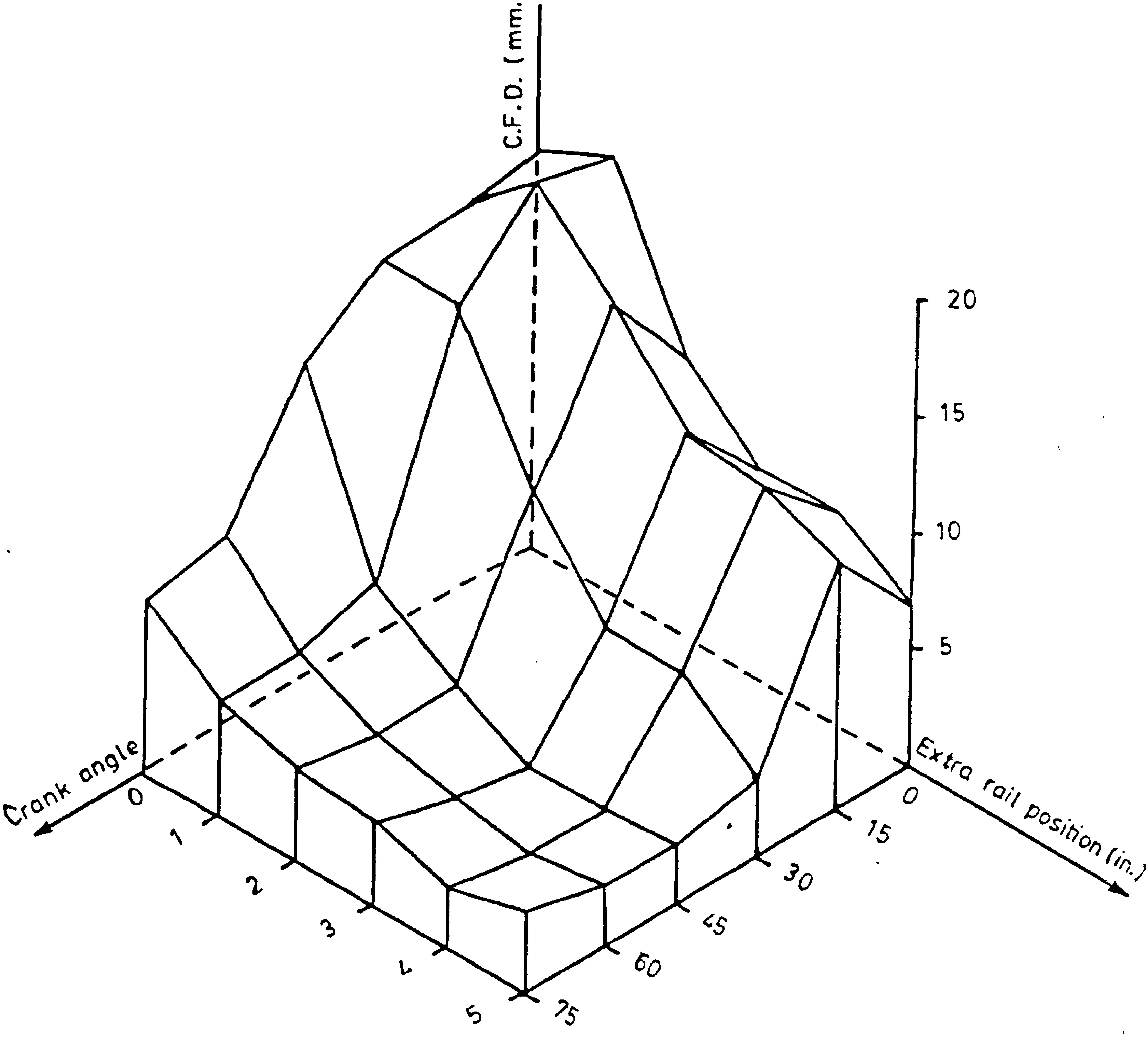


Figure 66. Effect of shed timing and shed unbalance on C.F.D. (plain weave - low warp tension)

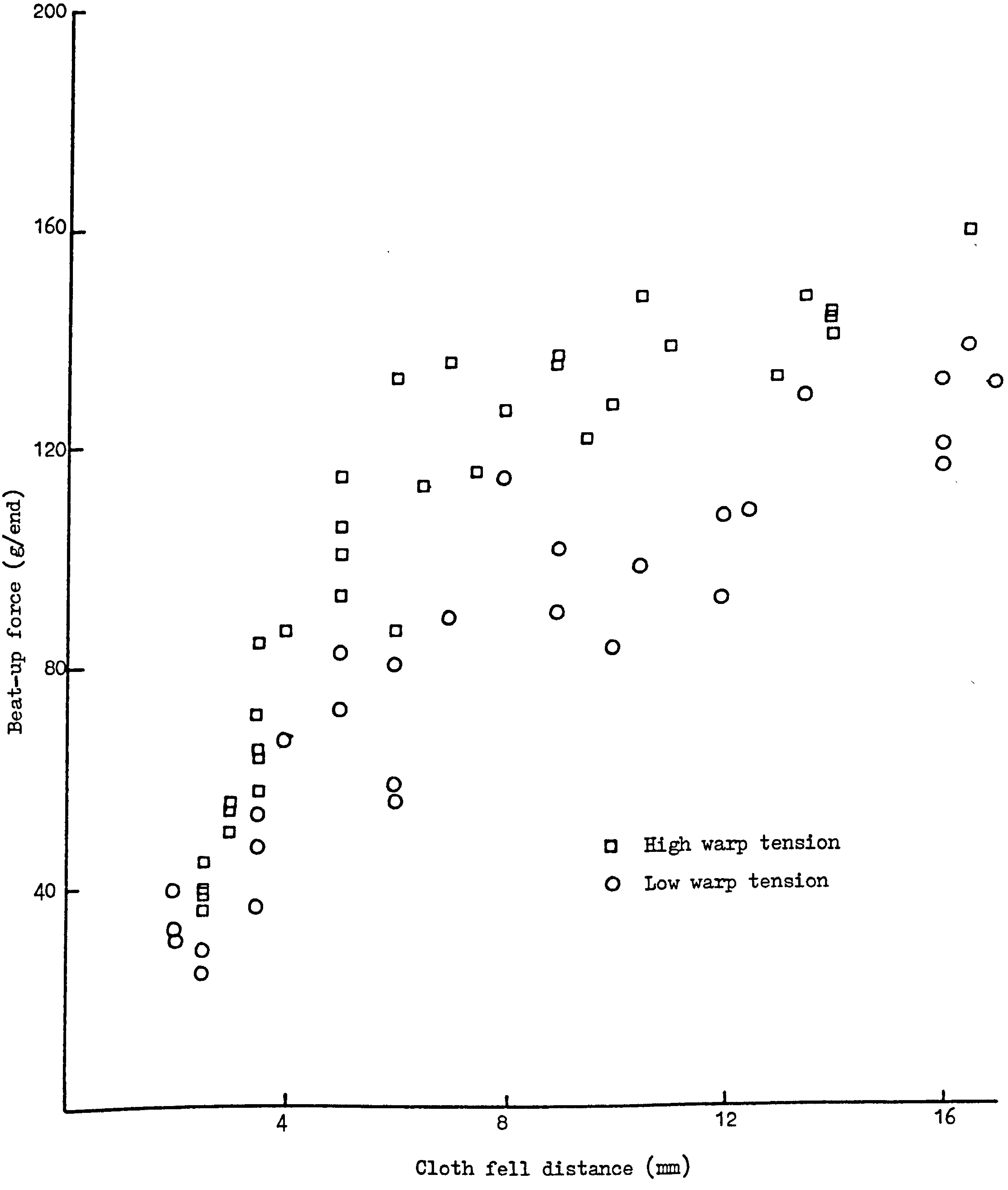


Figure 67. Relation between B.U.F. and C.F.D.

during that increased period the fell displacement caused by the reed is actually less than the fell displacement recorded. In addition, a large C.F.D. implies a temporary reduction of warp tension, caused by shedding or back rail movement, and that reduction of tension will cause a decrease in elastic moduli, thus further increasing C.F.D.

Note, by the way, that a change of "warp elastic modulus" is actually made up of a change in that of the tight sheet which may be in a region of nearly constant modulus and that of the slacker sheet which is likely to have a tension in a more curved region of the load/extension curve. There is also the possibility that the increased C.F.D. is due to the fell not being clearly defined because picks are slipping back. However, that explanation does not fit the present problem because such an effect would, according to Plate's theory, cause at the same time an increase in B.U.F. In fact, there is some evidence that considerable slipping of picks does occur and that it is not associated with increased B.U.F.

7.4 Evidence of picks slipping

If the loom is stopped with the reed away from the fell, it is usually noticeable that the last one or two picks are more widely spaced than in the body of the fabric, implying that they have slipped back after beat-up. They are particularly evident when the shed is unbalanced. During the course of the experiment, a note was made of the number of such picks, and although this result is subjective, it was felt that an error of not more than one would occur in this number. The tendency would be to underestimate it as only those picks which were judged to have clearly slipped were included. The number of slipping picks, of which up to six were observed, is plotted in Fig 68

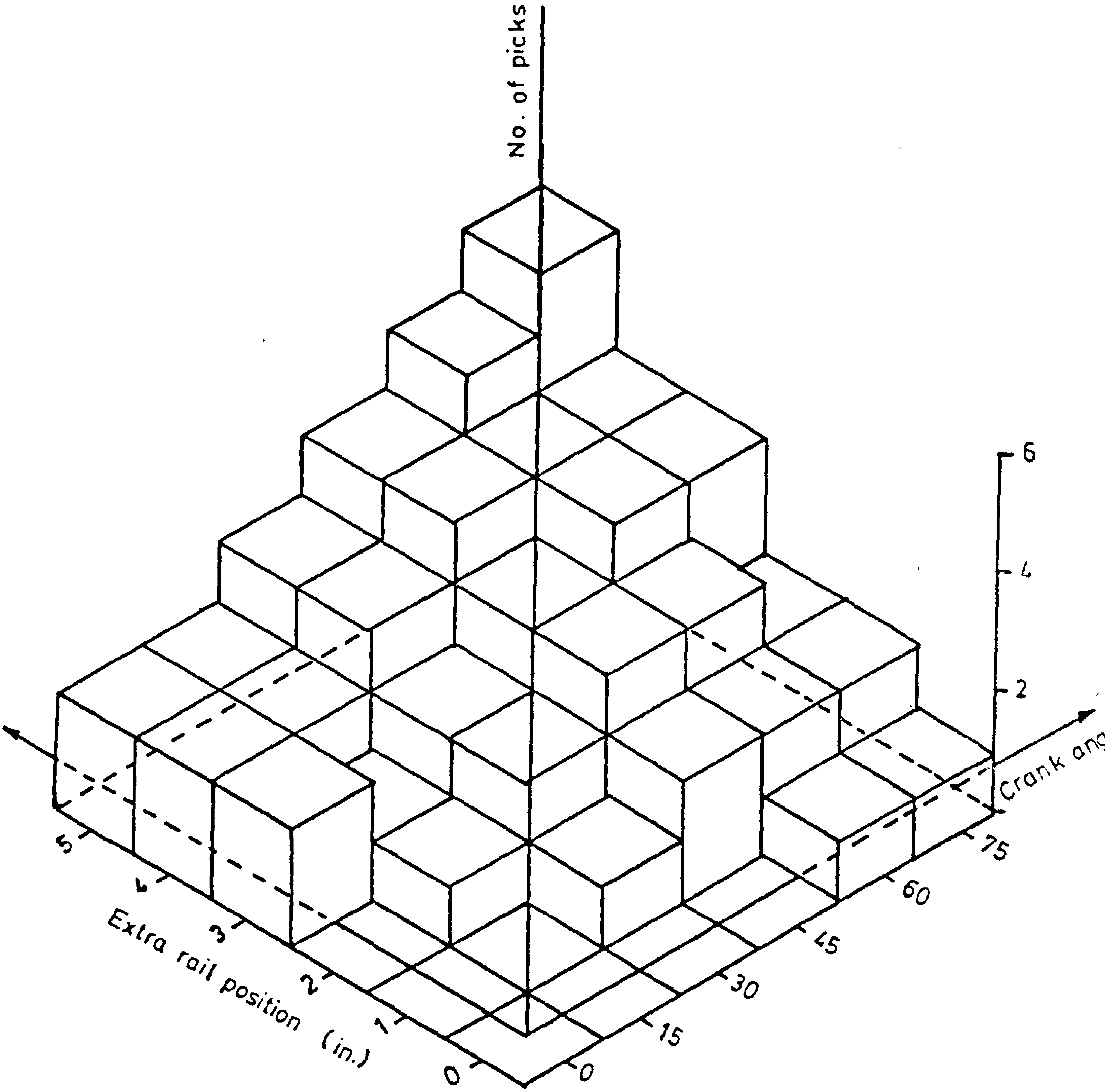


Figure 68. Effect of shed timing and shed unbalance on the number of slipping-back picks (plain weave - medium warp tension)

against the usual independent variables. Note, however, that in this case the base of the graph has been reversed to give a clear view and the lowest numbers, 1 and zero correspond to the settings that give high levels of B.U.F. Also the number can only be an integer, and this is reflected in the way the results are represented. At first sight these results seem to conflict with those of previous work. Plate suggested that BUF would be reduced if slipping back were prevented. Ito, however, showed that an unbalanced shed would make it easier to beat picks into the fabric, but they would also be more likely to slip out; the nett result, however, would be to decrease weaving resistance. This is clearly confirmed by these results, in which the minimum B.U.F. is obtained with those settings that, incidentally, cause more picks to slip back. Plate's view that a reduced B.UF would result if picks were prevented from slipping back might still be valid; if so, an even further reduction of the minimum B.UF should be possible if slipping back could be prevented artificially.

7.5 Tension ratios

It is clear that very large variations in weaving resistance for weaving nominally the same fabric are caused by varying loom settings. It seems that unbalancing the shed has, as Ito's simple theory suggested, the major effect. With the method of unbalancing used here, which is similar to that most commonly used in industry, a closed, i.e. crossing shed is, by definition, a balanced one, so that shed timing has an overriding effect because it is only when an early timing is used, so that beat up occurs in an open shed, that advantage can be taken of the unbalance effects.

Because tension traces in the two warp sheets have been recorded for many of the experiments, it is possible to examine the effect of tension levels and ratios more closely. First, Fig 69 shows the effect on B.U.F. of two levels (high and low) of applied (not measured) warp tension. It shows a definite, if not large, increase of B.U.F. with applied tension. In fact, the increase is roughly constant in absolute terms and represents a significant reduction (of about 20%) where choice of settings has already reduced B.U.F. to a low value. From the tension traces, it is possible to read off the open-shed tensions in the two sheets and also, but with a little less confidence, because it involves estimating the undisturbed trace, where it is in fact temporarily disturbed by the beat-up, the tensions at the time of beat-up. From these values the tension ratios can be found and also the total warp tension (Fig 70). Fig 71 shows the perimeter of a surface representing tension ratio T_t/T_s at beat up; tension traces for internal points had not been recorded. There is clearly a close, inverse relationship between B.U.F. and tension ratio. However, the situation is more complex than might appear. Firstly, the tension values show that the settings that give, broadly, the lowest values of B.U.F. and the largest values of tension ratio, give values of total tension that are larger than that for many other settings, so counteracting, to a small extent, the effects of unbalance. Secondly, although the tension-ratio roughly reflects the B.U.F. variation, it does not explain why the minimum B.U.F. occurs when the shed is not fully open. Possibly the accuracy of estimating tension ratio at beat-up does not justify giving too much attention to such details, but the small discrepancy serves to draw attention to other points that ought to be considered. So far, in considering the effects of shed unbalance on tension ratio, it has been noted that when the shed is closed, it is also balanced. However, it does not follow that as it is opened, it necessarily becomes ever more unbalanced.

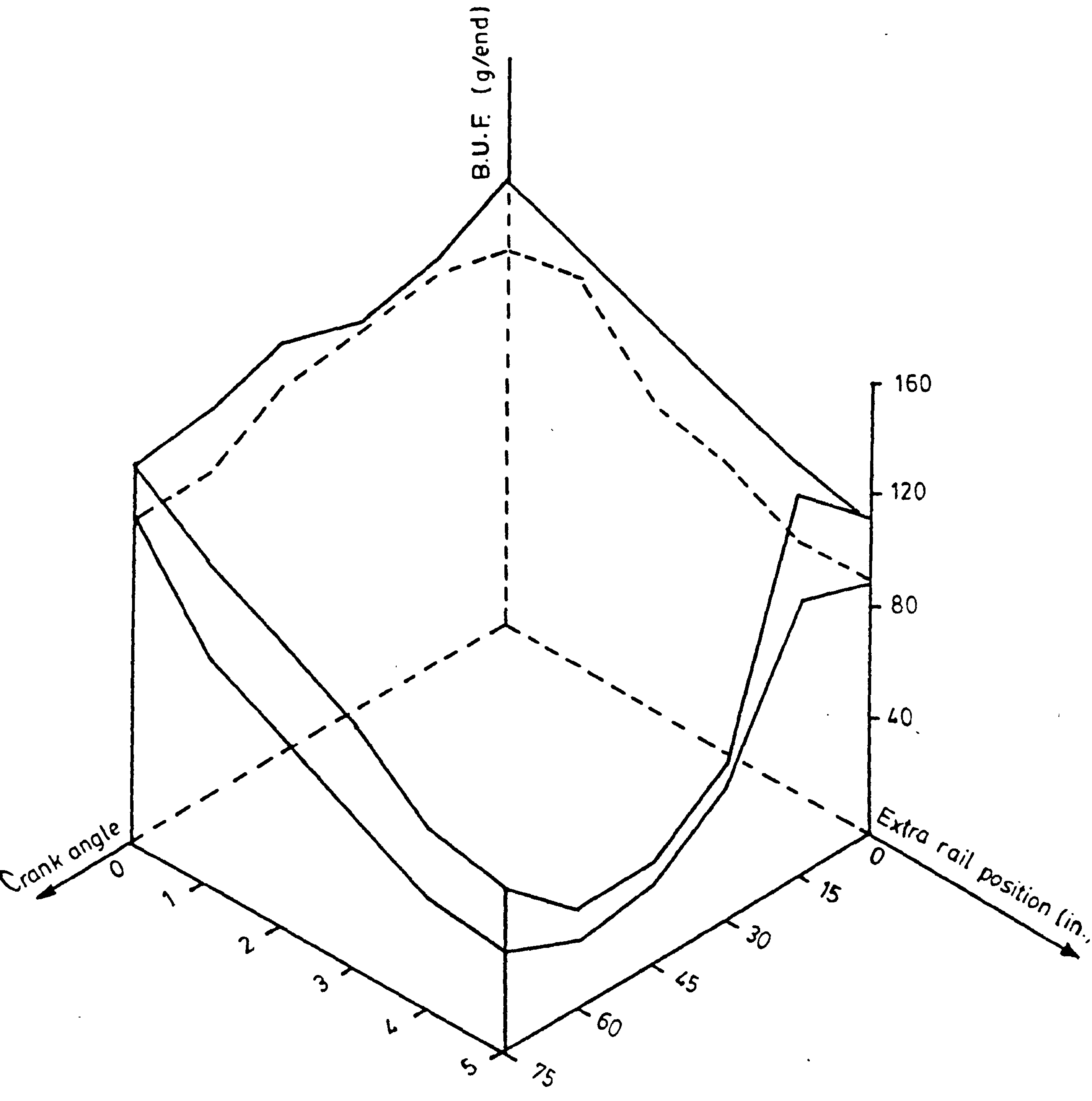


Figure 69. Effect of shed timing and shed unbalance on B.U.F. for two (low and high) warp tension levels

TABLE 15

Variation in tension ratio, total tension (from actual tension traces) and tension ratios (theoretically calculated under different extra rail positions and shed timings

Type of measurement	Extra rail position (in.) Shed timing code	0 (N)	+ 1	+ 2	+ 3	+ 4	+ 5
Tension ratio from tension traces at max. B.U.F.	L	1.2	1.1	1.2	1.3	1.2	1.2
	L + 1	1.2					1.3
	L + 2	1.2					2.0
	M	1.2					6.2
	M + 1	1.2					6.2
	M + 2	1.2	1.7	2.25	3.8	5.8	6.4
Average warp tension at max. B.U.F. (g/end)	L	39	37	39	37	39	41
	L + 1	42					44
	L + 2	49					53
	M	46					63
	M + 1	60					63
	M + 2	60	62	69	62	60	65
Tension ratio at max. B.U.F. theoretically calculated	L	1	1	1	1	1	1
	L + 1	1					2.02
	L + 2	1					4.12
	M	1					7.25
	M + 1	1					8.20
	M + 2	1	1.62	2.34	3.57	5.40	7.97

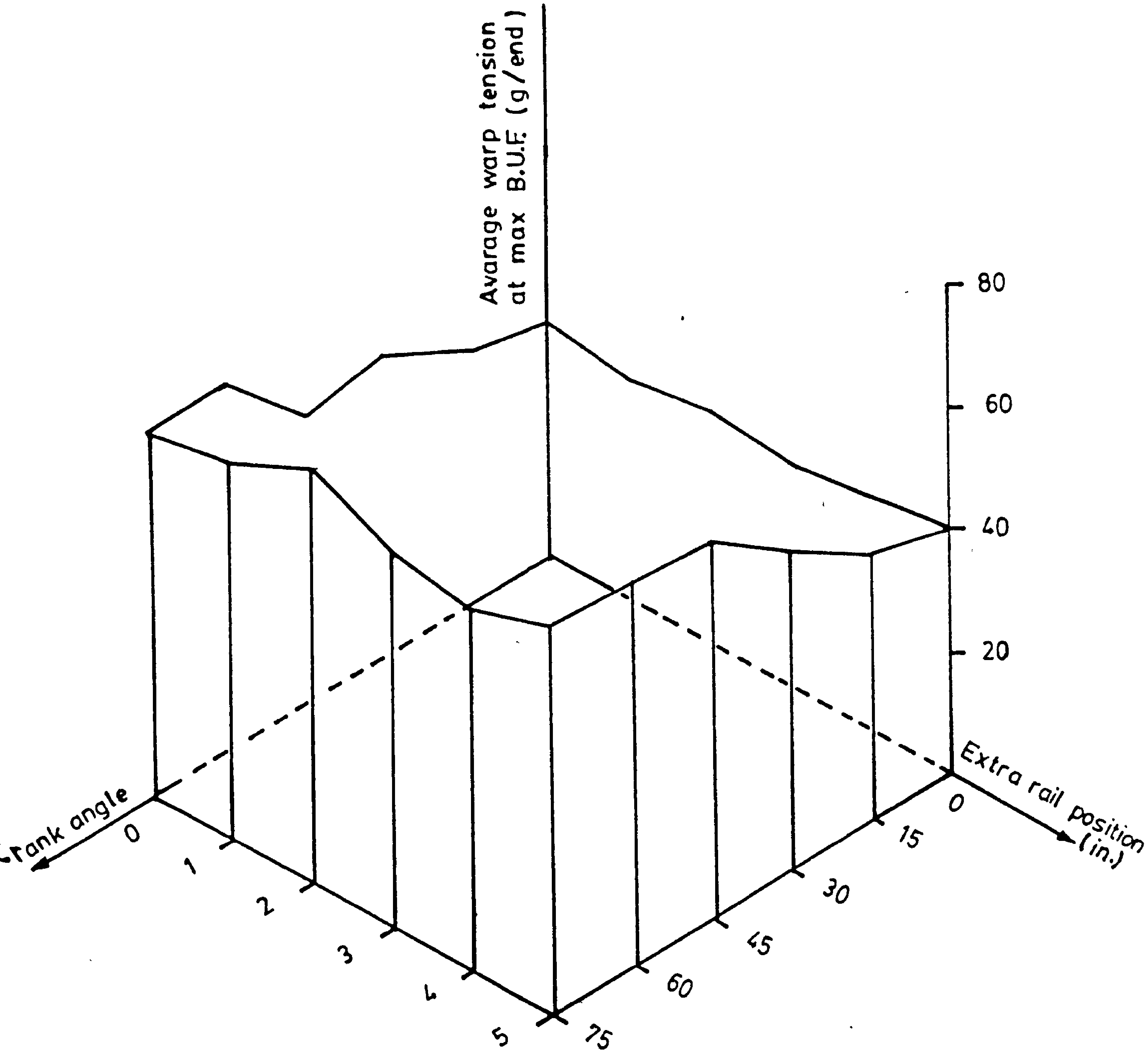


Figure 70. Effect of shed timing and shed unbalance on total warp tension (plain weave - medium warp tension)

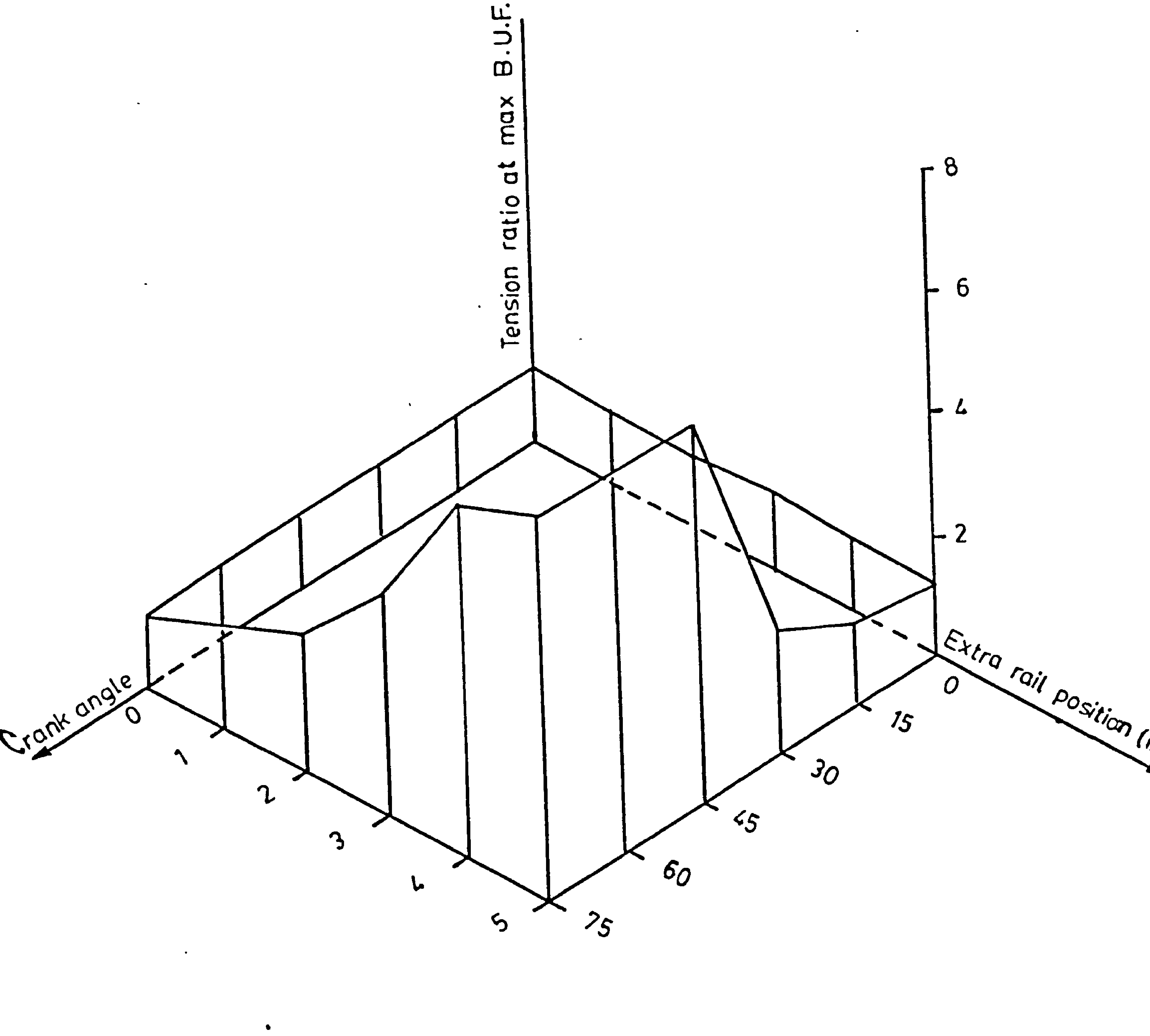


Figure 71. Effect of shed timing and shed unbalance on tension ratio at maximum beat-up (plain weave - medium warp tension)

In general, when the shed is closed in this situation, all the healds are below the line joining the fell to the back rail. When the shed opens the rising sheet goes slacker initially and then its tension rises a little; the lower sheet simply increases in tension. The ratio is likely (depending on the degree of unbalance) to pass through a maximum value when the slacker sheet is fairly near its minimum tension value. Some estimates of the way tension ratio might be expected to change in the present situation are given in Fig 72 and 73. The reason why this variation is not shown more accurately in the measured values is almost certainly because the measured values are those in the warp behind the healds. They are influenced by the friction of the healds, and although it has been argued that, in general, they will give a good indication of the changes in tension in the fell region, it is just at the same time when one of the warp sheets is passing through the minimum tension position, and is liable to have a change in the direction of heald friction, that the measured tensions are least reliable as a guide to the tensions and tension ratios near the fell. Therefore, the theoretically predicted variations in T_t/T_s may give a better indication of the detail of what is happening than the measured values at this particular time.

In spite of those doubts, it seems that the major influences on B.UF for the plain-weave cloth have been established. In order to confirm that they are being properly understood, it is reasonable to consider a different weave in which the various factors interact in a different way. An obvious choice is the 2/2 twill, a weave which is almost as commonly used as the plain weave, but which has at least some of the required features.

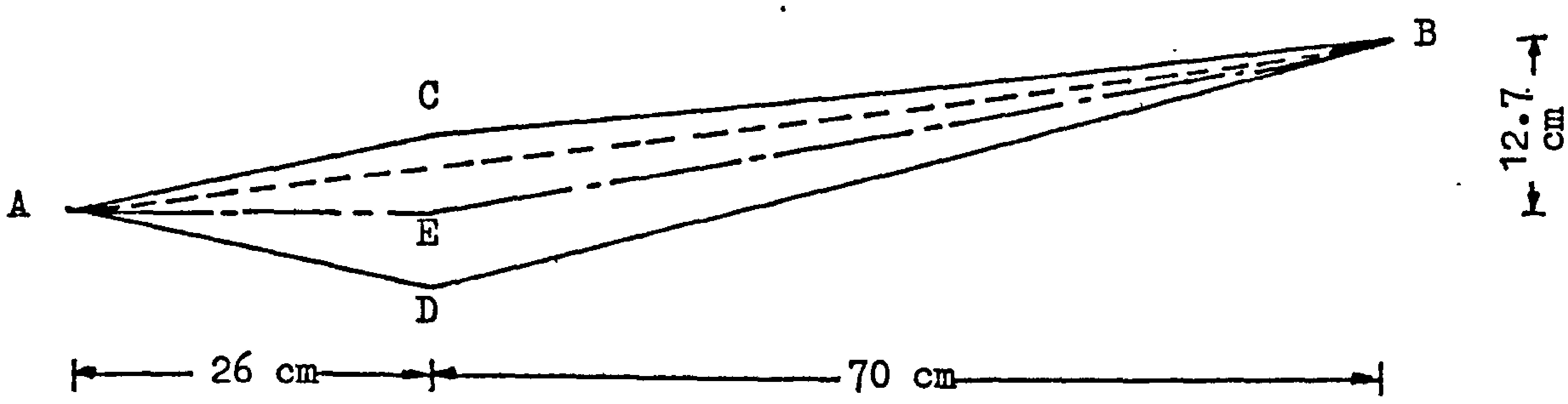


Figure 72. Actual geometry of top and bottom shed lines (extra rail raised 5 inches)

$$\text{Tension ratio} = \frac{\text{Length of bottom shed} - \text{unstretched length}}{\text{Length of top shed} - \text{unstretched length}}$$

Unstretched length = straight length of AB (1 - K)

where K = constant deduced from the known warp tension and the known elastic properties

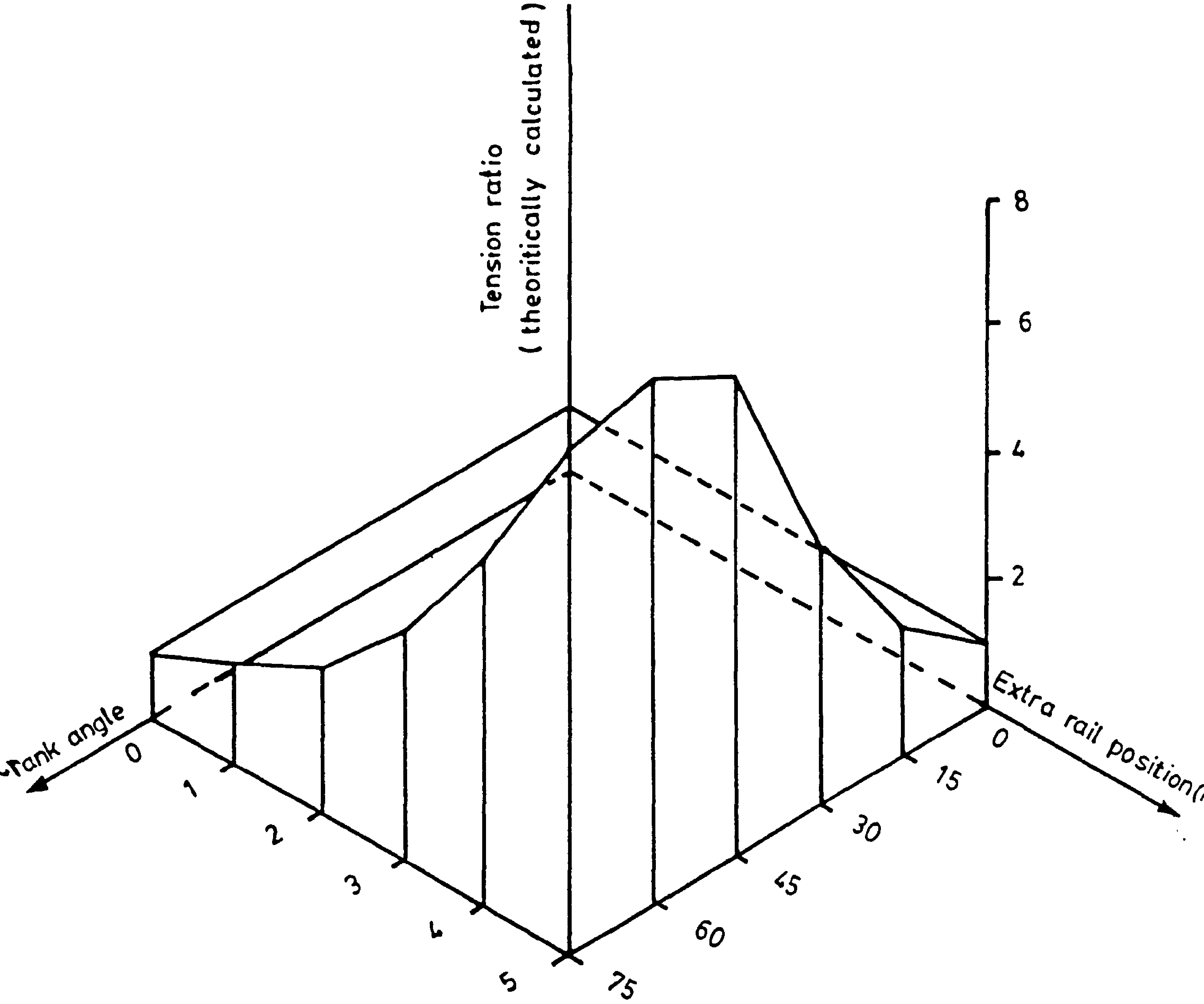


Figure 73. Effect of shed timing and shed unbalance on calculated tension ratio at beat-up

CHAPTER VIII

8. GROUP IV EXPERIMENTS

The effect of shed timing and shed unbalance on weaving resistance for the 2/2 twill

CHAPTER VIII

Group IV experiments - The effect of shed timing and unbalance on weaving resistance for the 2/2 twill weave

8.1 Introduction

The major difference in beat up conditions for the 2/2 twill as compared with the plain weave lies in the fact that there is no period when (on a loom with this type of dobby) the shed is closed - on each cycle half of the threads lie in their open-shed positions. Therefore shed timing will not have the same influence on shed balance as for plain weave and, if the explanations put forward in the previous chapter are correct, it should not have the same effect on weaving resistance.

Because it was desired to limit the number of experiments and interest was likely to be especially in shed timing, for these Group IV experiments only one level of warp tension, the lowest of the three, was used. For further economy, more of the traces were of the abbreviated form. Apart from these changes, the procedure was very similar to that adopted for the plain weave. In two respects, however, there were differences of detail. The tension measuring units, of which there were two, with associated circuitry, could not monitor the tensions on the four sets of warp threads forming the elements of one weave repeat. Any attempt to put threads from more than one set through a single tension unit would have resulted in the loss of information because some of those threads would have been changing, while others remained in the open shed. It was, therefore, decided to put threads associated with those heald shafts (1 and 5, 2 and 6) that had the same role in the repeat through each tensions gauge, accepting that some tensions would not be monitored. The other difference from plain weave was that cloth fell height would not change in exactly the same way and new corrections would be needed.

8.2 Preliminary experiments

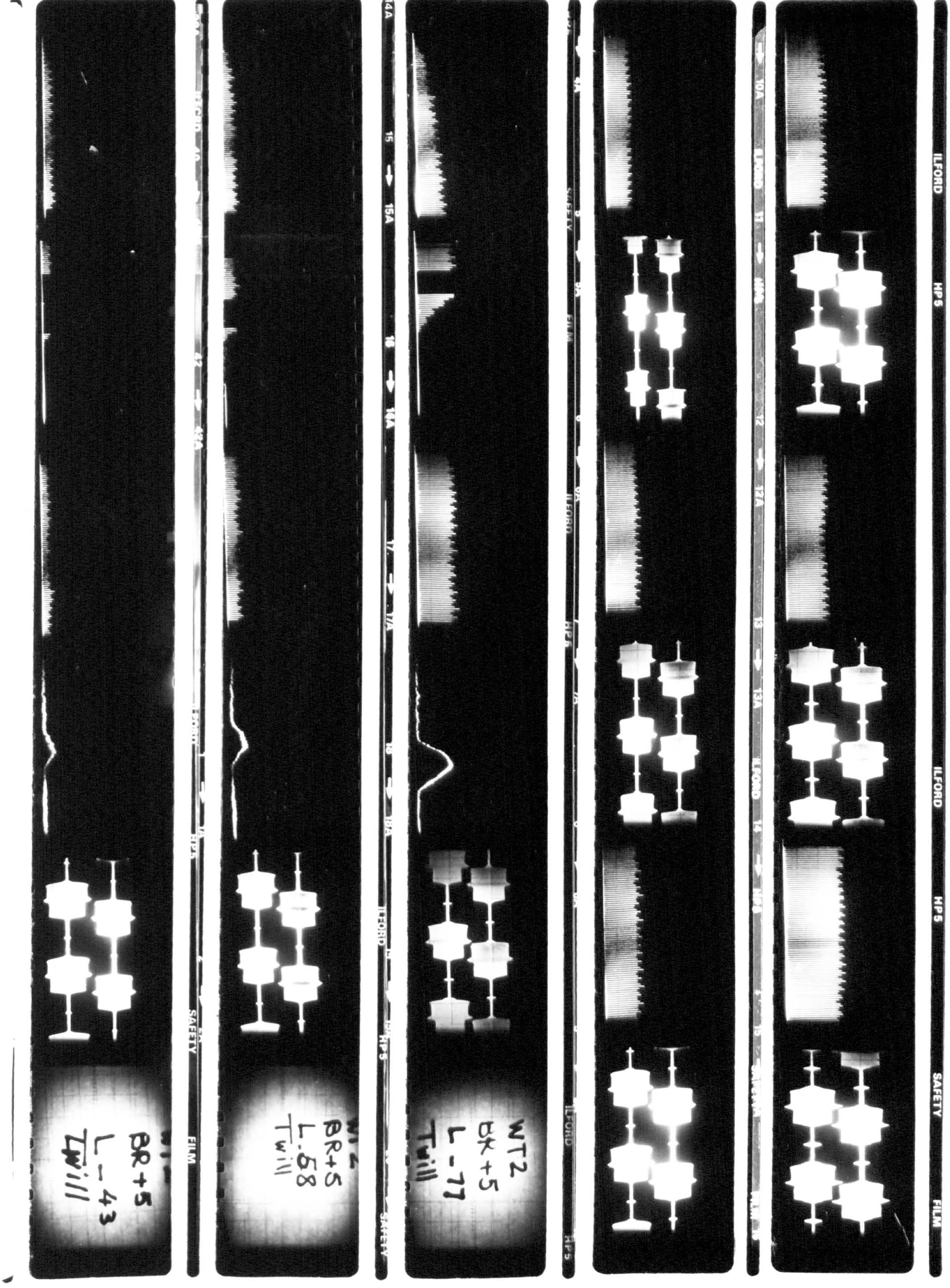
Obviously, to give a substantial weaving resistance a much closer sett would be required for the twill than the plain weave. Before choosing a final setting, a number of exploratory experiments were made, first with the same setting as the plain weave and then with closer setts until 75 picks per inch was chosen as giving a reasonably large weaving resistance. These preliminary experiments suggested that in this case a late shed timing was going to give optimum conditions. In addition, as warp tension was not being varied generally, six values of tension were used for one timing and back-rail position to confirm that the linear relationship found for plain weave also applied here, as shown in Fig 74.

8.3 Results - B.U.F.

Traces from some of the preliminary experiments are given on Fig 75 and 76; then the set of 36 short traces showing B.U.F. at stable weaving and decay of B.U.F. for weaving 2/2 twill at 75 picks per inch are shown in Figs 77 and 78. The values of B.U.F. extracted from the curves are plotted in the usual way (Fig 79). The effect of raising the extra back rail is similar to that for plain weave, but because there is no shed timing that gives a completely closed and, hence, balanced shed there is always some advantage gained from the unbalance and, with the unbalanced shed the influence of shed timing is reduced. What influence there is, is in the opposite sense from that of plain weave, with the minimum resistance coinciding with late timing. Discussion of the reason for this is best left until other data have been examined.

8.4 Cloth fell distance

Again, cloth fell distance varies in a similar way to B.U.F. but



TECHNICAL DATA

WT

3,4,5

-,1,2

Figure 74

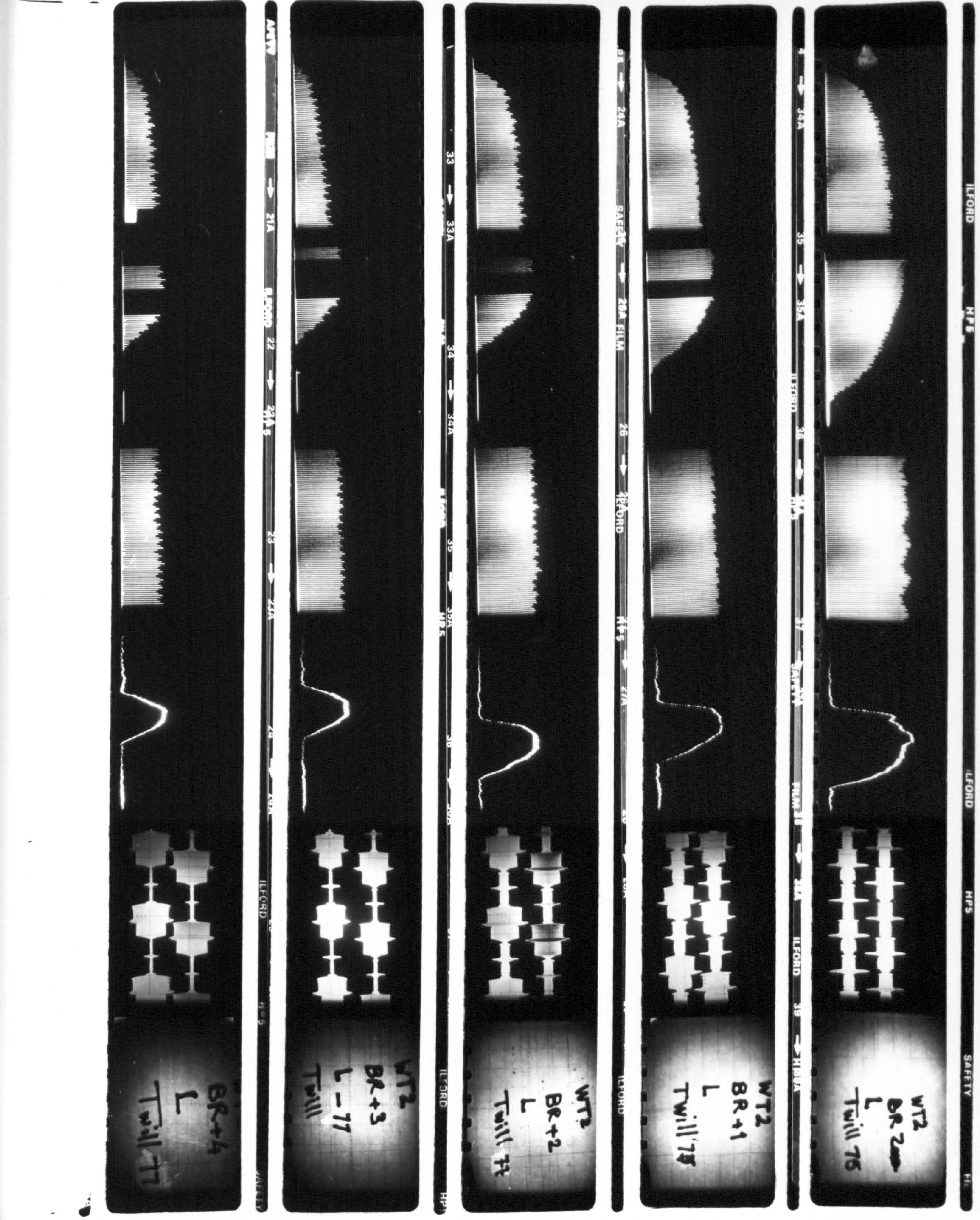

WT2
BR+4
L
Twill 77
WT2
BR+3
L-77
Twill
WT2
BR+2
L
Twill 77
WT2
BR+1
L
Twill 75
WT2
BR Zero
L
Twill 75
ILFORD
HP5
SAFETY
FILM
TECHNICAL DATA
SUBJECT

Figure 75

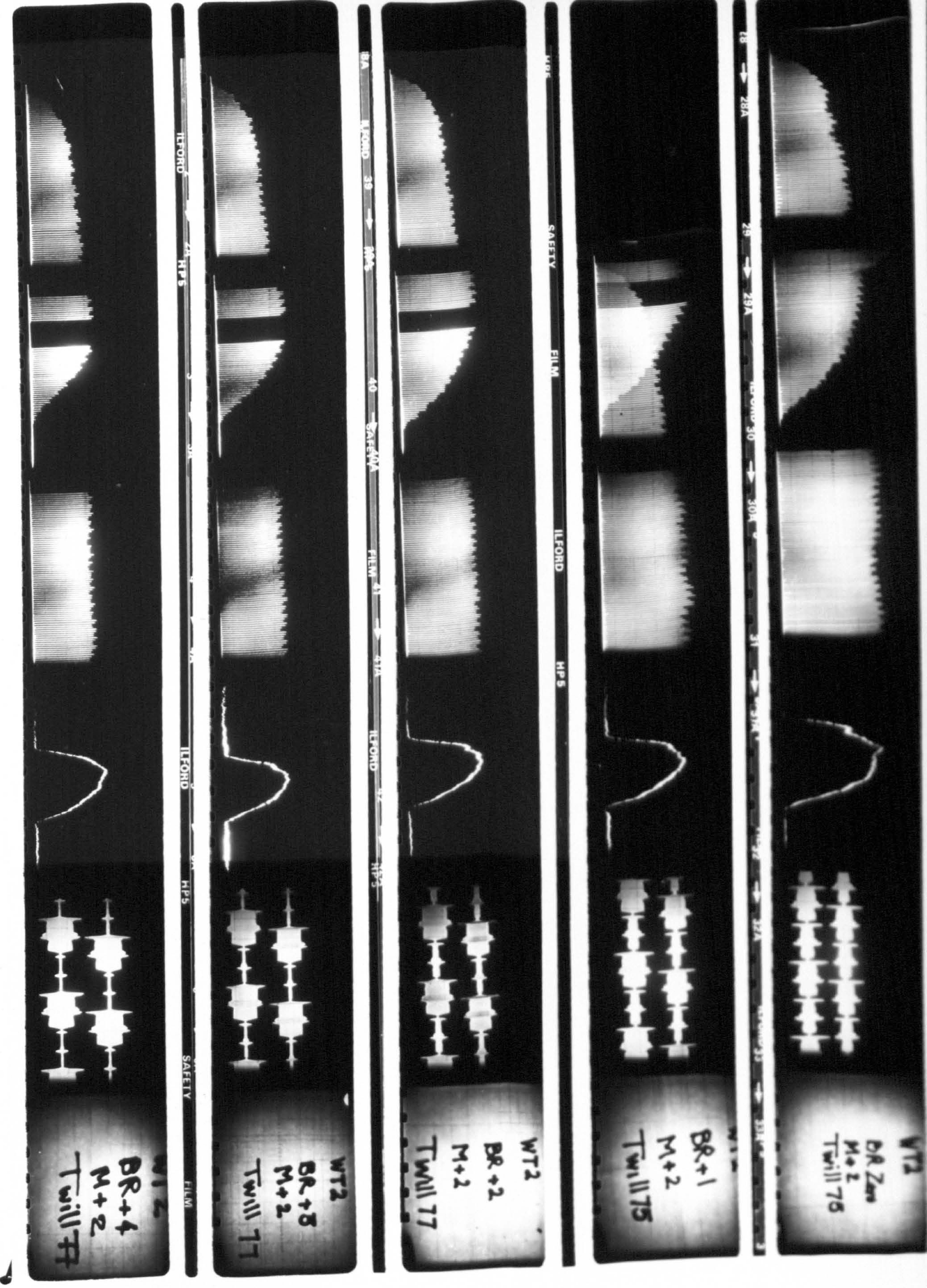

WT2
BR+4
M+2
Twill 77
WT2
BR+3
M+2
Twill 77
WT2
BR+2
M+2
Twill 77
BR+1
M+2
Twill 75
WT2
BR Zero
M+2
Twill 75
ILFORD HP5 SAFETY FILM

Figure 76

TABLE 16

Key for location of traces
2/2 twill weave

Shed timing code / Extra rail position (in.)	M + 2	M + 1	M	L + 2	L + 1	L
0	FIG.77			FIG.78		
+ 1						
+ 2						
+ 3						
+ 4						
+ 5						

Figure 77

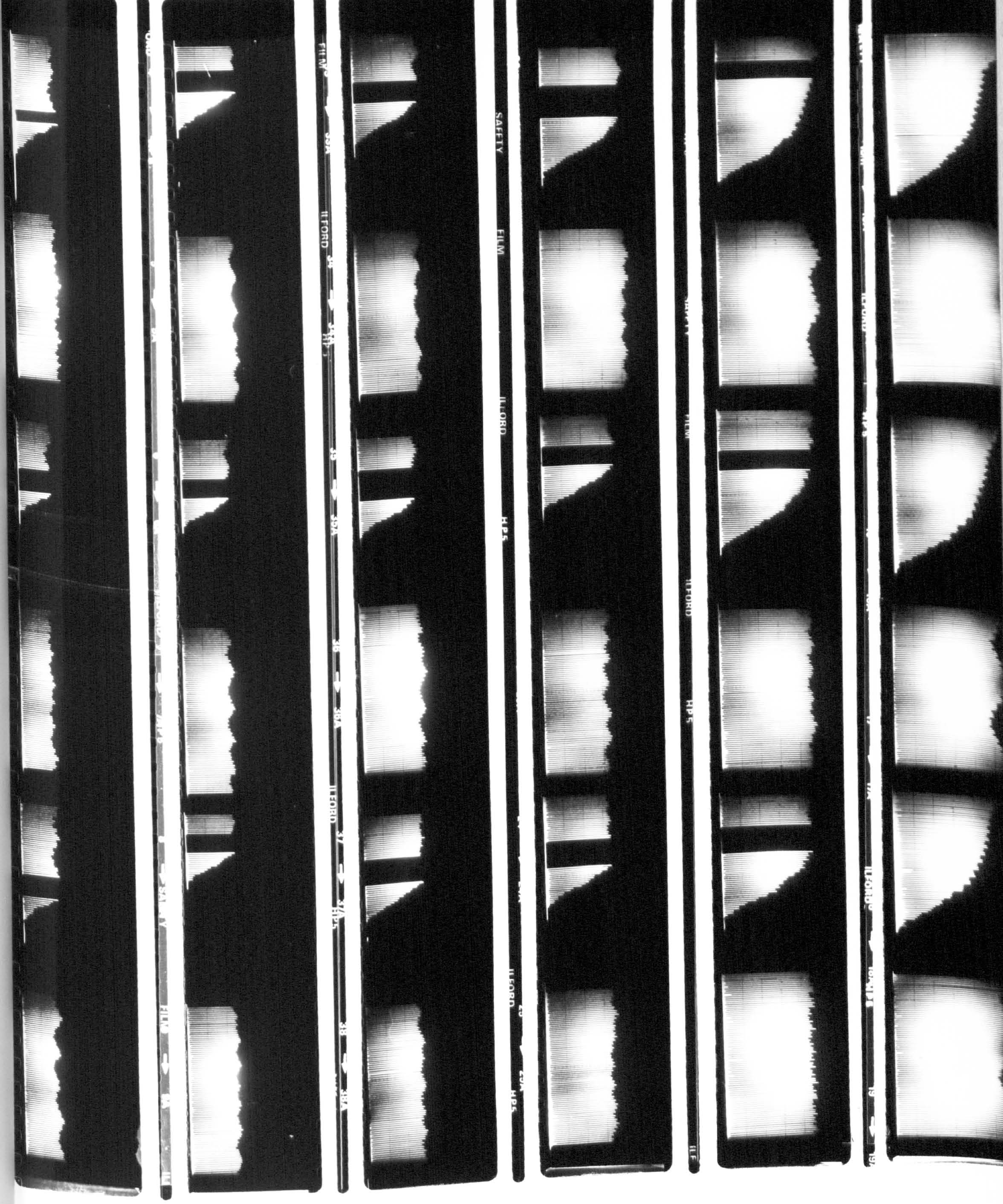


Figure 78

TABLE 17

Beat-up force for different shed timings and extra rail positions for 2/2 twill weave

Type of measurement	Extra rail position (in) / Shed timing code	0 (N)	+ 1	+ 2	+ 3	+ 4	+ 5
B.U.F. traces (mm)	L 0°	55	44	34	28	24	18
	L + 1 15°	52	44	21	20	23	16
	L + 2 30°	56	48	41	31	27	22
	M 45°	54	47	41	37	29	29
	M + 1 60	54	54	46	37	37	34
	M + 2 75 E. 90	54	52	48	39	35	34
C.F.H. (mm)	L	-4	-6	-8	-8	-8	-12
	L + 1	-4	-6	-8	-8	-8	-12
	L + 2	-4	-6	-8	-8	-8	-12
	M	-4	-6	-8	-8	-10	-12
	M + 1	-4	-6	-8	-8	-10	-12
	M + 2	-4	-6	-8	-10	-12	-12
Correction factor	L	1.04	1.07	1.09	1.09	1.09	1.16
	L + 1	1.04	1.07	1.09	1.09	1.09	1.16
	L + 2	1.04	1.07	1.09	1.09	1.09	1.16
	M	1.04	1.07	1.09	1.09	1.12	1.16
	M + 1	1.04	1.07	1.09	1.09	1.12	1.16
	M + 2	1.04	1.07	1.09	1.12	1.16	1.16
Actual B.U.F. (g/end)	L	184	153	123	103	89	71
	L + 1	174	153	118	111	85	63
	L + 2	186	166	146	114	100	86
	M	180	163	146	133	110	114
	M + 1	180	180	162	133	136	130
	M + 2	180	179	169	143	134	130

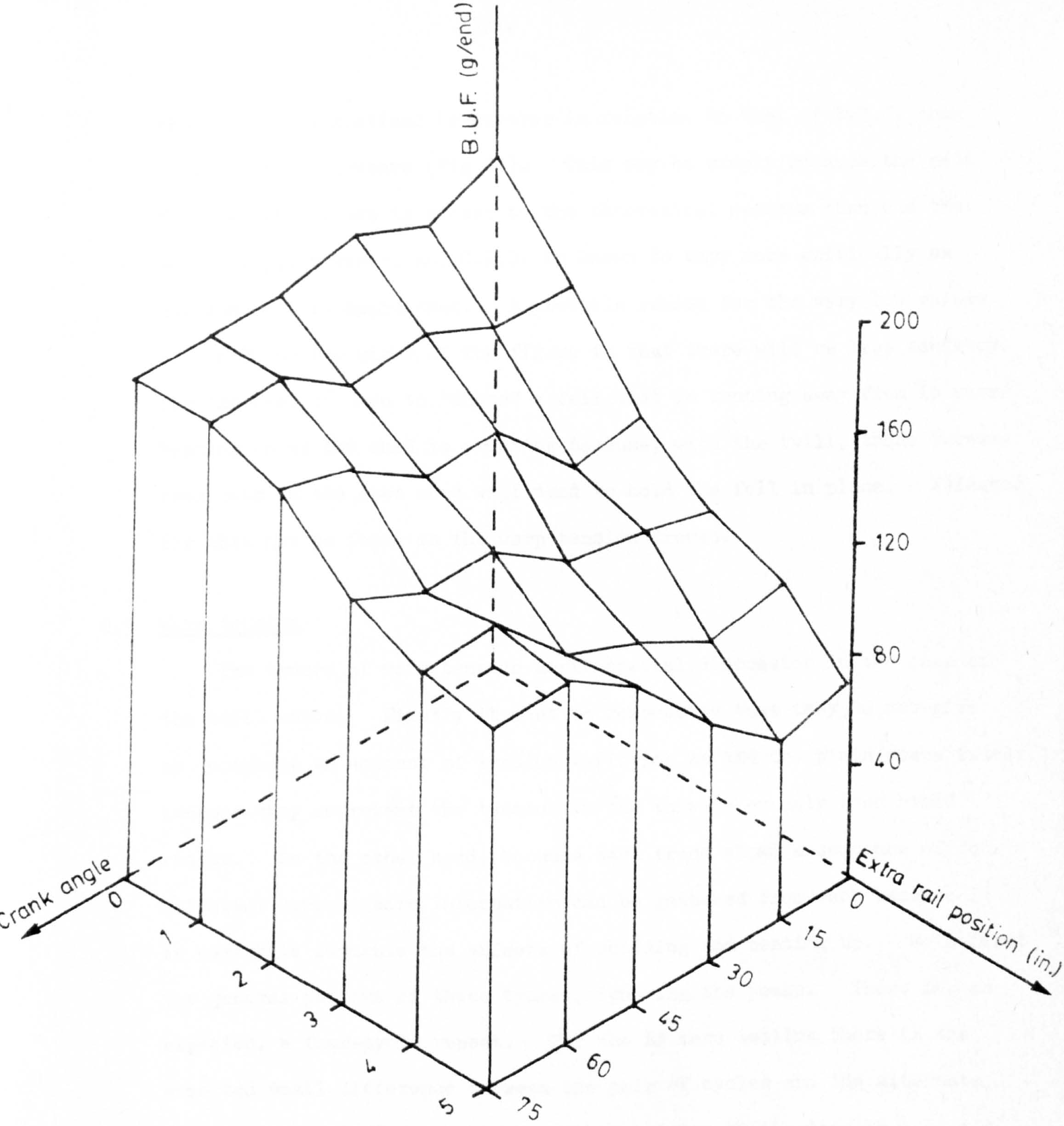


Figure 79. Effect of shed timing and shed unbalance on B.U.F. (2/2 twill weave - low tension)

the range of variations is greater in relation to that of B.U.F. than it was for plain weave (Fig 80). This may be simply because the sett for the twill weave is closer to the theoretical meximum than was the sett for plain weave, and C.F.D. is known to vary more critically as maximum sett is approached. A probable reason for the very low values of C.F.D. on the right of the figure is that there will be less tendency for the reed to have to "chase" a fell that is running away from it when beating up as the shed is crossing because, with the twill, those threads remaining in the open shed will tend to hold the fell in place. Evidence for this can be found in the warp tension traces.

8.5 Warp tension

The traces of warp tension merit special discussion in the case of the twill weave. Firstly it must be remembered that they do not give as complete an account of tension variation as did the plain weave traces, because they represent the tension in the threads on only four heald shafts. On the other hand, because each trace shows a sequence of four different cycles, more information can be gathered from each because it is easier to separate the effects of shedding and beating up. Note first the general pattern of these traces, ignoring the peaks. There is, as expected, a four-cycle repeat. For the BR zero setting there is the expected small difference between one pair of cycles and the alternate pair, but this difference has become very large by the time BR + 3, + 4 and + 5 are reached. Within the two cycles of a pair, the tension is always greater during the first than the second. This again is to be expected because in the first cycle the ends have just interlaced and, being marginally shorter are carrying more than half of the "tight sheet" tension; in the following cycle they carry rather less than half.

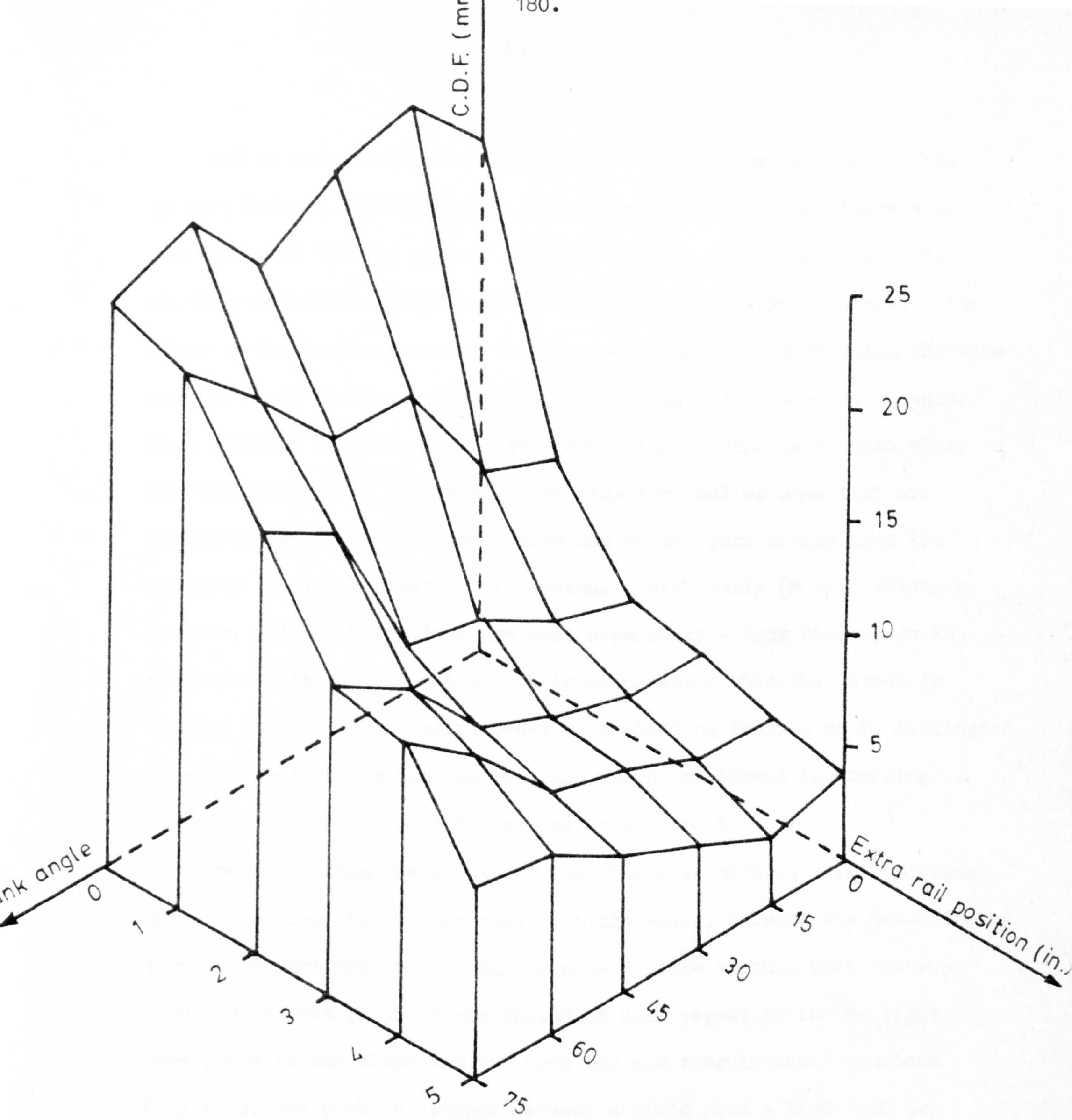


Figure 80. Effect of shed timing and shed unbalance on C.F.D.
(2/2 twill weave - low warp tension)

Before considering the tension peaks it is necessary to differentiate between different shed timings and to notice that there are two causes of tension peaks. One, of course, is the beat up force which occurs on every cycle (although it is not always apparent); the other is due to the crossing threads, when the shed is changing, throwing most of their share of warp tension on to those that are not crossing. When shedding is late, these two events almost coincide so that there are two sharp peaks within a repeat plus two smaller ones that are almost masked by the tension change due to the yarn moving from the slack to the tight sheet or vice-versa. With early (M + 2) shedding, however, all the variations are seen separately - four beat-up peaks per repeat, those during the high tension period when the thread is forming the "float" being preceded by a shedding tension peak, distingishable just before the beat up peak and, when the thread is crossing, a sharp dip in tension just before the beat-up peak.

These shedding peaks suggest that there is much less fell movement due to shedding than in the case of plain weave, because the non-changing threads support the fell. In the case of late timing, when beat-up occurs on a shed in which one thread of each repeat is in the tight sheet, one in the slack and two have low and roughly equal tensions (Fig 81a), the pick is trapped between a slack plus a tight and two slacks which, even though they do not all have the same angle of wrap, represent an unbalanced situation. If beat-up occurs in a crossed shed, however, the pick is trapped between a tight and a slack thread passing above it and a slack and a tight thread below it (Fig 81b). Again, not all angles of wrap are the same, but the system is symmetrical and balanced, consequently the weaving resistance is higher in this early shed situation.

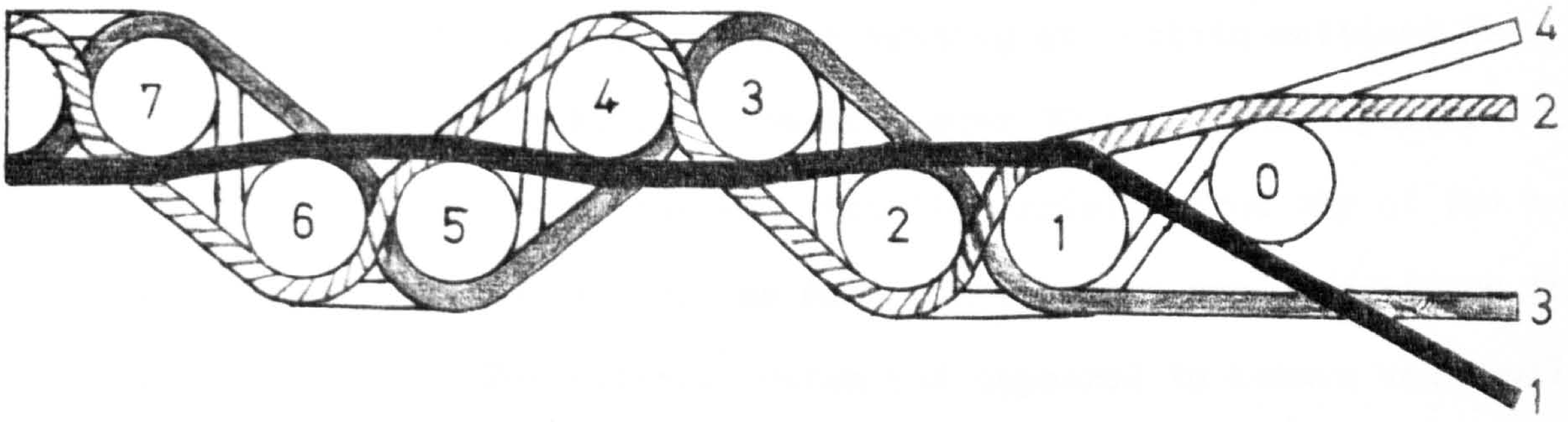


Fig. 81a. Beating-up 2/2 twill with late shed timing and shed unbalance

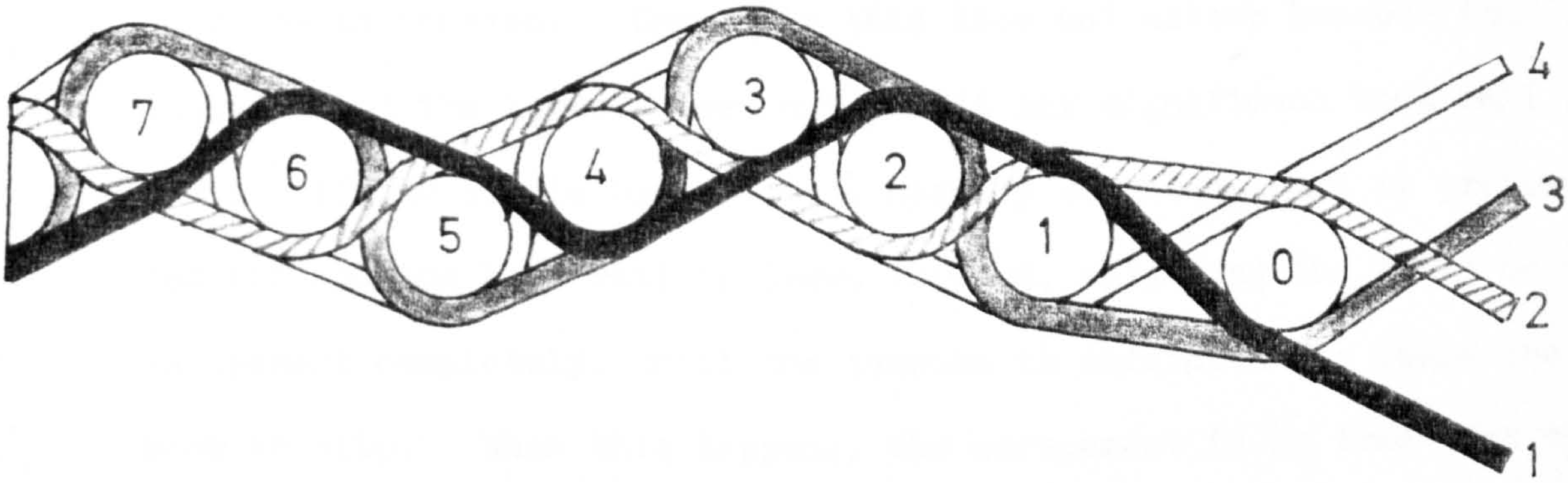


Fig. 81b. Beating-up 2/2 twill with early shed timing and unbalanced shed

8.6 Warp tension variations

One of the peculiar features arising at certain settings is a cyclic variation in B.U.F. repeating over 30 or 40 loom cycles. It does not coincide with take-up variation arising from any of the noted gear tooth frequencies, so the most likely cause was a variation in warp tension. The let-off system had appeared to behave very well, but it seemed desirable to check its behaviour more closely at those particular settings. When this was done it was apparent that the let-off was not operating uniformly because the simple brake at one end of the beam was over-riding the escapement-controlled system at the other end. It will be remembered that the escapement mechanism is restrained by a brake that is released as the back rail is drawn forward, and that the geometry is such that the forward movement introduces a significant increase in tension. Generally this does not matter because the operation of the let-off does not permit any significant back rail movement. If the simple brake is too heavily weighted, then it prevents let-off and the back rail is drawn forward, releasing the brake on the escapement completely, until the tension is sufficient to cause the beam to slip. When this happens, the escapement is so free that the escapement lever oscillates at its natural frequency, allowing the escapement wheel and the beam to rotate continuously, but slowly, so that it takes several loom cycles for the tension to fall to the point at which the other brake once again prevents rotation, so that the tension again begins to increase. The cyclic variation in tension produces a corresponding variation in cloth extension, fell position and beat-up force and there will be a corresponding small change in pick-spacing. It should be noted that this means that where tension values have been measured in this situation, they do not necessarily correspond to the average value of B.U.F. The maximum variation in B.U.F. is about ± 10%, but the settings that show the largest value of variation do not happen to be the ones for which warp tension was recorded.

Obviously, care should be taken that the control brake system is not over-ridden by the simple negative let-off. In this work the instructions in the manufacturer's manual were followed. However, the loom settings included some that involved very large values of C.F.D. It has previously been noted (p.96) that under these conditions the controlled let-off produces lower levels of tension than for settings where C.F.D. is small and it is probably for that reason that the simple let-off takes control.

CHAPTER IX

9. SOME FABRIC PROPERTIES

CHAPTER IX

Some fabric properties

9.1 Introduction

A study of fabric properties was not one of the objectives of this research. However, having a collection of fabric samples, the production of which was well documented, it seemed wasteful not to record at least some basic parameters. It was not practicable, however, after the very large number of weaving experiments, to carry out a comprehensive programme of testing. It was decided to measure the widths (hence end-spacings) and pickspacings in the various samples to see if fabrics that were nominally the same were, in fact, different - especially in view of the great differences in weaving resistance under different loom settings. Air permeability was also measured because it was known to give a good indication of reediness, and reediness is known to be reduced by using an unbalanced shed. Some measurements of load extension behaviour,* thickness, stiffness and drape were made on a few samples made under different, fairly extreme settings, but these showed no significant variation with loom settings, so they were not continued and no results are presented for them. All the measurements were made several months after most of the fabrics had been woven, but they were conditioned for 48 hours under standard conditions of R.H. 65%, temperature 20 ± 2°C. The fabrics were in the grey state.

One parameter that was not measured was yarn crimp. To obtain reliable values for so many fabrics would have involved a very laborious procedure. Had it been intended to include some study of fabric properties in the work, it would have been useful to mark off measured lengths of yarn before weaving in order that crimp could be deduced.

There had, however, been included in the warp a strip formed from

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* breaking load and extension

yarn of the same type and from the same batch as the rest of the warp, which had been dyed blue so that any changes in fabric appearance could more easily be seen. Some samples of fabric from this region are included on Page 196.

9.2 Results

Most of the results for plain weave, for fabrics woven at the medium tension setting are summarized in Table 18. The number of picks/10 cm is between 5% and 11% more than the nominal value set by the loom take-up. There is no very clear pattern to the individual values, but the averages over shed timing and over shed balance, which are also given, show a tendency for the lower values to coincide with the settings that gave generally lower values of weaving resistance. This raises the question as to whether those settings give any real advantage in reducing weaving resistance for a given end product. However, if weaving resistance is plotted against the resulting pick-spacing (Fig 82) there does not appear to be any strong correlation, i.e. settings that reduce weaving resistance do not necessarily give a slightly less dense fabric.]

The end spacing reduces by about 7% but there is no very clear pattern of variation. The weight/unit area varies in a way consistent with the changes in thread spacing. The changes in thread-spacings between fabric on the loom at the fell and fabric off the loom may result from yarn contraction and crimp interchange between warp and weft. The variations with loom settings will arise from the same factors, together with variations in the actual amount of warp consumed in making the fabric. [That is because the weft can only crimp by stretching; if the fabric is formed at a lower warp tension or with a more unbalanced

TABLE 18

Variation in pickspacing, end spacing, weight/unit area and air permeability with shed timing and shed balance for plain weave (woven under medium warp tension) .

Type of measurement	Extra rail position (in.) / Shed timing code	0 (N)	+ 1	+ 2	+ 3	+ 4	+ 5	Average
Increase in (1) number of picks/ 10 cm	L	8	15	18	18	11	11	13.5
	L + 1	10	13	15	18	16	13	14.2
	L + 2	11	19	16	12	13	8	13.2
	M	19	18	11	13	15	9	14.2
	M + 1	13	11	12	11	15	10	12
	M + 2	9	11	11	10	9	10	10
	Average	11.7	14	13.8	13.7	13.2	10.1	
Increase in (2) number of ends/ 10 cm	L	12.9	11.6	11.6	11.6	11	11.2	11.7
	L + 1	11.6	10.6	11.6	11.6	10.8	11.9	11.3
	L + 2	12.5	12.8	12.5	12.9	11.2	10.8	12
	M	12.8	11.6	11.6	11.6	11.2	11.9	11.8
	M + 1	12.5	11.6	12.2	11.6	11.6	11.6	11.9
	M + 2	12.5	10.8	12.2	10.8	11.6	12.1	11.7
	Average	12.5	11.5	12	11.5	11.2	11.6	
Weight per unit area (g/m^2)	L	233	237	236	239	235	229	234.8
	L + 1	228	232	244	234	228	229	232.5
	L + 2	235	243	239	234	239	230	236.6
	M	235	227	232	233	233	226	231
	M + 1	233	231	230	232	229	228	230.5
	M + 2	229	230	236	234	225	227	230.1
	Average	232.2	233.3	236.1	234.3	231.5	228.1	
Air permeability ($cm^3/sec/cm^2$)	L	19.6	18	18.8	12.6	7.1	9.9	
	L + 1	25.8	22	19.5	17.8	15	13.4	
	L + 2	12.7	10.5	13.5	13.4	13.8	14.9	
	M	23.7	17.9	13	10.4	9.5	10.6	
	M + 1	19.8	15.8	13.8	11.3	10.4	10.4	
	M + 2	18.7	17	15.2	11.2	11	8	

(1) from the nominal given by the pick wheel

(2) from the warp density in reed

(Plain weave -
medium tension)

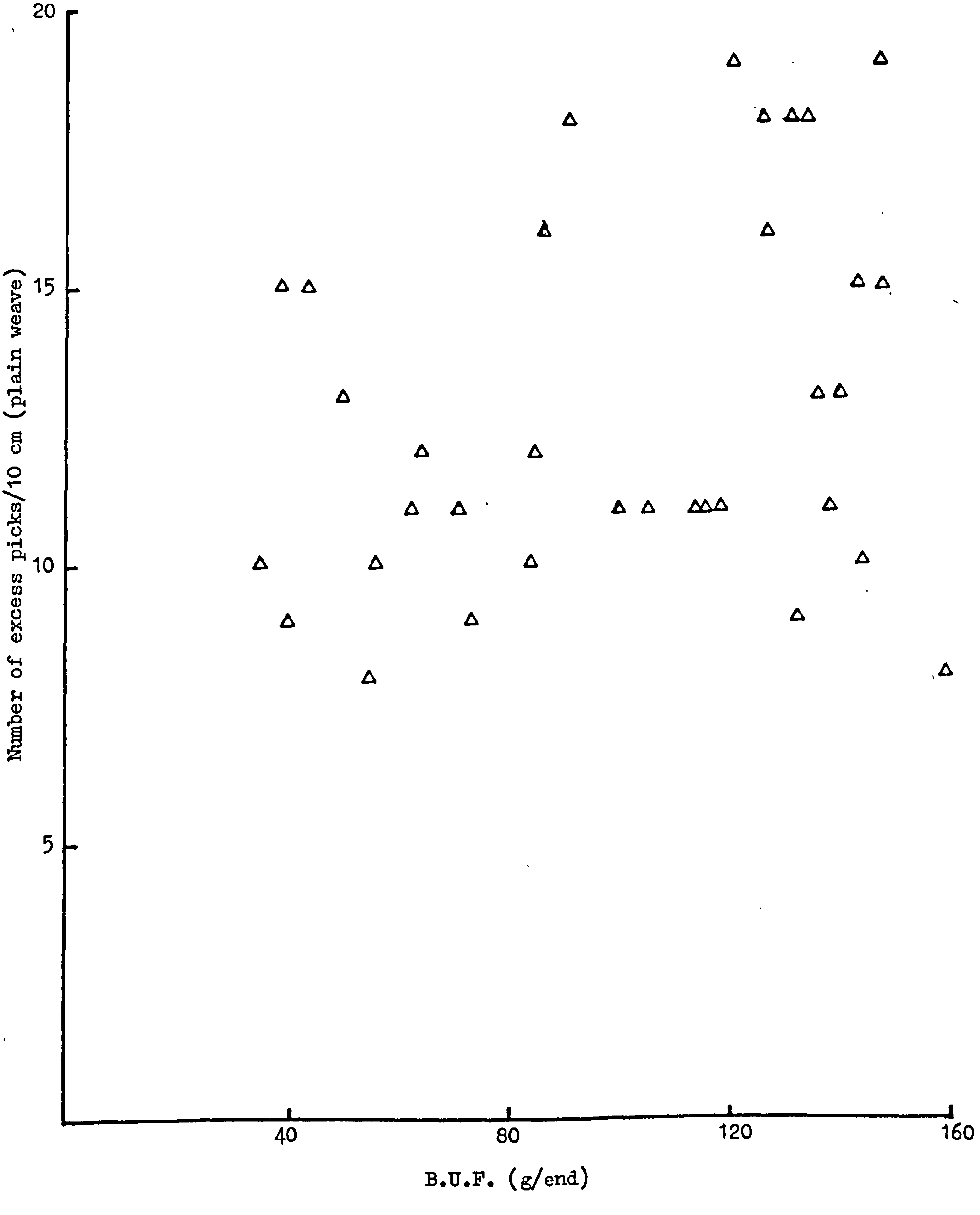


Figure 82. Excess picks plotted against B.U.F. (plain weave - medium warp tension)

shed, the force exerted on the weft by the warp will be reduced; therefore it crimps less and the warp has to crimp more, so a little more yarn is taken into the fabric. This mechanism probably accounts for the variation in pickspacing and fabric density. However, it is not possible without measured values of crimp to prove that this is the case.] The use of simple formulae of fabric geometry does not permit the changes in consumption and in yarn strain to be distinguished. [When similar figures for 2/2 twill (Table 19) are examined, rather greater width contraction occurs. This could indicate that in making a weave for which the shed is inherently less unbalanced, there is greater weft crimp and stretch, followed by greater contraction. Again, however, lack of accurate data prevents any such theory being proved.

The air permeability does show quite significant variations with loom settings, reducing for the unbalanced shed, as expected, and varying, as Figs 83 and 84 show, in a way very similar to that in which beat-up force varies. The general similarity of variation is shown in Figs 85 and 86 in which permeability is plotted against B.U.F. It is not suggested that one directly causes the other, but probably that both are very much dependent on friction forces between warp and weft, which in turn depend on inter-yarn pressures.

Finally, the fabric samples (Fig 87) from fabrics woven under near balanced and very unbalanced shed tensions indicate very clearly the variation in reediness on which the air permeability depends.

Thus, apart from the influence on local values of thread spacing, i.e. reediness and hence air permeability, the effects of loom settings on fabric properties seem to be fairly small - small enough that, given the variations expected in yarn properties, it would require more

TABLE 19

Variations in pickspacing, end spacing, weight/unit area and air permeability with shed timing and shed balance for 2/2 twill

Type of measurement	Shed timing code \ Extra rail position (in.)	0 (N)	+ 1	+ 2	+ 3	+ 4	+ 5	Average
Increase in (1) number of picks/ 10 cm	L	15	17	19	14	13	13	15.1
	L + 1	10	15	21	19	17	17	16.5
	L + 2	12	15	21	13	13	12	14.3
	M	5	17	15	15	13	15	13.3
	M + 1	7	7	15	15	17	13	12.3
	M + 2	2	5	7	7	8	7	6
	Average	8.5	12.6	16.3	13.8	13.5	12.8	
Increase in (2) number of ends/ 10 cm	L	17.5	16.7	16.1	16.2	15.6	14.5	16.1
	L + 1	17.5	16.7	16.1	15.9	15.6	14.2	16
	L + 2	17.5	16.7	16.1	15.9	15.4	14.5	16
	M	16.7	16.7	16.1	15.6	15.6	14.5	15.9
	M + 1	17.2	16.7	16.1	15.6	15	15	15.9
	M + 2	17.5	16.7	15.5	15.6	15.4	15.4	15.9
	Average	17.3	16.7	16.	15.8	15.4	14.7	
Weight per unit area (g/m^2)	L	303	325	325	324	307	304	311.3
	L + 1	314	317	306	313	309	310	309.8
	L + 2	313	315	315	306	309	309	311.1
	M	308	314	309	309	311	307	309.6
	M + 1	309	311	309	306	311	305	308.5
	M + 2	313	308	304	307	305	305	307
	Average	310	315	309.6	309.1	308.6	306.6	
Air permeability ($cm^3/sec/cm^2$)	L	3.3	2.7	1.8	2.0	2.1	2.0	
	L + 1	3.9	2.7	2.6	2.0	1.8	2.1	
	L + 2	3.7	2.9	2.3	2.6	2.2	2.2	
	M	3.6	3.0	3.2	2.2	2.2	2.4	
	M + 1	4.1	3.3	2.8	2.9	1.8	1.9	
	M + 2	3.8	3.7	3.6	2.4	2.0	2.2	

(1) from the nominal given by the pick wheel

(2) from the warp density in reed

(2/2 Twill weave)

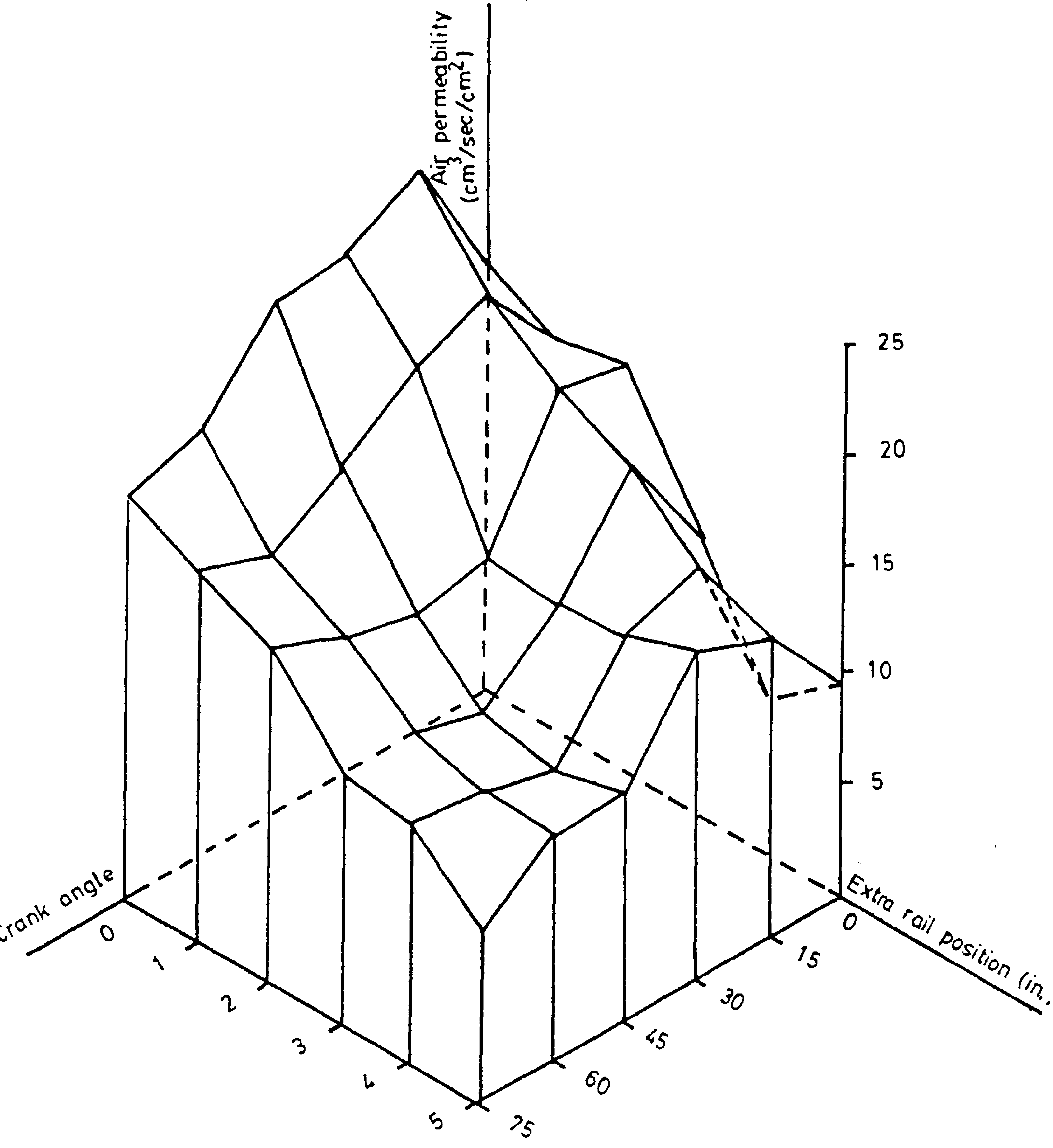


Figure 83. Effect of shed timing and shed unbalance on air permeability (plain weave - medium warp tension)

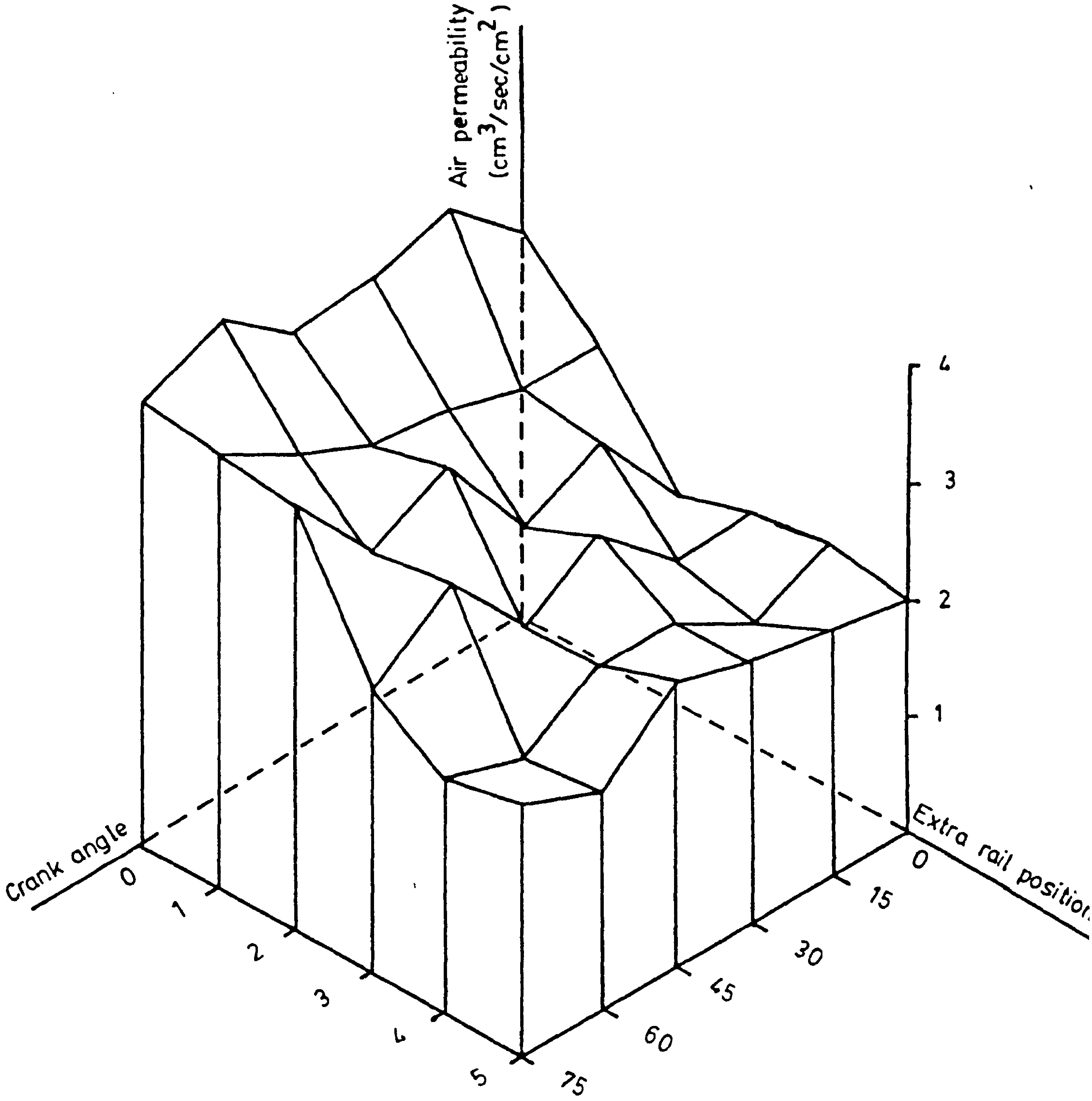


Figure 84. Effect of shed timing and shed unbalance on air permeability (2/2 twill weave - low warp tension)

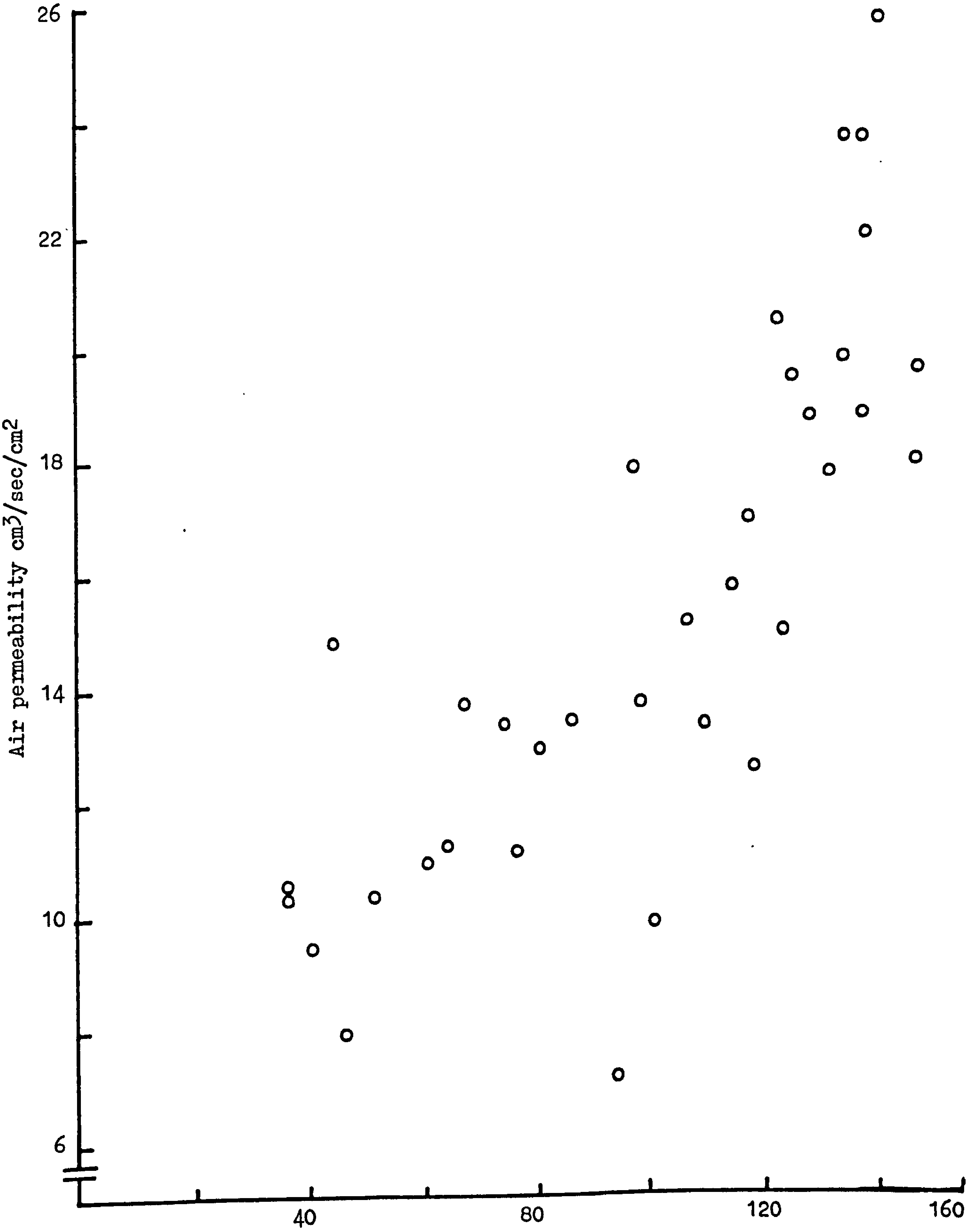


Figure 85. Air permeability plotted against B.U.F. (plain weave)

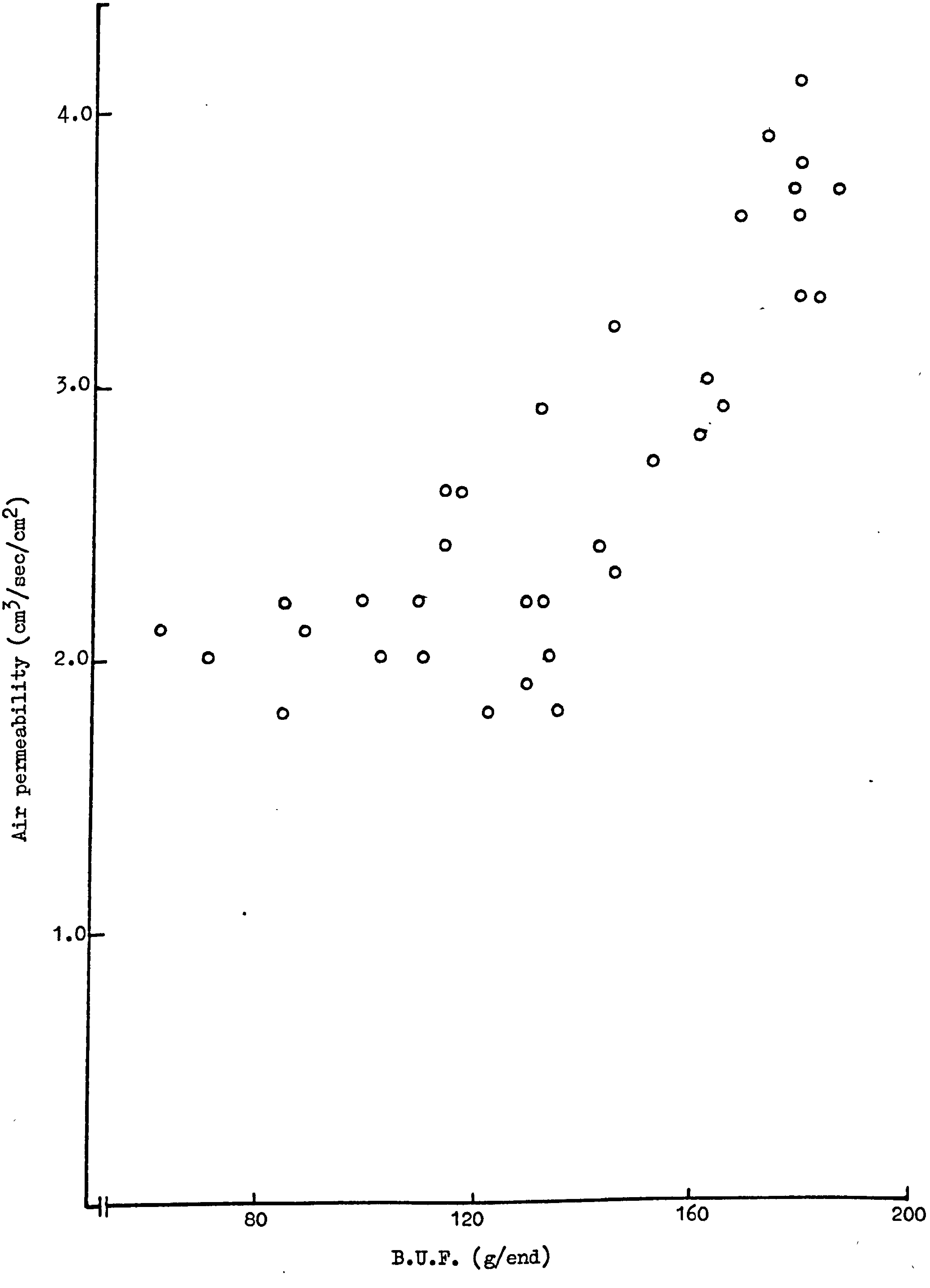
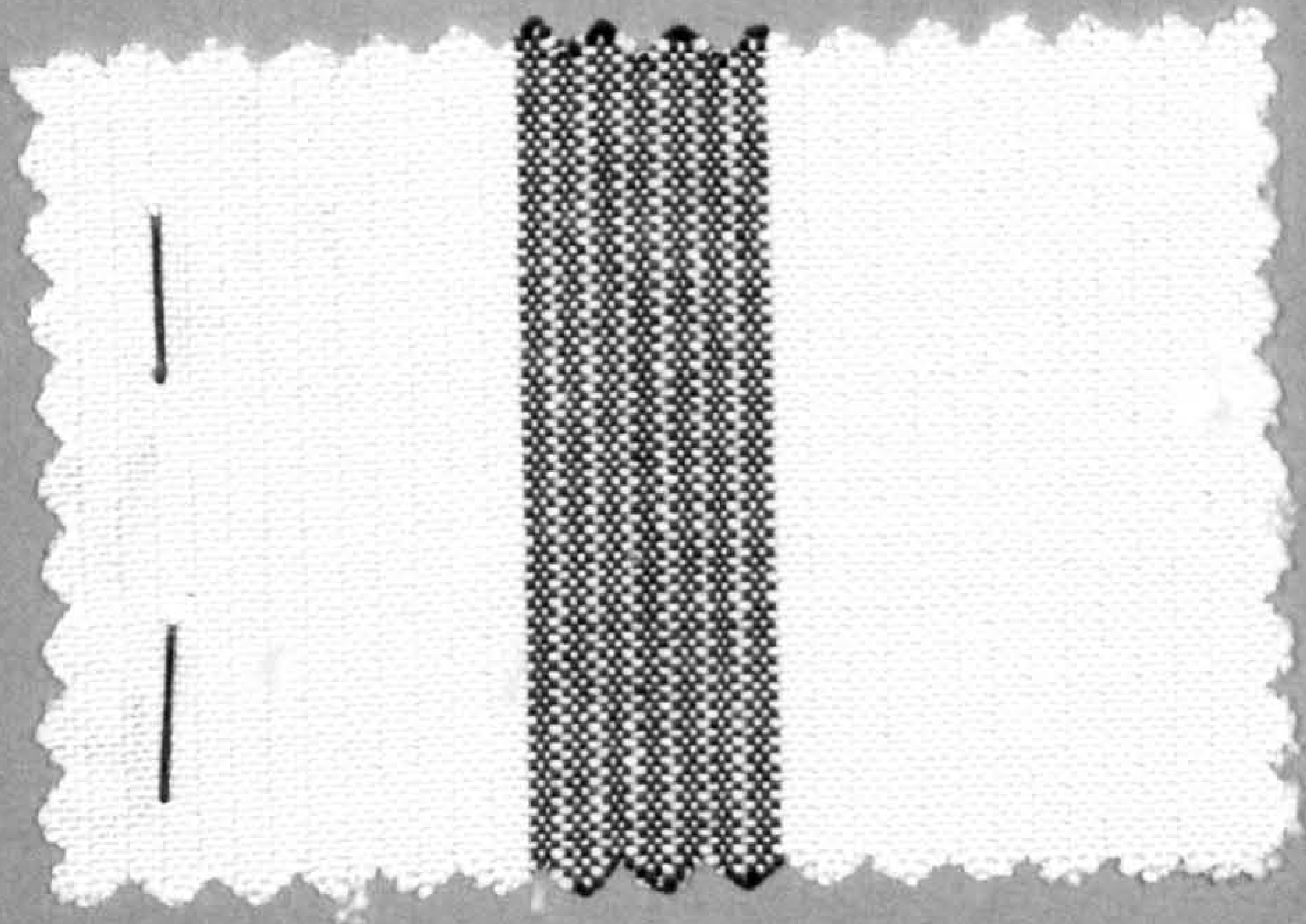
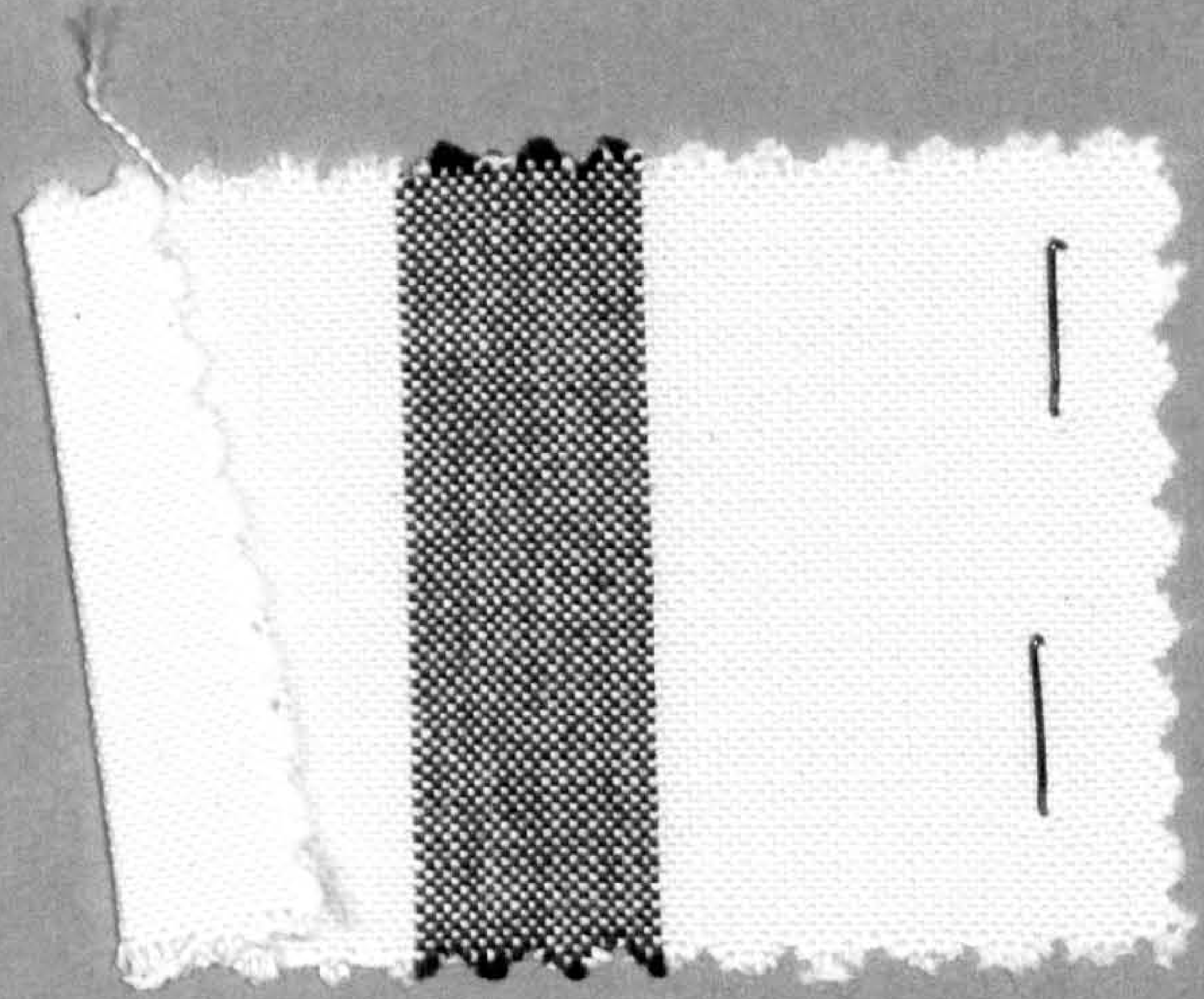


Figure 86. Air permeability plotted against B.U.F. (2/2 twill weave)

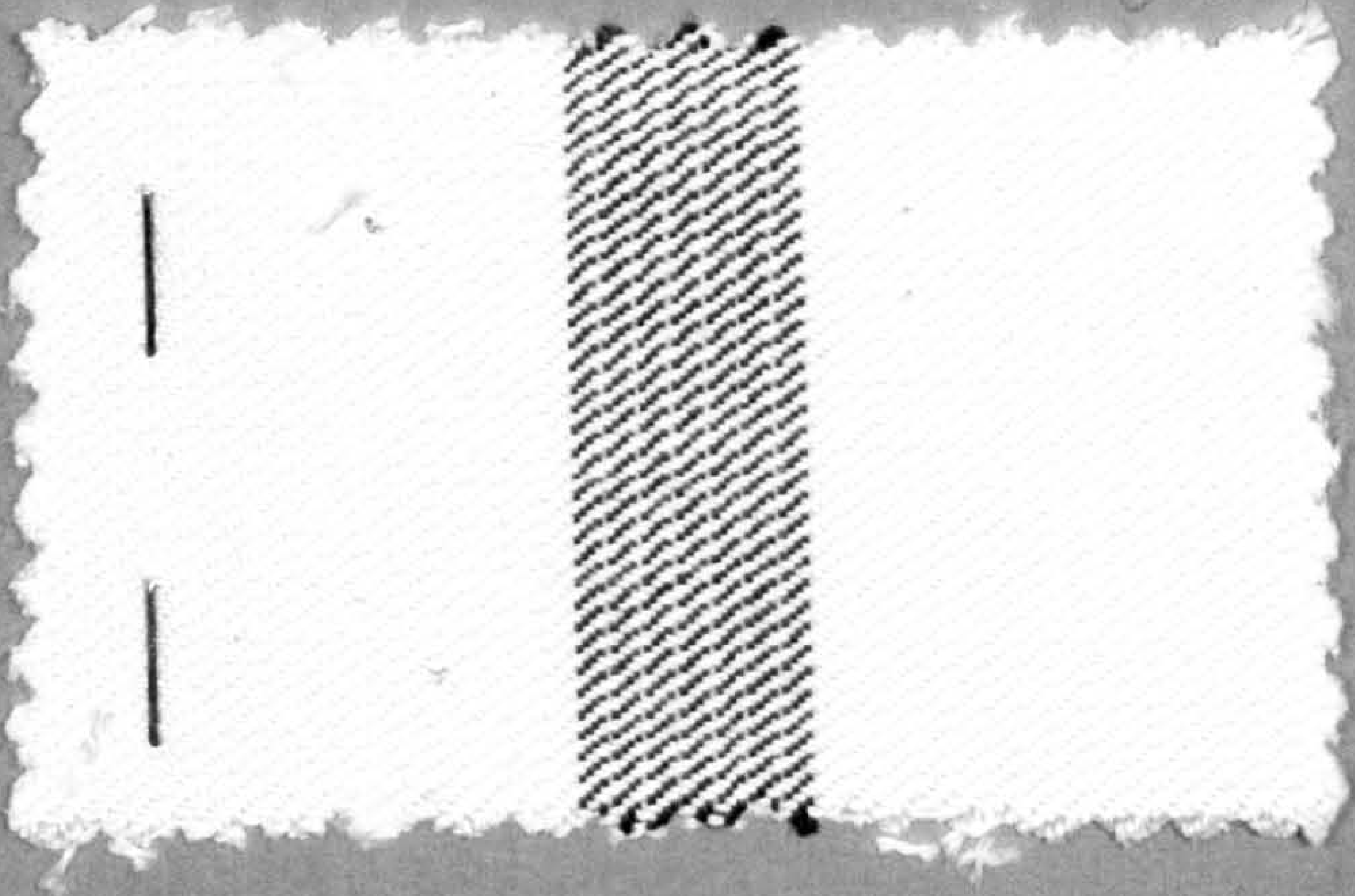


Plain weave woven with late shed timing and normal extra rail position

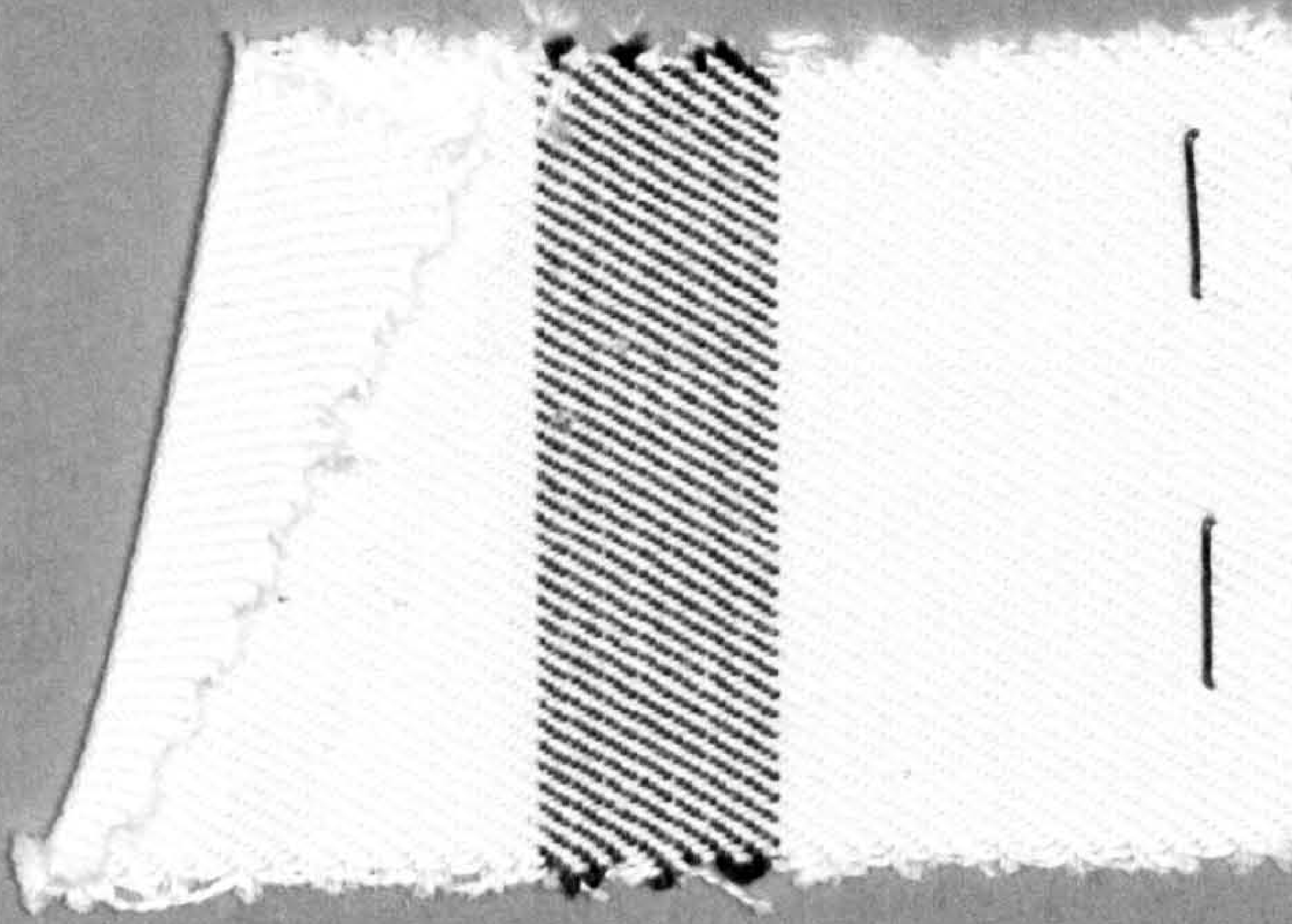


Plain weave woven with early shed timing and raised 5 in. extra rail

Reed marks



2/2 twill weave woven with late shed timing and normal extra rail position



2/2 twill weave woven with early shed timing and raised 4 in. extra rail

Figure 87. Fabric samples woven under balanced and unbalanced shed tensions

carefully designed experiments and probably a careful statistical treatment of the result to identify and explain the influences. At the same time, the effects are not insignificant in practical terms, fabric widths, for example, varying over a range of about an inch for the range of loom settings used.

CHAPTER X

10. DISCUSSION
and
CONCLUSION

CHAPTER X

DISCUSSION AND CONCLUSION

10.1 Introduction

The results presented in Chapters 7 and 8 satisfy to a large extent the aims of this work because they show how weaving resistance is affected by the loom settings chosen for investigation for two of the most common weaves. These results, and the discussion of them, have shown clear patterns of variation; but they have not fully explained why the variations occur. The purpose of this chapter is to see what further information can be extracted from the recorded traces and to attempt to form a unified picture of the influence of loom settings on the whole beat-up operation.

10.2 The beat-up trace

The whole set of results depend upon the measurement of B.U.F. Although it is mainly the peak value that is of interest, and often only the peak values are recorded and discussed, each of these peaks is obtained from a signal that, on a faster timebase, gives a trace such as that first shown in Fig 8E. While there has been nothing so far to suggest that such a trace may not be valid, there are some peculiarities that require more detailed examination. Although the sley movement is symmetrical about front centre (see Fig 18), the single beat-up trace is not usually symmetrical, and it will later be seen that its peak value does not usually coincide with front centre. Generally it rises more rapidly than it falls.

There are a number of reasons why the form of this trace should not be similar to the expected form of the sley displacement curve (which itself may not be quite symmetrical if loom speed varies within the loom cycle). First the fell is changing during beat-up because a pick, or a series of picks, is being pushed into the cloth. But that would cause the trace to start earlier and build up less rapidly; it might fall less rapidly if picks slipped back with the reed, but not if slipping back were delayed until the next shed-change. A second possible cause ? is friction at the healds causing the effective free length of warp to be, initially, much reduced, with a correspondingly more rapid increase in B.U.F; but the same reason would cause a steep initial part to the falling slope. Differences between dynamic and elastic behaviour of the yarn might have an effect - but it will be seen that there is evidence that any such effect is small. The trace is shown on a constant time-base, but sley movement is related to crank angle. A steep rise to the B.U.F. curve, therefore, might indicate that the loom was moving faster as it approached front centre than as it returned. Both sley mechanics and the elastic resistance of the fell might produce a variation in loom speed, but that would be expected to be symmetrical about the front centre position. The work done in driving the dobby might have an unsymmetrical effect (varying with shed timing) but that is estimated to be quite small. For the reasons mentioned, but after considerable study, these various explanations for the asymmetry were discarded.

The most obvious explanation, considered before any of these, was the one put forward by Badve who had argued that B.U.F. would be proportional to the displacement of the fell by the reed, relative to that it would have had due to shedding and back rail movement. He had shown that, for what he defined as "early", "medium" and "late" timings, the extra displacement was given by the vertical distance between curves similar to those in Fig 90 (a). The B.U.F. traces derived from this displacement would be slightly asymmetrical and their maxima would not quite coincide with front centre. Applying these ideas to the present work, the fell was evidently being drawn toward the reed as beat-up took place; therefore B.U.F. would still be rising at reed front centre and the peak would occur after front centre.

Unfortunately no timing markers had been used during the original experiments so, in order to confirm that the above explanation might fit, a supplementary experiment had been arranged in which a few recordings were repeated, including an additional trace having a pulse of duration about 1/100 of a loom cycle starting at front centre. They are reproduced in Fig 88, and they contradicted completely the explanation set out.

After this failure, the series of possible explanations mentioned earlier were examined in turn and each discarded.

The shapes, and variation of shapes, of these traces can be seen in Fig 89 which shows those corresponding to positions around the edges of the "three-dimensional" graphs used in previous chapters. They show increasing height with the more balanced shed and increasing width with later shedding, while asymmetry increases with height of trace except for very small traces, where the asymmetry is reversed.

Considering these shapes, it seemed that a possible explanation might lie in the mechanism put forward by Badve if the effect of shedding and back rail movement were to produce a base line rather like Fig 90 (b) than 90 (a) given by Badve. However, it seemed most improbable that the back rail could swing rapidly enough to give such an effect.

As no other explanation could be found, the loom was operated and this part of the mechanism closely observed. There was very little swinging of the back rail, but there was movement of the warp over it and an oscillatory rotation of the rail. That was caused probably partly by the extension of the yarn below the back rail, but also by

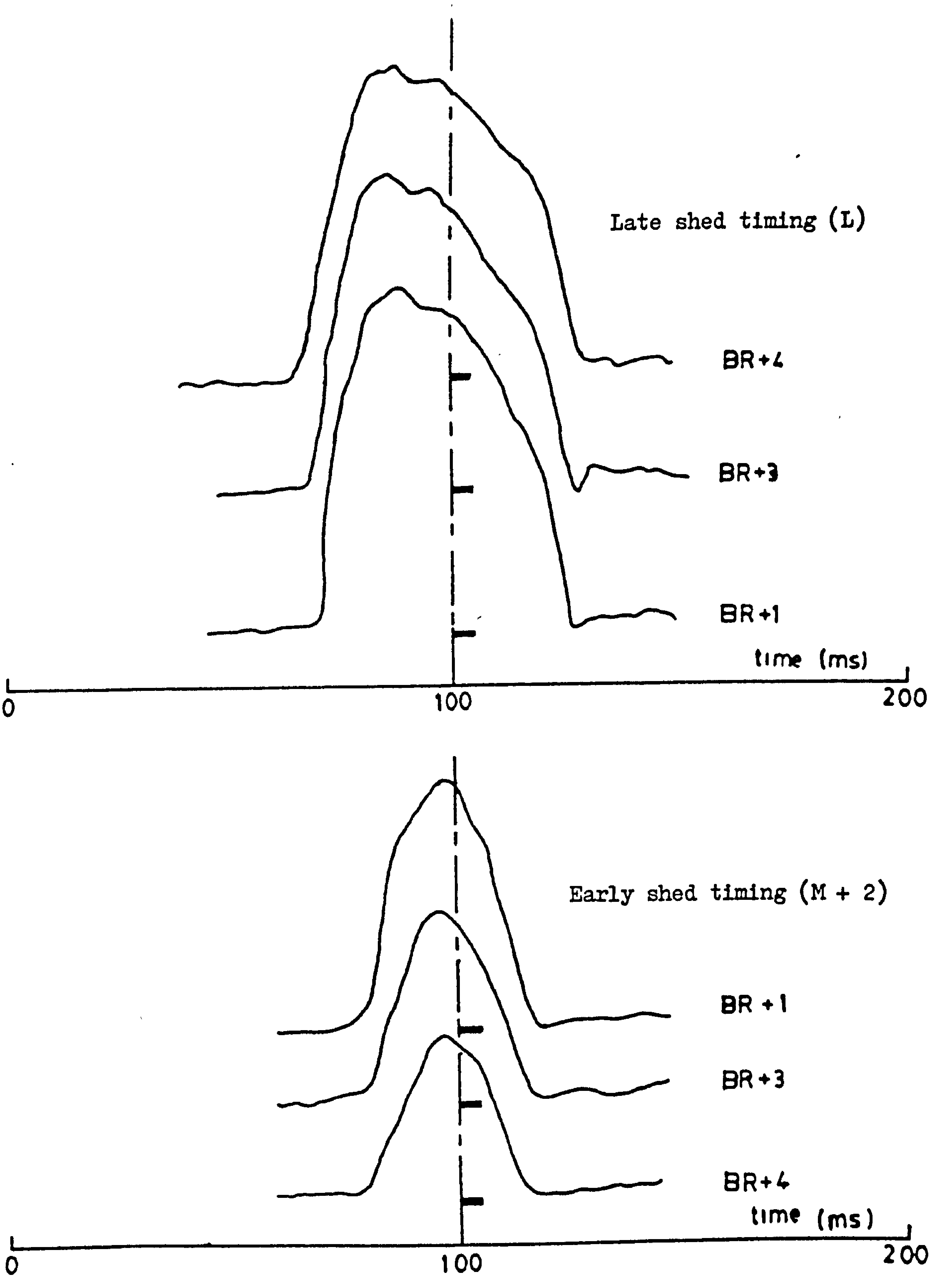


Figure 88. B.U.F. traces with front-centre marker

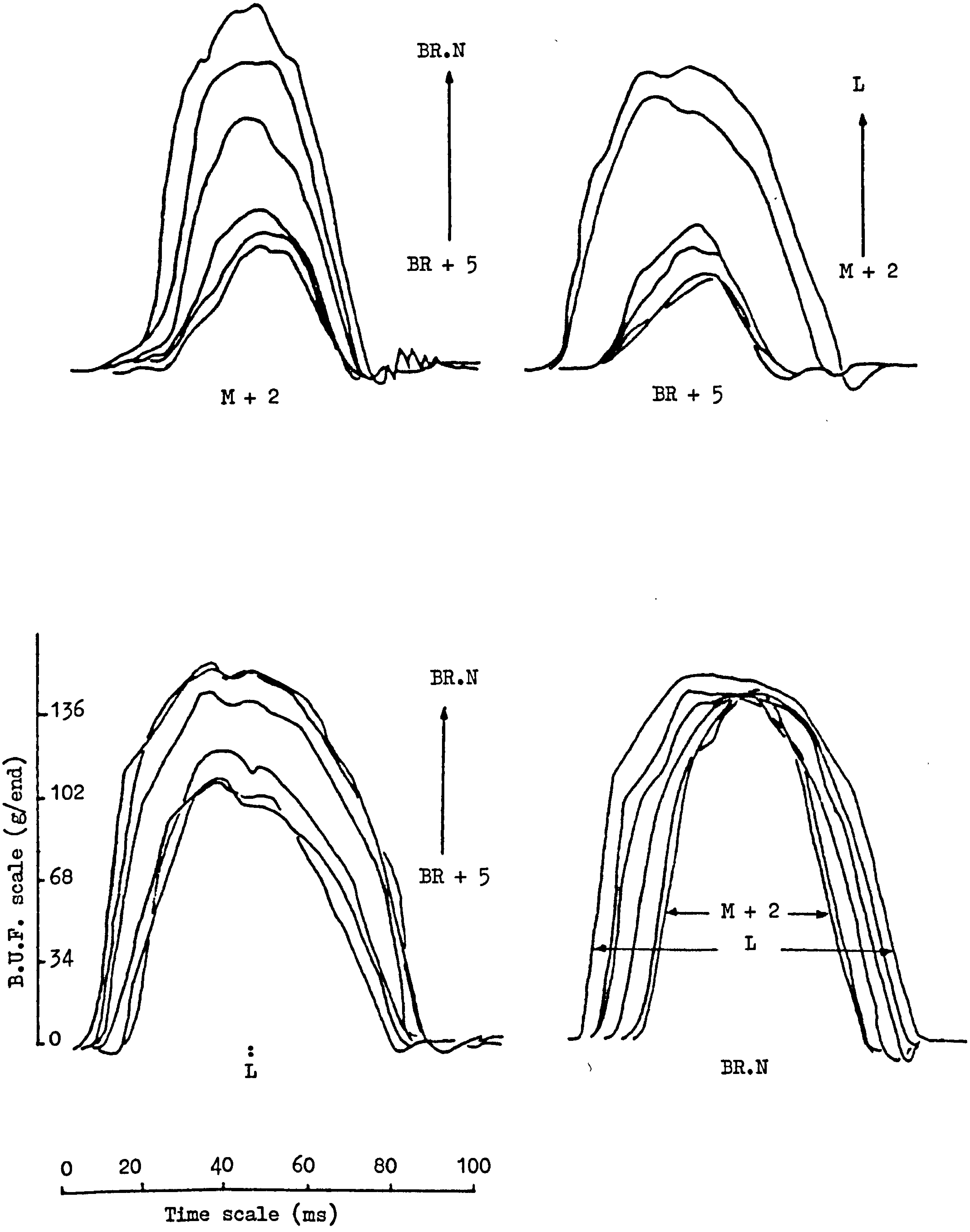


Figure 89. Effect of shed timing and shed unbalance on single B.U.F. traces

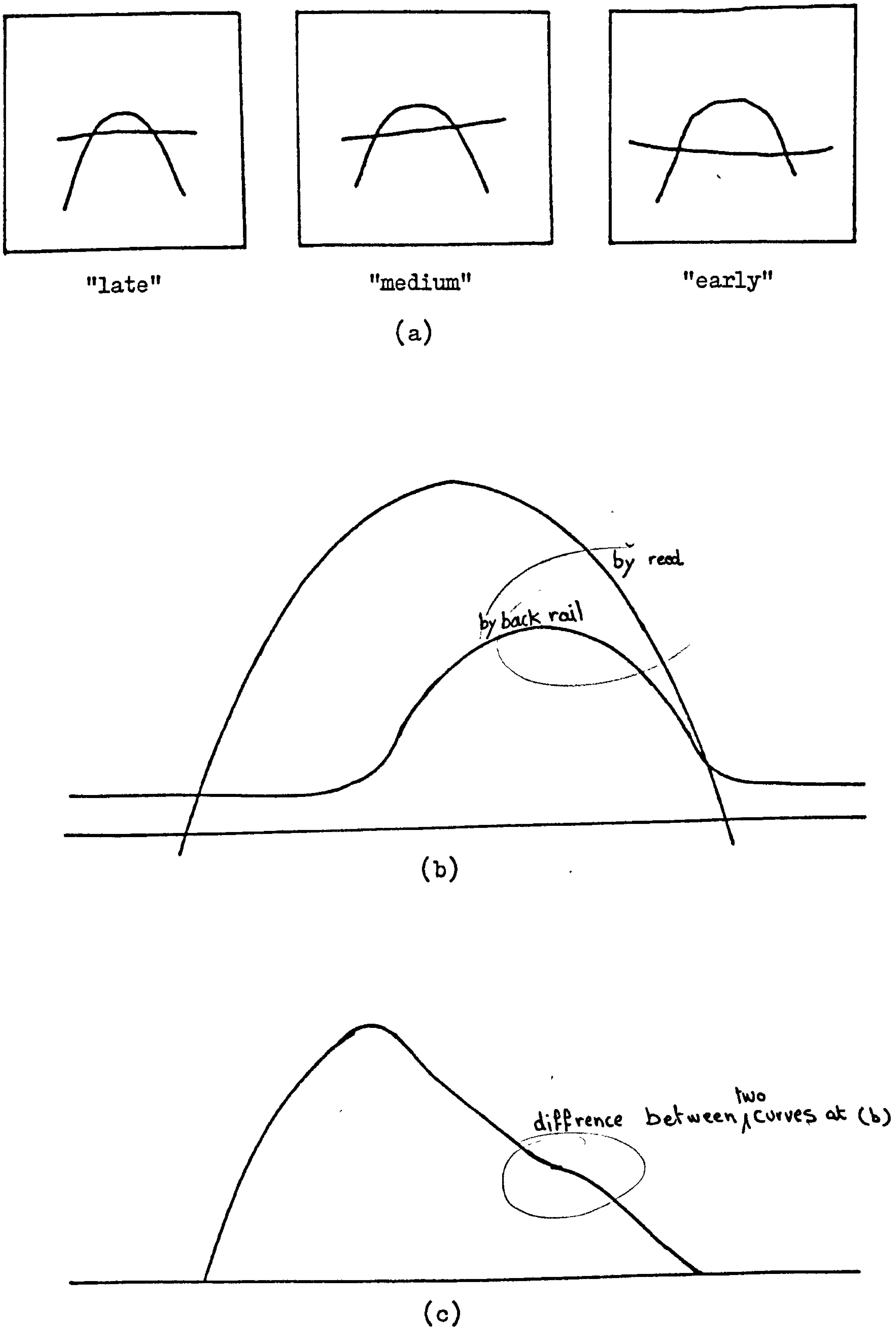
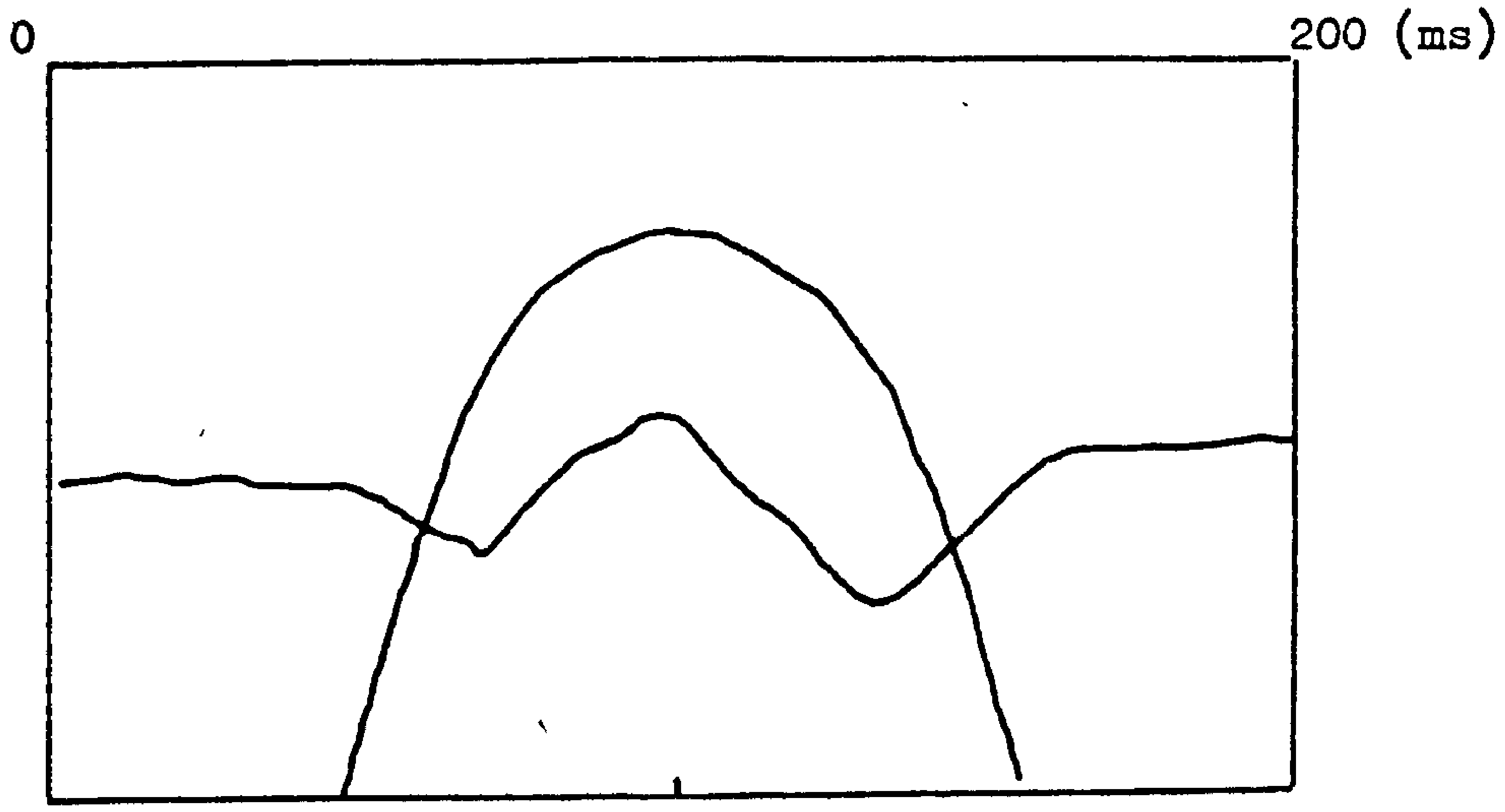


Figure 90. Fell displacement by reed and back rail
(a) as measured by Badve
(b) as required to explain the single B.U.F. at (c)

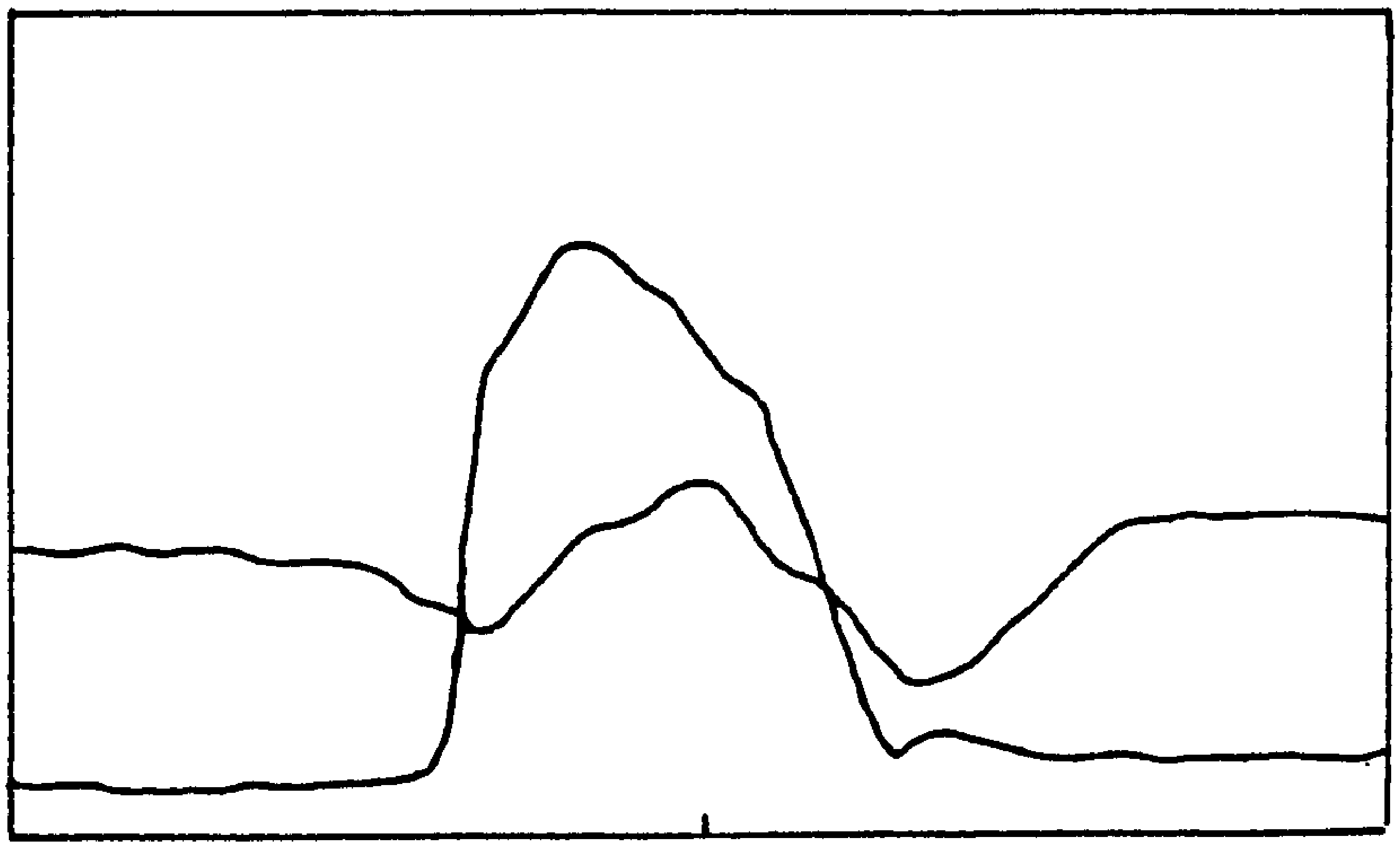
rapid bending of the supplementary back rail (seen in Fig 21, 22, just below the suspended back rail). This could have the rapid effect on the fell needed to explain the form of B.U.F. traces.

At a very late stage of the work, when all other experiments had long been completed, a final supplementary experiment was conducted - partly because there had just become available two capacity-type proximity indicators. Two plates were mounted on the loom frame so that a third, mounted on the sley, would mesh between them at beat-up (an arrangement identical with one used by Badve). Similarly two plates were mounted on an insulating block clamped to the lower back rail and arranged to mesh with a fixed plate supported on a heavy stand on the floor. Thus movements of both the sley and this rail could be recorded simultaneously. The resulting traces are shown in Fig 91 (a); they are not necessarily to the same scale. They do show that the tension variations caused by this movement will have an effect similar to that anticipated, the differences between the curves increasing rapidly at first followed by a slower increase and a relatively gradual decay.

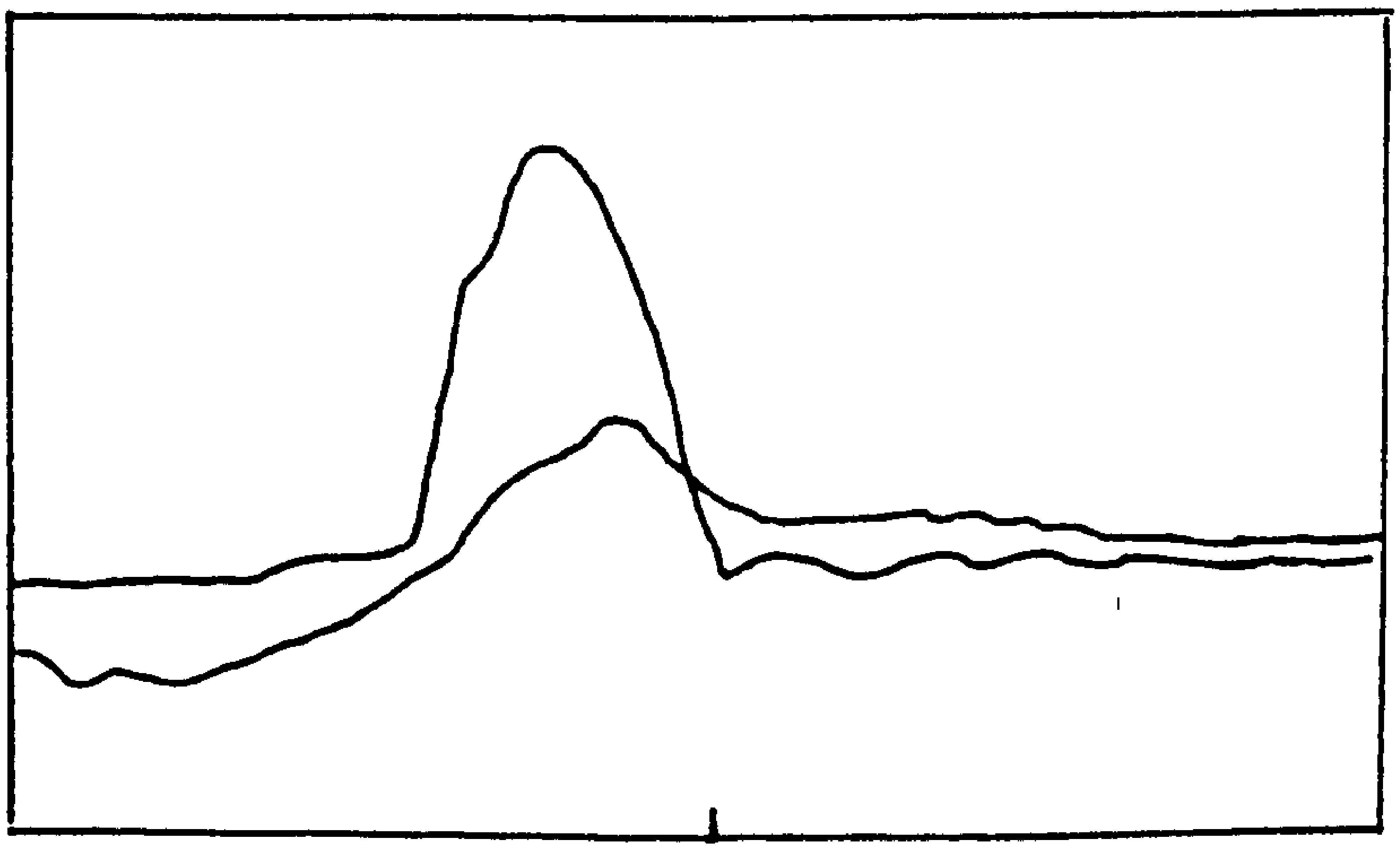
In order to take account of the magnitudes of the two effects, the sley was locked at front centre, so the cloth was pulled against it by warp tension. The lower back rail was displaced and its displacement, together with the "B.U.F." trace produced by that displacement recorded together. The gains were adjusted until these traces were the same magnitude, i.e. the trace of back-rail displacement represents the contribution to the B.U.F. caused by that displacement. With these settings, weaving was carried out at two shed-timing settings, the B.U.F. and the rail's contribution to it being recorded together. Note that in this a forward movement of the rail produces a reduction in force; i.e. to synthesize a B.U.F. trace unaffected by the bending of the rail, the two



(a) Sley displacement and lower back rail deflection



(b) Single B.U.F. and lower back rail deflection
(BR + 1 - late shed timing)



(c) Single B.U.F. trace and lower back rail deflection
(BR + 1 - early shed timing)

Figure 91

traces should be added. Clearly the peculiarities of the shape are to a large extent explained by the bending and the conclusions of the earlier chapters are not affected by this explanation.

As further confirmation of this vibration of the supplementary back rail, it may be noted that in many of the tension traces in Chapter 7 there is a noticeable minor peak after the main one.

In Fig 91 (c) it will be noted that a change of shed timing does not merely produce a shift in the position of the "back-rail" trace, but also a change of shape. It is to be expected that its behaviour will be a complex function of both shedding and beating-up, a detailed discussion of which does not fall within the aims of this work. It should be remembered that the "Badve" effects shown in Fig 90 (a) are likely also to influence B.U.F.

When the two displacement curves are broadly in phase as in Fig 91 (a) then it follows that to develop a given B.U.F. the fell displacement has to begin earlier and finish later - i.e. the measured fell displacement will be greater and the width of the beat-up trace will be greater than if the curves are less nearly in phase.

Finally, before leaving the single beat-up trace, it may be noted that the small oscillation that follows the largest B.U.F. traces appears to be at the natural frequency of the reed cap.

10.3 The build-up of B.U.F.

A further piece of evidence that has not yet been examined in detail is the curve of beat-up force v. number of cycles, since the start of weaving. This curve was automatically plotted on the oscilloscope screen by choosing a slow timebase when recording B.U.F. with the oscilloscope in the "store" mode. It was observed continuously during weaving so as to recognize when stable conditions were reached, but it was also recorded in the early stages when pickspacing was varying, in case it showed any interesting variation. Greenwood showed that, if the assumptions of his theory were valid, then by differentiating the basic equations $(L + p)(p - D) = K$ (in the present notation) with respect to pick number n and using the fact that $\frac{dL}{dn}$ is the difference between pickspacing and take-up, a differential equation relating p and n is obtained. That can be integrated to show that p is a rather complicated exponential function of n; but when the difference between p and take-up, say q, is small it reduces to $(p - q) = (p - q)_o \, e^{-(1+\frac{K}{c^2})n}$ i.e. the "error" decays exponentially, p tending to the value q, of take-up. Similarly the B.U.F. builds up rapidly at first, but then approaches its steady value quite slowly. In this case, assuming Greenwood's equation $B = (L + p)(\frac{E1}{L1} + \frac{E2}{L2})$ is true and writing it as $B = (L + p)\lambda$ then, considering two successive values B_{n+1} and B_n of the series forming the build-up diagram,

$$B_{n+1} - B_n = \lambda (L_{n+1} + p_{n+1}) - \lambda (L_n + p_n)$$

$$= \lambda (L_{n+1} - L_n) \overset{+}{-} \lambda (p_{n+1} - p_n) ;$$

$$\text{but} \quad L_{n+1} - L_n = p_n - q$$

$$B_{n+1} - B_n = \lambda (p_{n+1} - q)$$

$$\text{or} \quad \frac{dB}{dn} = \lambda (p - q)$$

Another way of putting this is that CFD, to which B is proportional, is the sum of all the errors, p - q, since weaving started. In theory, therefore, it should be possible to deduce from the build-up curve a relationship between weaving resistance and pickspacing. In particular if, as was suggested on theoretical grounds by Plate and Ito, the relationship is discontinuous so that at certain initial values of p there has to be a finite change in B to achieve a smaller p, then for a few successive cycles p will have the same value; therefore $\frac{dB}{dn}$ will be constant, i.e. the "build up" curve should have straight sections at these critical values.

Unfortunately, when the curves are examined, it seems that they will be very sensitive to disturbances such as yarn irregularities or variations in warp tension. However, there certainly does appear to be straight sections on some of the curves, particularly those with late timing and unbalanced sheds.

10.4 B.U.F. decay envelopes

The decay curves are not quite the complement of the build-up curves. They represent the force exerted by the reed on the fell as the fell is gradually drawn away by the take-up during successive cycles of operation of the loom without weft. As explained earlier, provided that slipping back of picks occurs in the same way as during normal weaving, the number of lines in the descending series is a measure of C.F.D. Also when picks are not slipping back, the envelope of this series of lines represents a load/extension curve for the warp and cloth in parallel, the slope representing the term $(\frac{E_1}{L_1} + \frac{E_2}{L_2})$ of Greenwood's equation. These two aspects of the decay trace, together with the possible influence of slipping picks will be considered in more detail.

10.5 Cloth fell distance

Values of cloth fell distance deduced from those curves have already been presented on the assumption that they are valid, and the fact that they vary with loom settings in a way broadly similar to the B.U.F. suggests that they may be. The differences, mainly that C.F.D. increases more rapidly than B.U.F. as the shed is made more nearly balanced are probably due to the back rail beginning to swing in or out of phase with the reed. There are, however, two other methods of measuring C.F.D. that might be used. An obvious method is to measure it under static conditions using a ruler or a dial gauge. A less obvious one is to use the width of the base of the single beat-up trace already discussed as a measure of the duration of contact of reed and fell. Assuming loom speed to be constant within the cycle, the duration can be converted into degrees of crank-shaft rotation and then into reed movement. That, in turn, has been converted into C.F.D. on the assumption that the contact period is symmetrical about front centre (previous discussion suggests it is not quite symmetrical). which [illegible] (ie modified SHM!)

In Fig 92, the values of C.F.D. obtained by measuring the width of the single B.U.F. trace and those obtained by static measurements of fell position are both plotted against the values deduced from the B.U.F. decay envelope. The latter method seems to give values about 20% higher than the others, and there is some scatter, probably not due to measuring errors but to the effects of phase differences between the displacements of sley and back rails already discussed in Section 10.2.

For those settings that give a low weaving resistance, the two methods used give virtually the same values of C.F.D. These are the situations in which the decay curve is a straight line, suggesting that the bending of the lower back rail has no significant effect. If that is so, the slope of this curve should, as mentioned in Section 3.8, represent the combined elastic modulus of warp and cloth, Greenwood's $\frac{E_1}{L_1} + \frac{E_2}{L_2}$ or the practical less linear equivalent of it.

A large number of decay curves from the Group I experiments were examined under an enlarger and the slopes (initial slopes where there

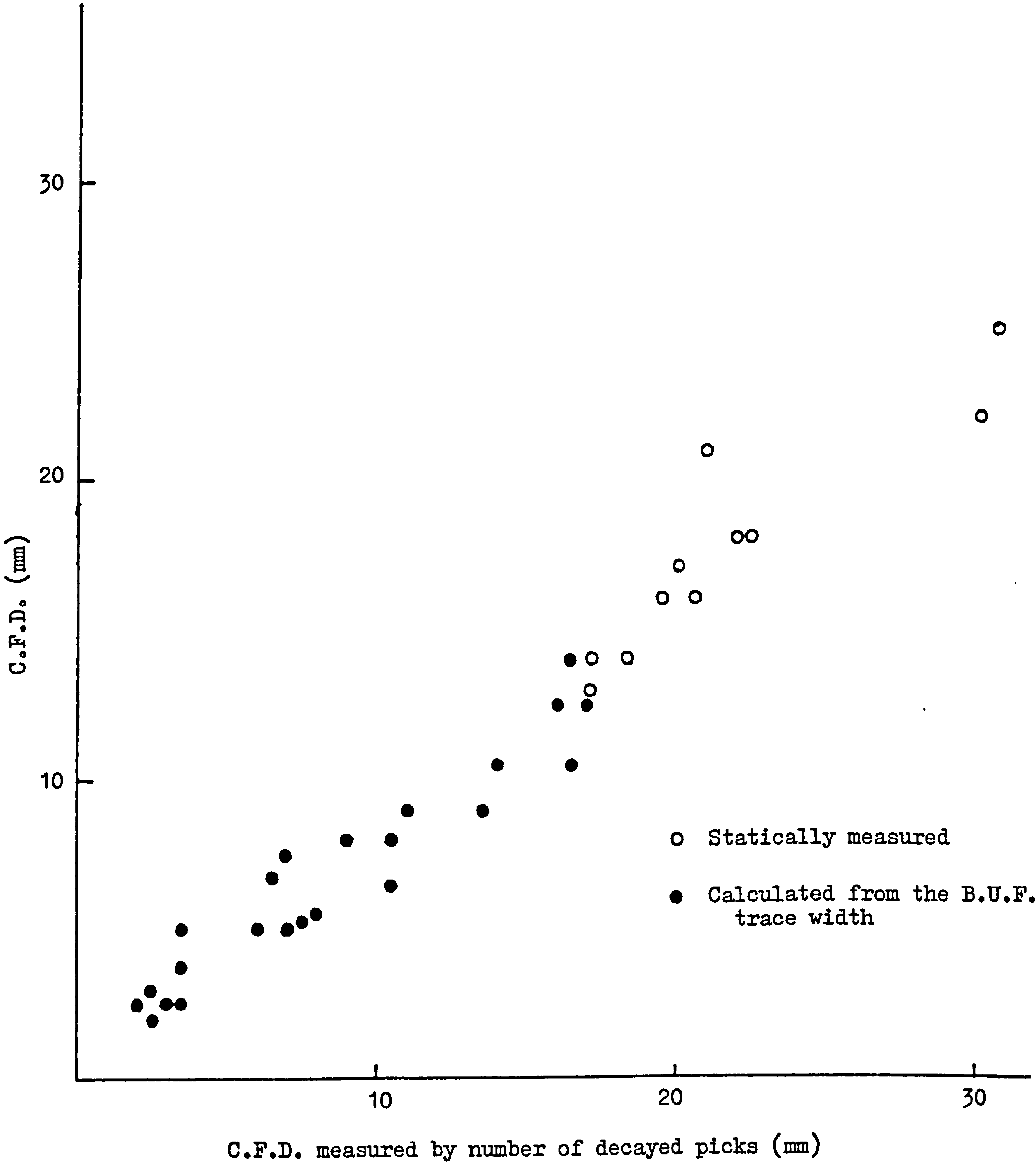


Figure 92. Relation between C.F.D. statically measured, calculated from the B.U.F. trace width and measured by the decayed number of picks

was variation) measured. Fig 93 shows a selection of such curves drawn from experiments in which only the basic warp tension was changed. They are reversed to conform with the more usual way of showing load/extension curves. The slopes decrease as the tension decreases corresponding to the lower values of elastic modulus at lower tensions.

For the full set of results, the decay slope (gf per end per unit of take-up) was converted to a fell load/displacement curve (gf per end per mm) and plotted against basic warp tension (Fig 94). On the same graph are shown five points representing the load/displacement curve slope for the cloth fell calculated from the measured load/extension curves of yarn and fabric for different values of basic tension. Obviously, in spite of the expected scatter on such a graph, the results suggest that the B.U.F./fell displacement relationship closely follows the "static" elastic modulus.

It was previously suggested that the next stage of the decay curve - often a shallower constant slope, but sometimes a curve - represented the change of effective modulus from $(\frac{E_1}{L_1}+\frac{E_2}{L_2})$ under normal conditions to $\frac{E_1}{L_1}$ under bumping conditions. However, using practical load/extension curves, there is no sudden change and, in most cases, there is little change at all in the value of the combined modulus, because the curvatures of the two load extension curves tend to balance each other. The explanation for the changes in slope probably lie in the changing shape and phase relationship of the displacement curves in Fig 91 (a) (Section 10.2), caused at least partly by the increase in effective C.F.D. due to the additional slipping-back of picks. These are likely to affect the decay curves in two ways. First, they cause a region that is neither strictly cloth nor warp, but rather partly formed cloth which deforms on each beat-up as if it had a much lower elastic modulus

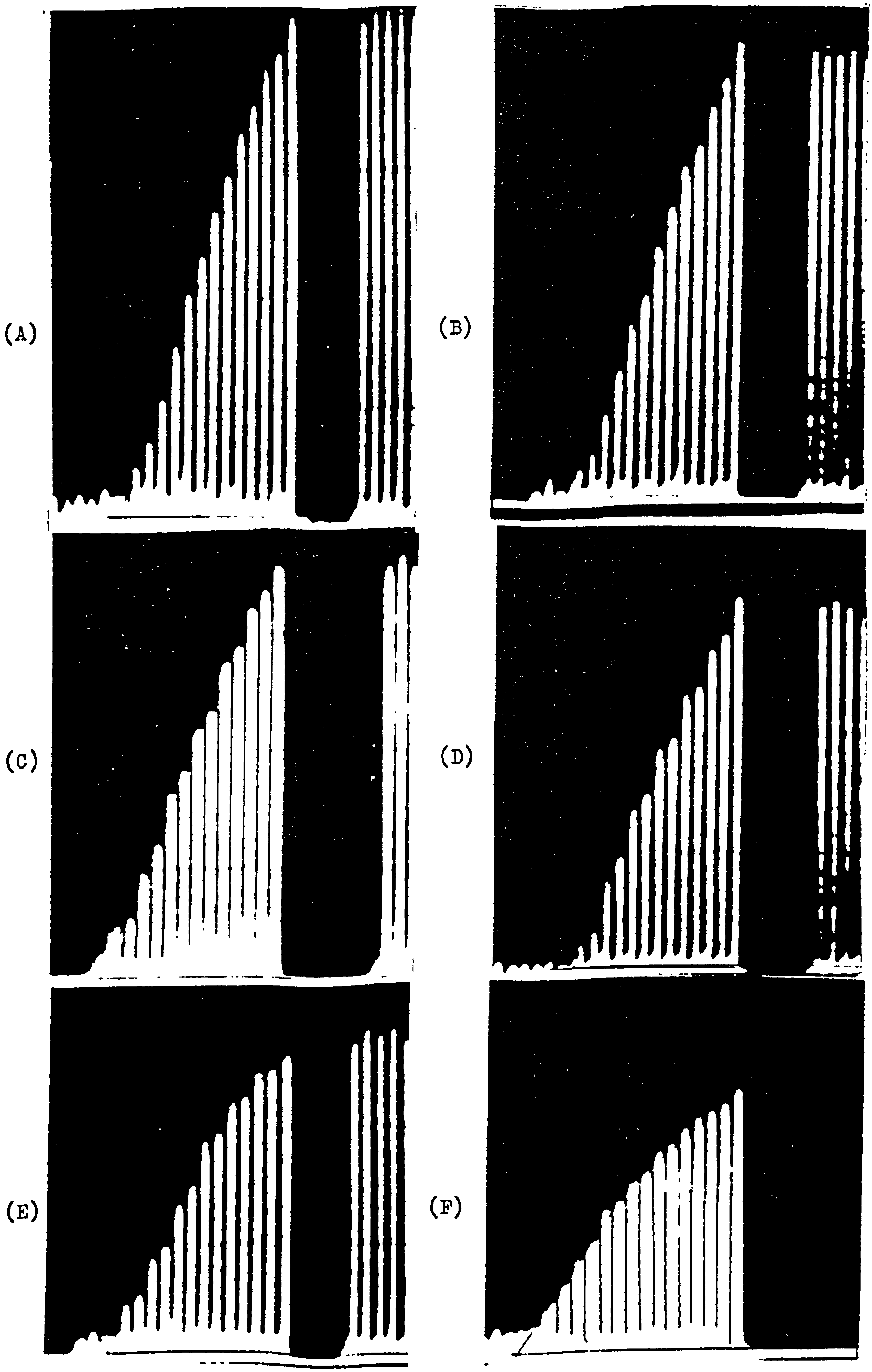


Figure 93. B.U.F. decay curves "reversed"

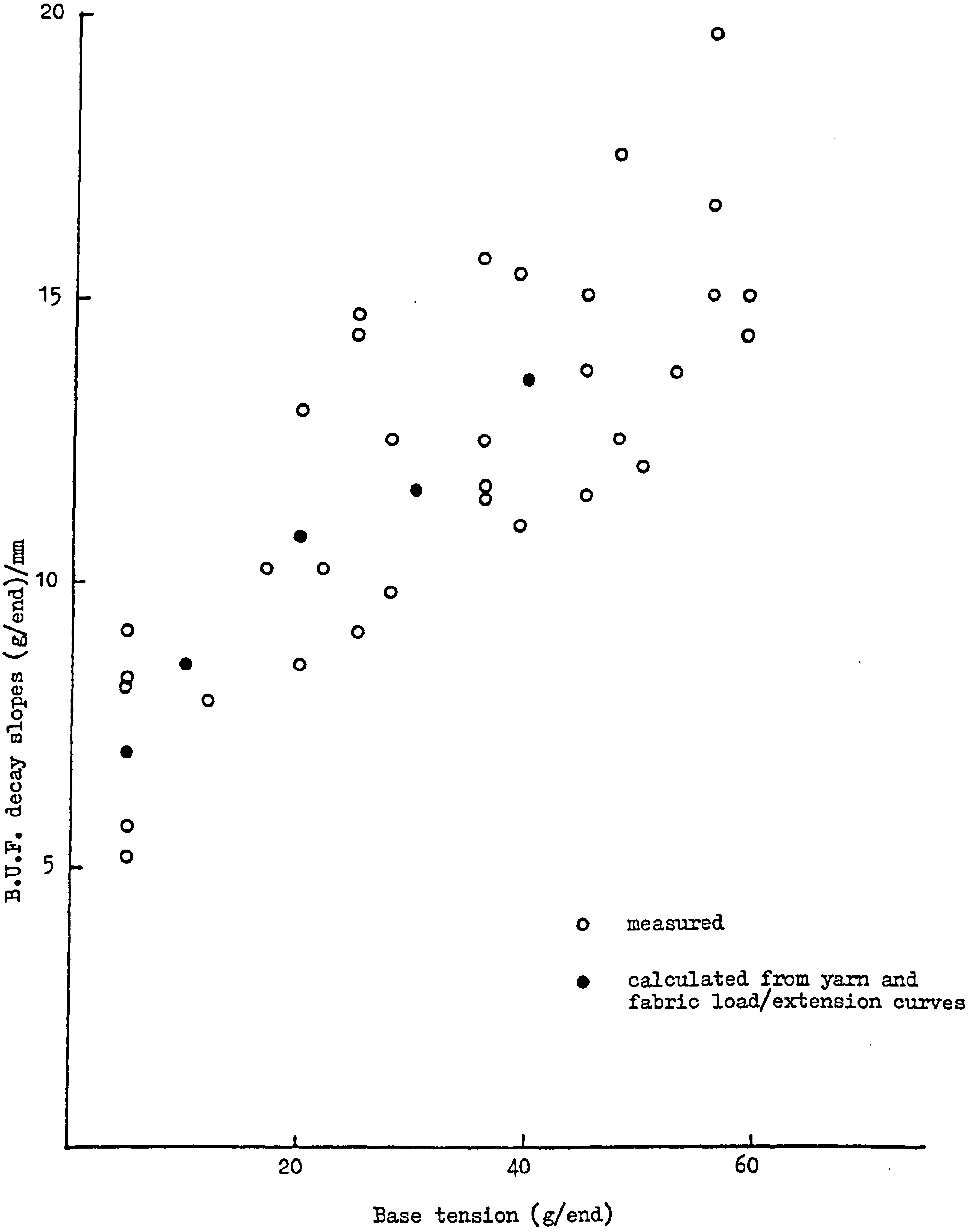


Figure 94. The B.U.F. decay slopes v. the base tension

than the true cloth or the warp. As a result, C.F.D. is very much increased for a given B.U.F. and the duration of contact of reed and cloth is also increased. As a result, the suspended back rail, which is disturbed by the beat-up, begins to move forward causing the fell to move away from the reed, so increasing the indicated C.F.D. as the reed has to chase it to produce the extra disturbance that develops the B.U.F. When the loom runs without weft and the successive forces decrease, the "chasing" effect also decreases so that in successive cycles the "extra" disturbance is not much reduced and the decay of the B.U.F. envelope is slow. So the graphs of C.F.D. in Chapter 7 show values of C.F.D. increased out of proportion to B.U.F. for late timings and balanced sheds.

Detailed variations in the shapes of these curves will also arise due to the relative timings of shedding and beat-up discussed in 10.2. A lot of attention has been paid to them during this work, much of it not finally reported, because it seems clear, after discussion, that C.F.D. as measured by any of the methods described is not so much a basic factor in weaving as a feature of the particular loom, and "perhaps" ? the elasticity of the warp. Consequently, in summarising the results, little attention will be given to C.F.D.

10.6 The independent variables

There are four settings on a loom that directly affect the process of fabric formation and that are usually variable under the control of the operator. They are take-up rate, weight applied to the warp through the back rail, shed timing and shed balance. In this work the take-up rate has not been varied, nor has the type of yarn. The others affect dependent variables that, in turn, affect weaving resistance. Thus basic warp tension, which is primarily a function of the applied weights, may be influenced by shedding because the warp let-off mechanism is influenced by the dynamic behaviour of the back rail. The tension during the beat-up period will certainly be influenced by shed timing. The tension ratio between the upper and lower sheets is primarily a function of shed geometry, but because that merely sets the difference in extended lengths of the two sheets, the ratio is influenced by the average level of tension. Movement of yarn against the friction of the healds may also make the ratio at the fell different from the ratio of measured tensions. The main influence on tension ratio, apart from shed geometry, is shed timing, because a closed shed is also a balanced one, unless an active unbalancing mechanism is introduced. Shed timing, controlling shed angle at beat-up, remains as an independent setting. The independent variables, then, influence warp tension at beat-up, tension ratio at beat-up and shed angle at beat-up.

10.7 Factors affecting weaving resistance

There seems no doubt that the major influence on weaving resistance, for given yarns and pickspacing, is the tension ratio. Comparison of Figs 61, 62 and 63 with Fig 73 summarizes the evidence. In order that the tension ratio should have its maximum value at the required time the shed timing must be fairly early. The general level of warp tension has some influence - a greater tension causing greater inter-yarn forces and thus increasing the weaving resistance, but the effect is relatively small except when the weaving resistance has already been reduced by choice of other settings, when reducing basic tension may give a further significant reduction in weaving resistance.

The effect of dividing total warp tension unequally between the two warp sheets reduces the pressure between warp and weft and thus reduces the friction forces. By doing so it makes it much easier to beat picks into the fabric. It also makes them more likely to slip back, but the nett effect, just as Ito predicted from his very elementary analysis, is still a reduction in weaving resistance. If slipping back could be prevented, an even greater reduction might be achieved. For example, on a gripper Axminster carpet loom in which a comb with hooked teeth is placed under the fell so that the teeth support the pile tufts, the teeth also prevent the weft slipping back. When a non-pile fabric was woven normally and then with the fabric supported clear of the teeth, the former gave a small but significant reduction in weaving resistance. Even without such an aid, weaving resistance in the present work was reduced by 70% to 80%.

As has been pointed out, cloth fell distance as measured is not of special significance. It consists of reed-fell "interference" as defined by Badve, which generates beat-up force and must be related to B.U.F. by yarn and fabric elastic properties, together with fell movement caused by the interaction of shedding, beat-up and dynamic properties of the warp and back rail systems that are not easy to predict. The practical effect of C.F.D. is that if it becomes too large, then it may cause such violent behaviour of a suspended back rail system as to cause mechanical breakage to occur or control of the let-off to be lost.

When the weave is 2/2 twill, unbalancing the shed again causes a considerable reduction in weaving resistance, although not so great as for plain weave. This is evidently because the effect of unbalance is diluted due to the fact that the pick is not trapped between slack threads on one side and tight on the other, each group compressing half the warp. Rather the shed will be approximately balanced around the pick, or there will be ¼ of the threads slack, ¼ tight and the other half, in the act of crossing, about average.

10.8 Practical implications

It is reasonable to ask what are the practical implications of these results. First, if a fabric is woven under minimum weaving resistance conditions, is it the same fabric as if it were woven under different settings? The evidence is that the pickspacing may be marginally greater than expected as compared with other settings; if so a marginal adjustment in take-up rate would correct the spacing while retaining most of the advantages regarding weaving resistance. At the same time, fabric cover would be better (for plain weave, at least) in the fabric woven at minimum resistance. There might, however, be a danger of "repping" faults if the loom were to be left standing with the shed open.[24]

One of the objectives in reducing weaving resistance would be to reduce the stress and abrasion on the yarns, and hence reduce end breakage. However, unbalancing the shed shares the tension very unevenly so that even if the B.U.F., and hence peak total warp tension, is much reduced, the tension in the tighter sheet might still show no significant reduction. In fact, a survey of the results suggests that there is no significant change in peak tension. Table 20 shows some examples involving both small increases and small decreases, but when it is remembered that these are measured at the back of the loom, and that they are taken from single traces, it is obvious that no clear conclusion can be drawn. What is clear, however, is that these peak values occur in each warp end only in alternate loom cycles, when the end is in the tighter shed, so that, from the point of view of fatigue and abrasion, there probably is an improvement.

TABLE 20

Peak warp tension at beat up (g/end)

Warp tension level / Extra rail position (in.)	Low (WT2)		Medium (WT 3.5)		High (WT 5)	
	Late timing (L)	Early timing (M+2)	Late timing (L)	Early timing (M+2)	Late timing (L)	Early timing (M+2)
	1.1	[illegible]	1.5	1.7	1.6g/TEX	1.8g/Te
0 (N)	67	81	88	99	92	106
+ 1	78	95	92	99	95	117
+ 2	78	99	1.7 99	2.0 120	[illegible] 106	120 2.0g/T
+ 3	71	99	78	106	92	117
+ 4	71	88	74	106	88	124
+ 5	67	-	71 1.20	124 2.1.	88 [illegible]	131 2.2

It has been seen that the reduction in weaving resistance is achieved by a reduction in the effects of friction and appears to be accompanied by picks slipping out of the fabric. Apart from holding them in with a system of hooks, as mentioned in relation to carpet weaving, or by some device such as an auxiliary reed, it might be possible to arrange a mechanism to unbalance the shed when beating-in while balancing it as the reed withdraws. Systems of cam operated rollers or lease rods have often been suggested in articles or patents, but whether there was any attempt to synchronize them with the beat-up is not clear; as full beat-up does not often coincide with front centre, that might be difficult.

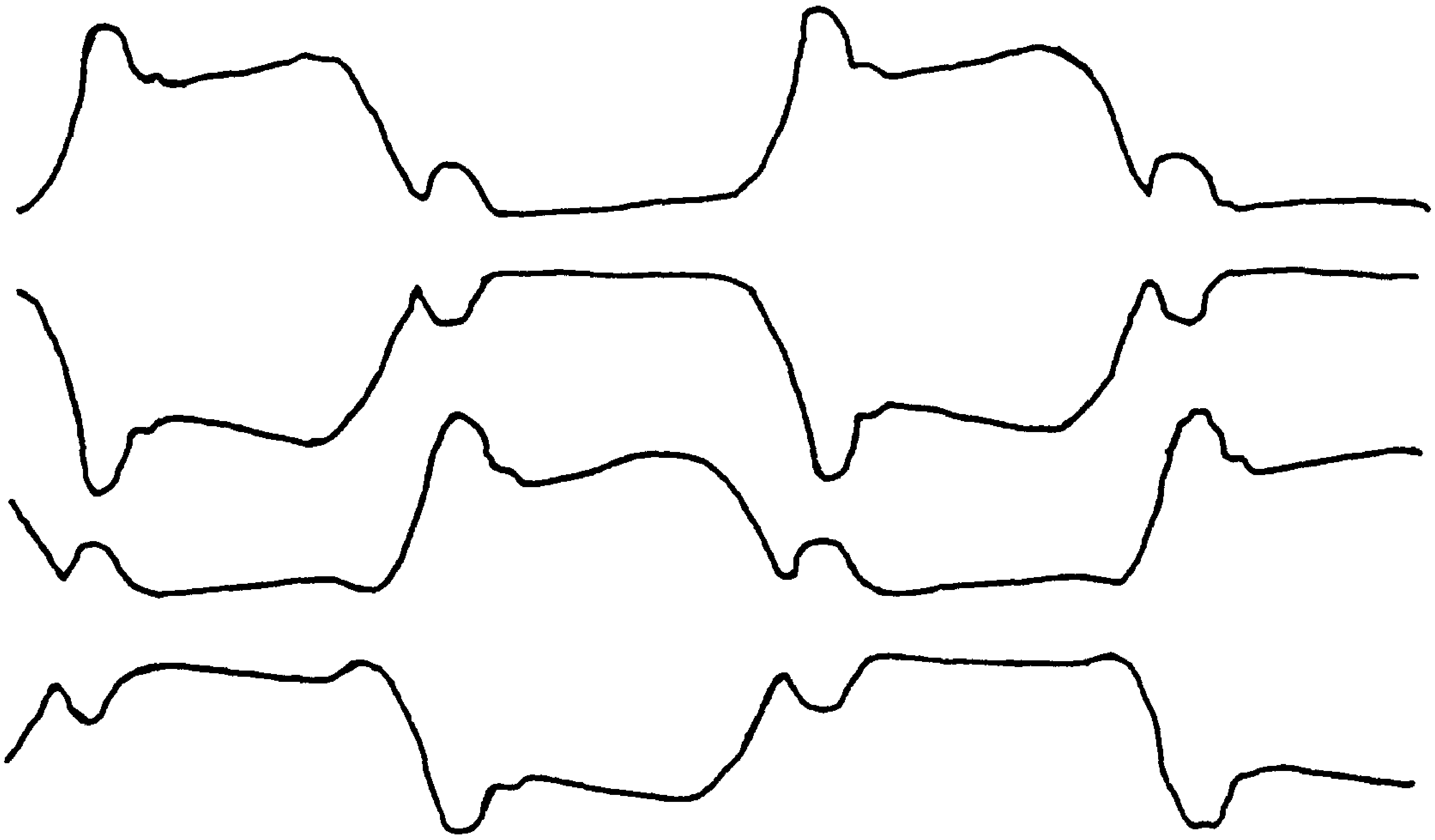
One of the novel methods of beating-up on a loom that has received publicity from time to time is not to use a reed, but to increase the crossed-shed angle until it is sufficient to squeeze the pick forward into the fabric. It is interesting that the minimum resistance settings used here come very close to that situation and it would be of interest, and should form part of future research to see if they would permit a fabric a little more open than the present one to be produced.

One of the major pre-occupations of weavers seems to be achieving maximum possible sett. Much of the theoretical work on fabrics has been devoted to predicting these limits and much of the practical work in trying to achieve them. It seemed reasonable, therefore, to include in this work an account of what could be achieved using the minimum resistance settings in this loom. If the loom was capable of weaving the standard fabric (43 p.p.i.) under the worst settings with a B.U.F. of 159 gf and a C.F.D. of 17 mm, then by changing to the best settings which, for the same fabric required a B.U.F. of only 24 gf/end with a C.F.D. of 2.5 mm, a considerable increase in sett should be possible. The various formulae (Section 3.7) had suggested a maximum of 44 to 52 p.p.i. while Badve with very similar yarns and warp sett had found 48 to be the maximum.

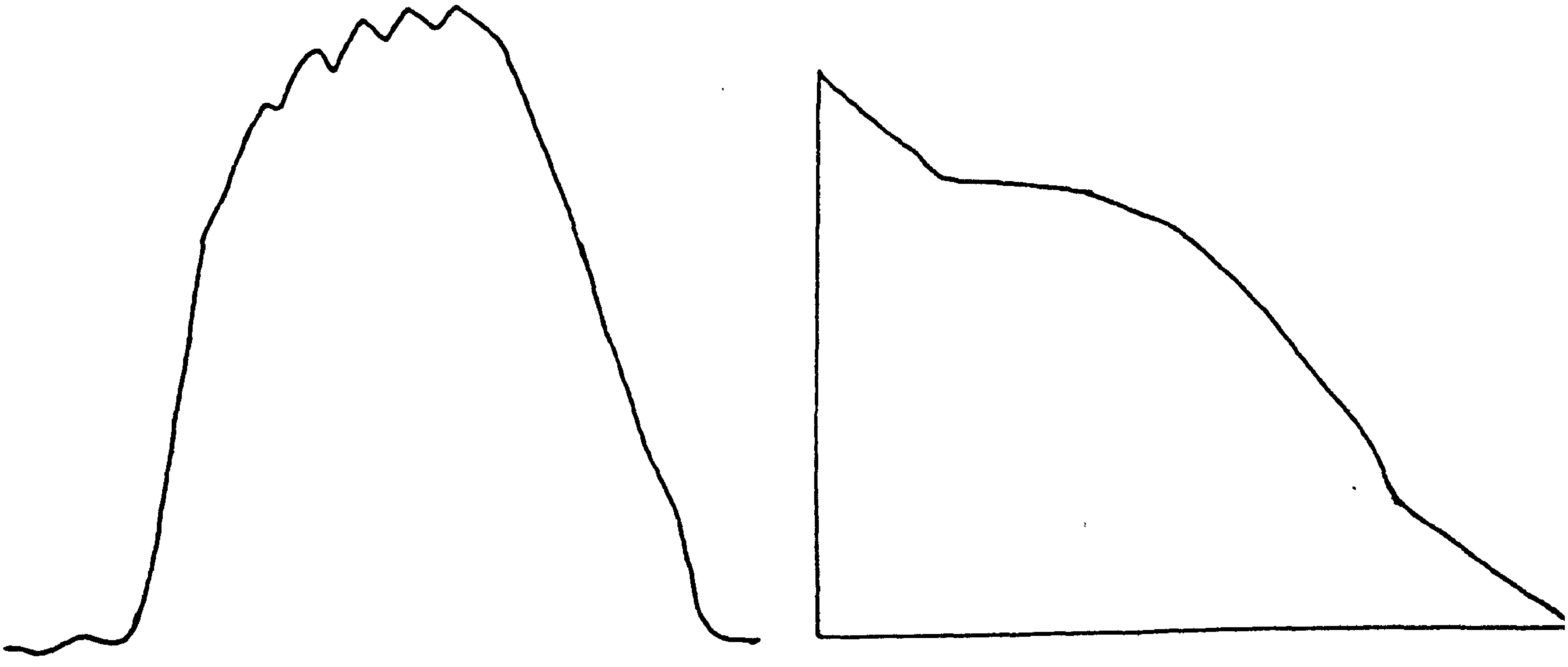
NOT

?

There was no difficulty in increasing the sett to 58. Beyond this the increase in C.F.D. was causing problems and it became necessary to increase warp tension a little, so increasing weaving resistance but, presumably by raising elastic moduli, decreasing C.F.D. Eventually stable weaving at a nominal 64 p.p.i. was achieved. The cloth fell distance was 21½ mm for 61 p.p.i. and B.U.F. 140 gf/end. Outlines of the traces for this setting are shown in Fig 95. The serrated top of the single beat-up peak is possibly related to the gear tooth frequency of the driving gear on the crankshaft. If it is, it suggests that the loom speed had dropped to about ¼ of its normal average value. That may, in fact, have happened because when the nominal sett was increased to 64 p.p.i. the resistance stopped the loom. It was then found that the shed timing had slipped a little and when that had been slightly



Warp tension traces



Single B.U.F. trace

B.U.F. decay curve

Figure 95. Warp tension traces, single B.U.F. and B.U.F. decay curve of 61 p.p.i. plain weave

adjusted, it was possible to weave at 64 p.p.i. The maximum B.U.F. was then 166 gf/end. The very dense fabric produced showed no change in pickspacing when it was removed from the loom, and only 2% contraction when wetted. Samples of the two fabrics are shown as Fig 96.

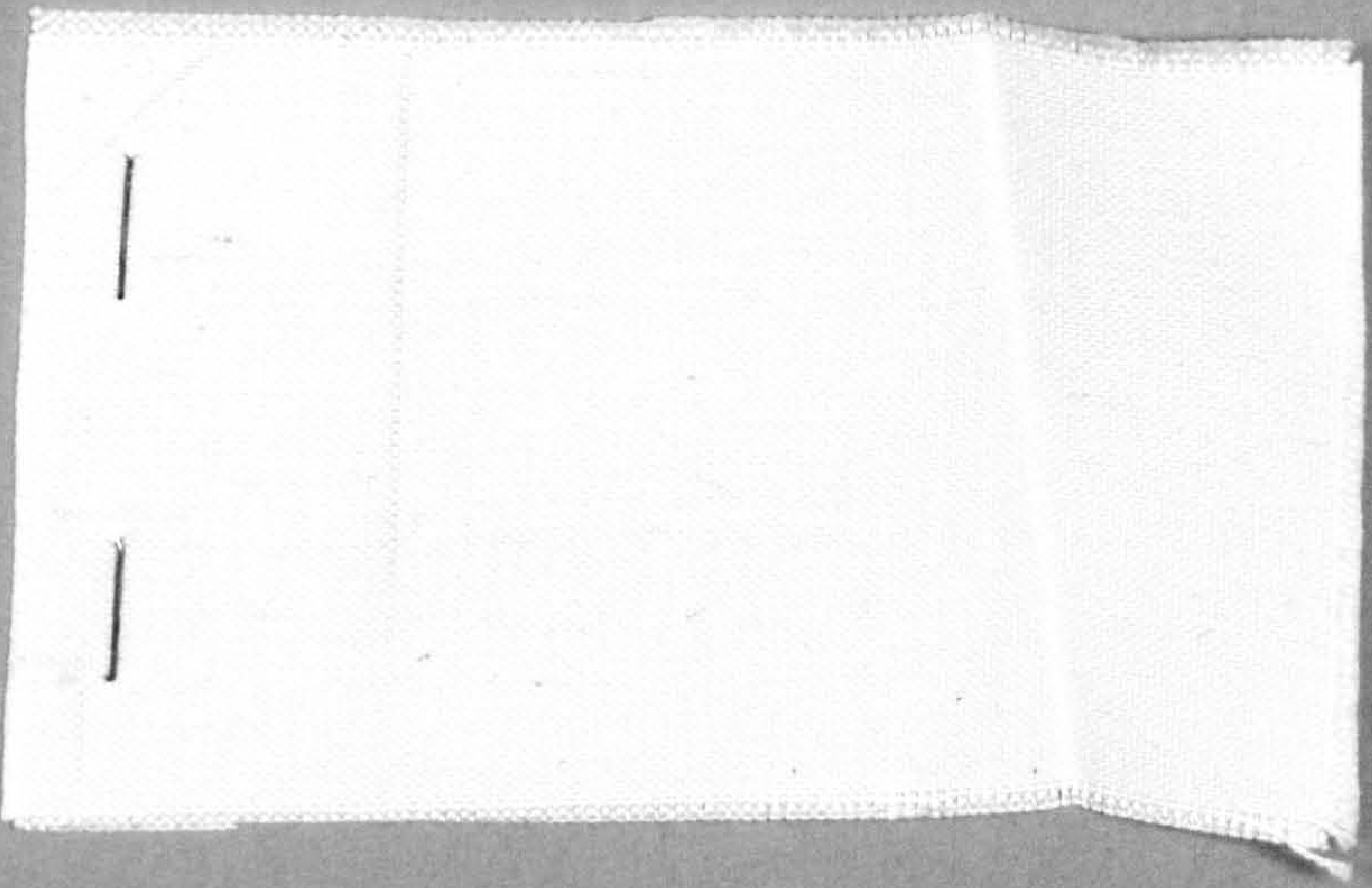
By choosing the best conditions for 2/2 twill, it was possible to increase the sett to 98 p.p.i.

Instrumentation

The instrumentation has been fully discussed in the early chapters. It is, however, worth mentioning that both the beat-up force gauges and the Wetzel type tension gauges have proved extremely reliable. It has, for example, been possible to return to the loom after an absence of three months and find that, 10 minutes after switching on, the performance and calibration have not been detectably different from the previous occasion.

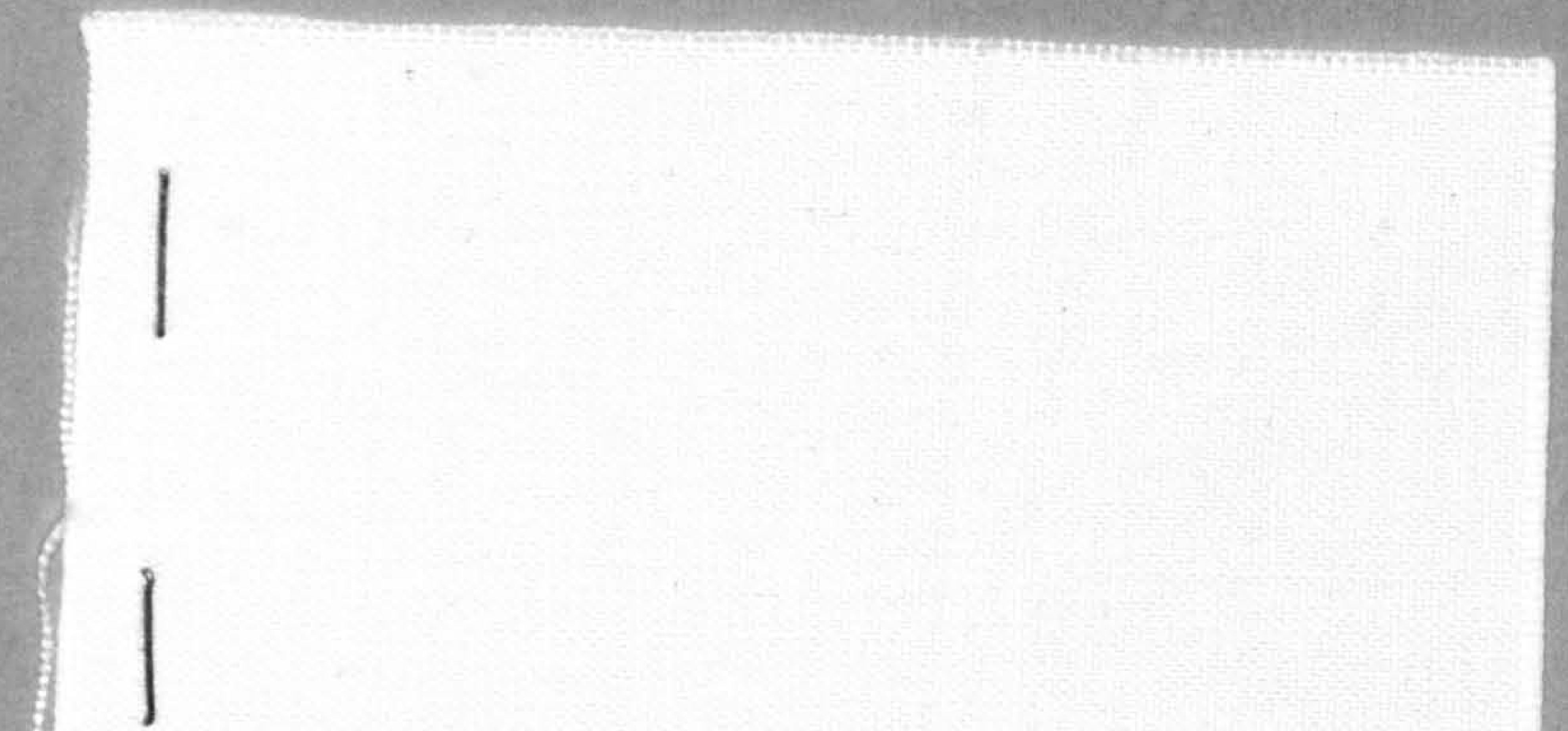
10.9 Conclusion

A method of measuring beat-up force on a running loom, partially developed by Yehia[14] and Leung[15] following pioneering work by Badve[13] has been refined and applied to study the effects of loom settings on weaving resistance. The method uses strain-gauged cantilevers to measure the rotation of the upper and lower reed-baulks and combines the signals from the two cantilevers in a proportion, determined by experiment, that makes the system insensitive to inertia effects arising from the normal oscillation of the sley. The method has proved very reliable and appears to have been very successful on the Crompton and Knowles W-3 loom to which it was applied. It might be less successful on a loom with a different sley construction or one having badly worn bearings. The



48x61

61 P.P.I.



48x64

64 P.P.I.

Figure 96. High sett fabrics

system has been used together with Wetzel-type[19] warp tension gauges, also based on strain-gauges to measure the beat-up force and warp tensions during the weaving of plain weave at a nominal 43 p.p.i. and 2/2 twill at 75 p.p.i. using 59 tex (2/20s) cotton-vincel warp and 53.4 tex (2/22s) cotton weft. Experiments covered ranges of warp tension from 5 to 56 gf/end, shed unbalance giving ratios of tighter to slacker sheet tensions ranging from 1.2 to 10 and shed timings that had the shed crossing at front centre or top centre or any of five settings inbetween. The results show conclusively that, for plain weave, weaving resistance reduces dramatically as the shed is unbalanced, but that, as might be expected, advantage can only be taken of that effect when beat-up occurs while the shed is open and therefore unbalanced; that, in turn, requires that the shed be timed early, though the precise timing for minimum resistance might depend on the type of loom and perhaps on factors such as warp elasticity. For 2/2 twill also the unbalanced shed gives lower resistance than the balanced one, though the effect is not so great because, with the passive methods of unbalancing considered here that rely only on changing shed geometry, it is not possible, with a weave repeating over four ends, to obtain such a high degree of unbalance. The most effective shed timing for the 2/2 twill was a rather late one.

56 g/e
[illegible] on [illegible] 12/82
∴ [illegible] [illegible] 6
[illegible] [illegible]

The reduction of weaving resistance by unbalancing the shed will not necessarily always reduce the maximum peak tension on the warp yarn; and if it does, the effect will probably be small, but the frequency of such peaks will be halved. It will, however, reduce the forces on the loom sley to around 20% of what they might be and it has been shown that it makes it possible to weave more highly sett fabrics.

When settings close to those that give minimum weaving resistance have been adopted, a further considerable reduction may be achieved by reducing the tension applied to the warp. The extent to which this can be done may however be limited, because reducing the working tension reduces yarn elastic modulus and causes the fell displacement needed to develop a given force to increase, which may lead to violent movement of the back rail and associated components.

The fell displacement by the reed is directly related to the beat-up force; but on it there is superimposed a further displacement caused by the movement of other parts of the loom. The latter may be greater than the former. When attempting to measure them it is difficult to distinguish between the two. A great deal of time in this work and considerable space in the thesis have been spent on investigating cloth fell distance. But the conclusion reached is that it is of no importance in relation to the general principles of cloth formation, being too much influenced by the peculiarities of individual looms. If the performance of a particular loom is of interest then it must be considered, and if, as in this work, the performance of instrumentation is being assessed it also has to be considered; but generally it should be disregarded unless it is so large as to cause problems in weaving.

Obviously there is much more work to be done using this instrumentation. Other weaves, other yarns and other setts should be used and the performance of active methods of unbalancing the shed investigated.

It may be argued that the conclusions reached in this work are not novel and that weaving shed managers and loom tuners are aware that the best settings are similar to those identified here. That is, up to a point, true for plain weave. It is less certain that the different settings required for the 2/2 twill would be known. What this work has done, however, is to explore a wider range of settings than would normally be attempted, to provide quantitative data about the kind and degree of advantage that can be gained, and to explain how it is gained. Moreover, it has provided the means and techniques that can be used to investigate a much wider range of situations.

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