FACTORS CONTRIBUTING TO UNSTEADINESS IN 16MM FILMS

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SUMMARY.

When reduction prints from 35mm negatives are made onto 16mm film, screen picture unsteadiness may be caused at any of the following points: (1) in the 35mm negative, (2) in the 35mm intermittent mechanism of the printer, (3) in the 16mm intermittent mechanism of the printer, (4) in the 16mm film perforations and (5) in the 16mm projector mechanism. The accuracy to which these various mechanisms and films must be made is discussed. An outline of the basic principles of film perforating is given and the standards relating to perforating tolerances are considered. An important tolerance which has so far been omitted from the specifications for 16mm sound film is described. A practical specification to cover this point is suggested. The importance of standardisation in 16mm projector intermittent mechanisms is discussed and the effect of various mechanisms on the resultant screen picture is shown.

INTRODUCTION.

In recent years the projection of 16mm sound films has extended so rapidly that, inevitably, some people have come to expect the picture and sound quality produced on these films to match that of standard 35mm work. This is particularly true of reduction prints made from 35mm original feature films and also of commercially made advertising and industrial pictures originally filmed in the 16mm format. The picture quality generally acceptable in 16mm projection leaves much to be desired when magnified to the greater screen sizes encountered when this gauge is used in theatres or lecture halls. Picture steadiness is, of course, more noticeable to observers following, for example, the operation of intricate mechanisms, outline drawings used in some industrial films and the many types of diagram films used for visual education. It would seem likely that, with the addition of sound to 16mm films and the improvements made in laboratory techniques over the intervening years, the opinion has gradually developed that 16mm films should be capable of screen quality equal to that of 35mm films. It is hoped that this paper will show this to be fundamentally impossible, and also outline precautions which should be taken to eliminate the considerable amount of picture unsteadiness which can exist particularly in reduction prints but also in any film originated in the 16mm gauge.

GENERAL CONSIDERATIONS.

Assuming that a 35mm picture is to be reduced onto 16mm film by means of the conventional intermittent or "step" optical reduction printing machine, unsteadiness may be caused at any of the following points:-

(a) In the 35mm picture negative.

(b) In the 35mm intermittent mechanism of the printer.

(c) In the 16mm intermittent mechanism of the printer.

(d) In the 16mm film perforations.

(e) In the 16mm projection mechanism.

It is first necessary to decide upon the magnitude of screen picture unsteadiness which may be tolerated. In this connection we will consider the following tolerances for 35mm standard format film projection:-

(1) That the unsteadiness of the centre of the picture, measured in the projector gate, shall not exceed plus or minus 0.0005-ins., that is, a total jump of 0.001-in.

(2) That the unsteadiness of the corners of the picture, measured in the projector gate, shall not exceed plus or minus 0.001-in., that is, a total jump of 0.002-ins.

Since the purpose at this moment is to establish a "yard stick" by which to compare 35mm and 16mm projection steadiness, the following considerations remain true when tolerances different to those quoted above are applied. The corners of the picture have been permitted a tolerance twice that of the centre of the picture because it is believed that movement away from the centre of interest is not so apparent to the eye.

Assuming that such conditions exist in the average theatre, the actual unsteadiness as measured on the screen may be readily calculated. Given a standard format picture a relatively modest screen size of 24-ft by 18-ft at a throw of 146-ft will be achieved with a 5-ins projection lens. Thus the magnification is approximately 350 times. Since, for the purpose of this illustration, the centre of the picture (as measured in the projector gate) is permitted a movement of 0.001-in this will appear as a movement of 0.350-ins on the screen. If the seating in the theatre is then arranged in accordance with the recommendations made during 1942 by the Projection Practice Committee of the Society of Motion Picture Engineers (and the bulk of theatres were built before that time!) the most distant seat should be six times the screen width, or 144-ft from the screen, and the nearest seat should be 0.87 times the screen width or 21-ft from the screen. The position of the average audince should therefore be 81-ft from the screen.

Now assume it is possible to obtain the same degree of accuracy in positioning a 16mm film in the gate of a good quality 16mm projector. This being so it should be possible to enlarge the picture to the same degree without experiencing any loss of photographic quality. A magnification of 350 times will produce a screen picture of 11-ft by 8-ft 3-ins at a throw of 73-ft with a 2½-ins lens. Arranging the seating as before, the most distant seat would be 66-ft from the screen, the nearest 9½-ft, and the average seat 37½-ft from the screen. If unsteadiness due to a film movement of 0.001-in exists in both projector gates and, in each case it is magnified 350 times, the average 16mm viewer must inevitably experience greater picture unsteadiness than the average 35mm viewer.

The arrangement of the seating is, of course, only dependent upon the picture size, regardless of the film size or projection apparatus, and is so arranged to ensure that the picture will subtend the same angle to the average viewer in all cases. A moment's consideration will show that, whilst the picture size has been reduced in the case of the 16mm film, the amount of picture unsteadiness has remained constant - namely 0.001-in at a magnification of 350 times. If, therefore, picture unsteadiness is expressed as a percentage of the total picture height it is seen that, in the case of the 35mm film this amounts to 0.162% whereas, in the case of 16mm film it increases to 0.353%.

If, therefore, it were possible to produce 16mm prints with a final mechanical accuracy equal to that recommended for 35mm release prints, and also to obtain a 16mm projector as accurate as a 35mm machine, the resultant screen picture (viewed from the equivalent average distance) would show greater unsteadiness than the 35mm picture viewed under similar circumstances. The unsteadiness of the 16mm picture would exceed that of the 35mm picture as 353 exceeds 162, that is, it would be 2.1 times greater. This amount is, of course, the ratio between the height of a 35mm projector aperture and that of a 16mm projector aperture. On first consideration it may be thought possible to overcome this difference by placing the audience at a greater distance from the screen. Quite apart from reducing the apparent size of the picture, such a move would mean placing the audience 2.1 times further from the screen - that is, in the example given, extending the distance between the screen and the closest observer to 40-ft.

Clearly the foregoing suggestion is quite impracticable and, as a basis of consideration, a screen movement of 0.350-ins at a magnification of 350 times must be accepted, assuming no losses of steadiness in the projector mechanism. In other words, we must aim to print successive pictures onto the 16mm film within a total tolerance of 0.001-in, or plus and minus 0.0005-ins.

For the benefit of those who may not be familiar with optical reduction printing, a typical machine is seen in Figure 1. In this figure, light from the source "L" is focused by means of the condenser lens "C" onto the objective lens "O". An image of the picture on the 35mm film "F" is reduced and focused onto the 16mm film "G" by means of the objective lens "O". Shutter "S" is rotated to interrupt the light beam whilst the two films are moved forward by an amount equal to one picture. In this outline drawing the films are moved by simple claw mechanisms shown at "J" and "K". As in projector mechanisms, it is necessary to provide the usual feed sprockets "M", the hold-back sprockets "N", the supply spools "P" and the take-up spools "Q". Due to variations in overall density between successive scenesin some 35mm negatives, it is necessary to provide means of **rapidly** adjusting the intensity of the printing light "L", but this and similar refinements are not relevant to the present considerations.

It is now most convenient to work back from the 16mm film, through the printing mechanism, to the 35mm film and shown the additive causes of unsteadiness in the 16mm print.

16MM FILM PERFORATING AND STANDARD RECOMMENDATIONS.

There has been as much inventive genius displayed in the design of film perforating machinery as in any branch of cinematography but, for the purpose of this paper, it is only necessary to become familiar with the basic principles of such machinery. Figure 2 shows in outline the cycle of operations and the various parts of the "head" of a typical perforating machine. At "A" are seen the essential parts of the mechanism. The pilot pins are used to accurately locate the film before and during the perforating operation. These pins are tapered over the region near their extremities to permit easy entry into film perforations which may not be accurately positioned beneath them. The punch legs are usually cut from separate plates, but are "ganged" together for final milling and grinding. These legs are shorter than the pilot pins and, being moved at the same time and by the same mechanism as the pilot pins, do not enter the film until it has been accurately placed. The shuttle is best described by likening it to the "under-foot" of a sewing machine since it is used to engage with the newly made perforations and to advance the film in readiness for the next perforating operation.

The sequence of operations is therefore as follows. Firstly the pilot pins enter the perforations, as seen at (b), Figure 2, and at the same time the shuttle commences to move to the right. The pilot pins then continue their downward motion and the punches make three perforations in the film whilst the shuttle comes to the end of its traverse. This condition is seen at (c), Figure 2. The punches and pilot pins then move upwards, clear of the film, and the shuttle pins move into the perforations as shown at (d). The shuttle then moves to the left, carrying the film with it as shown at (e), by an amount sufficient to bring the last two perforations immediately below the pilot pins. The shuttle then moves downwards and clear of the film, as shown at (f) and the cycle of operations is repeated. These diagrams show the operation of a typical perforating machine, and, whilst all machines are similar in principle, some perforators make more or less than three perforations in one operation.

From the plan view of the perforating head shown at "G" the film is seen to be guided in the perforating machine by passing it through a channel formed by two pairs of "guide rails", one pair on each side of the perforating head. The complete guide rail assemblies are mounted in sliding beds, to permit their easy removal when the machine is being overhauled, and are fitted with fine screw thread adjustments capable of resetting the rails parallel to the main body of the punches. The guide rails at the rear of the perforating head are termed the "fixed guide rails" and are held rigidly in their beds, but the rails in front of the perforating head, termed the "floating guide rails", are spring loaded and move sufficiently to accommodate all the variations of film width likely to be encountered and also to accommodate film which may be curved.

From these considerations it will be apparent that two major errors may occur in the perforating operation. Firstly it must be remembered that we are considering the perforation of 16mm film in machines which make three perforations along the length of the film at one blow of the punch, as shown at "C", Figure 2. The two spaces between these perforations are therefore formed automatically and depend upon the construction of the punches. However, the third space is made by drawing the film forward sufficiently to place the last perforation made directly beneath the right-hand pilot pin, as seen at "F", Figure 2. If therefore, for any reason, the film is not moved forward by the correct amount this third space will not be equal in length to the other two spaces. Secondly, the path along which the film travels may not be precisely parallel to the main body of the punches.

The first mentioned defect is known as "uniformity error" and tends to isolate the perforations into groups of three. This may be caused by either of two errors in adjustment, or a combination of both errors. Firstly, the mechanism controlling the stroke of the shuttle, or underfoot, is mounted in such a manner that its position relevant to the punches may be varied and, secondly, the distance between the pilot pins and the punch legs may be incorrect. The second type of defect is known as "squareness error" and this is illustrated in Figure 3. Squareness error may occur if the channel formed by the film guide rails is not parallel with the perforating head since, under these conditions, the film must travel through the machine at an angle to the punches.

Any machine designed to perforate film will only repeat a fixed set of conditions for a relatively short period and will then require adjustment to take up wear and movement due to the continual vibration, etc. The type of machine described has many points in its favour, not the least of which are the adjustments provided to correct "uniformity" and "squareness" errors.

It is, however, necessary to provide tolerances between which the various dimensions of the perforated film may fall, but which will be sufficiently close to the chosen standard dimensions to maintain a high quality in the final screen picture.

Such tolerances are laid down by national standardising bodies, and a typical series relating to 16mm film are shown in Figure 4. The diagram on the left of this figure shows the working tolerances permitted in 16mm silent, or double perforated film, whilst those on the right of the figure show the tolerances permitted in 16mm sound, or single perforated film. It is important to note that some of the dimensions illustrated are different to those currently defined in standard specifications - for example, dimension "F" is a measurement between the centres of perforations, whereas standardising organisations usually employ dimension "F" to indicate a measurement between the inner faces of two rows of perforations. Similarly, it is important to restrict the use of these dimensions merely to illustrate this paper - any reader wishing to consider dimensional standards in general should refer to the most recent publication by appropriate standardising body; i.e. the British Standards Institution, the American Standards Association, the International Standards Organisation, etc.

In considering the effect these tolerances have upon the steadiness of the screen picture only two dimensions need to be discussed in detail. These are dimension "B" and dimension "G". Dimension "B" is specified as 0.3000-in and is permitted a tolerance of plus or minus 0.0005-in. This dimension, which appears in both diagrams, is referred to as "film pitch" and the tolerances place a limit upon the amount of "uniformity error" which may be present. It is permissible, for example, for the pitch between any adjacent pair of perforations to fall to 0.2995-in, whilst that between the next pair may rise to 0.3005-in, thus giving a total uniformity error between successive frames of 0.001-in.

Dimension "G" is obtained by measuring the distance between two lines at right angles to the film edges and passing through the centres of two perforations, one on each side of the 16mm silent film stock, and therefore only appears in the left-hand diagram. It is recommended that this dimension should not exceed 0.001-in. However, this dimension has not been defined with any great accuracy, since it may be taken to apply to the difference between perforations which are misplaced in a purely longitudinal direction, as shown at the left of Figure 3, or equally well to perforation centres which have been misplaced by "squareness error" as seen at the right of Figure 3.

However, the construction of a film perforating punch is such that the pairs of perforations "A-A" and "B-B", Figure 3, are each made by punch legs cut in a single piece of flat metal and are bolted together to form a complete punch unit. It is in this "assembled" state that the punch legs are milled and ground. It is therefore impossible for the punches to be misplaced and, at the same time, to remain parallel to the film edges as suggested.

It must therefore be assumed that dimension "G" is intended to limit the amount of "squareness error" which may be tolerated. This belief is reinforced by the manner in which such a dimension "G" is illustrated in B.S.677: Part 2: 1958 where on Page 13, the perforations are shown at an angle to the film edge and as they would appear if "squareness error" were present. Such an assumption is very reasonable since squareness error is known to have a considerable effect upon picture steadiness and also since no other measure of squareness error is given.

This being so it is very important to note that no limit on "squareness error" has been specified in any standard recommendations for perforating 16mm sound film. It is, of course, of even greater importance to establish a similar limitation on the "squareness error" permissible when perforating 16mm sound film since it is moved through the various printer and projector gates by an unbalanced force only applied to one side of the film.

It thus becomes necessary to decide upon a method of measuring squareness error which does not depend upon comparisons made between two sets of perforations and which will, therefore, apply equally well to sound or silent film stock.

Figure 5 shows a section of film perforated with considerable "squareness error" and illustrates one method whereby this requirement may be fulfilled. Line "XX" divides the film longitudinally into two sections of equal width, "AB" is a line at right-angles to the film edge, passing through the centre of perforation "P" at "E" and cutting "XX" at "B". "DC" is also a line at right-angles to the film edge, passing through the centre of perforation "Q" at "F" and cutting "XX" at "C". The important dimension "G" is therefore represented by "BC" which is limited to 0.001-in. A line from "E" to "F" is at right-angles to the main body of the film punch and intersects "XX" at point "O".

"OC" will therefore be limited to $\frac{BC}{2}$, or 0.0005-in. If the film was free from "squareness error" "CF" would be at right-angles to the film edge and also at right-angles to a line "FR" which would pass through the centre of the lower right-hand perforation at "R". However, since "CF" has moved to position "OF", this will cause line "FR" to move to position "FS". It can be easily shown that a movement of 0.0005-in. from "C" to "O" will cause a corresponding movement of 0.0006-in. from "R" to "S".

If perforation "Q" is so placed that the distance from "F" to "D" is according to the recommended standard, namely 0.072-in., as indicated at "E" in Figure 6, and is the second or middle perforation of the three made at one blow of the punch then the remaining two perforations, shown at "M" and "N" may each move 0.0006-in. However, "M" will move towards the film edge and "N" will move away from the film edge when squareness errors are present.

Thus, for the maximum permissible squareness error, the three dimensions corresponding to the three perforations made at one operation, "M", "Q", and "N", each taken from the film edge to the centre of the perforation, will be as follows:- "AB" will be 0.0714-in., "FD" will be 0.0720-in and "CH" will be 0.0726-in.

In other words, this method transposes the recommended dimension "G" illustrated with double perforated silent film into a dimension "FD", Figure 6, and suitable for limiting the squareness error of perforations made in single sided material as used with sound film. This new proposed dimension "FD" has the following tolerances:-
"FD" = 0.0720-in. plus or minus 0.0006-in.

It will be realised that dimension "FD" is also the dimension shown at "E" in Figure 6, and which indicates the distance from the centre of the perforation to the film edge; assuming all the perforations to be parallel to that edge, dimension "E" is permitted a working tolerance of plus or minus 0.0020-in. One may therefore question the value of this new dimension since it appears to be superimposed upon the existing tolerances. However, one may be assured that satisfactory gauging methods are available which quickly isolate these various tolerances and so can yield a direct measure of perforating "squareness" taken from the film edge and in the manner suggested.

The most important point to establish is that perforations may enjoy the existing tolerances on dimension "E" when they all remain parallel to the film edge, but a series of perforations should also be measured along the film length - and variations in dimension "E" from one perforation to the next will then indicate the degree of "squareness error" which is present - this variation should not exceed plus or minus 0.0006-in. The main purpose of this paper is to propose that the tolerances provided in standard specifications for 16mm single perforated sound film - and related to a dimension generally designated as dimension "E" - should be amplified to read as follows:-

> "Dimension "E" is provided to measure two characteristics: (a) the average margin between the perforations and the film edge and, (b) the squareness or degree of parallelism between perforations and the film edge. When considering "average margin" dimension "E" is permitted an overall tolerance of plus or minus 0.002-in. whereas, when considering squareness or parallelism, variations throughout a series of measurements taken between at least four consecutive perforations and the film edge must be considered - and such readings must remain within plus or minus 0.0006-in. of each other regardless of their average magnitude."

We can now state the two important tolerances which effect picture steadiness in 16mm sound films. These are seen in Figure 6. That which limits the permissible "uniformity error" is shown at "J" as being 0.3000-in. plus or minus 0.0005-in., and that which limits the permissible "squareness error" is shown at "FD" as being 0.0720-in., plus or minus 0.0006-in.

It is now useful to consider the design of the intermittent mechanisms used in optical reduction printing machines which must, of course, be capable of handling films containing the maximum permissible errors in "uniformity" and "squareness".

The 16mm intermittent mechanism of the optical reduction printer.

The intermittent mechanisms used in Optical Reduction Printing machines may be divided into three main groups. Firstly, those which employ a Maltese Cross or similar mechanism to rotate a sprocket wheel intermittently. Secondly, those which employ a claw mechanism in conjunction with a pressure plate and, thirdly, those which employ a claw mechanism and also a system of pilot pin registration to position the film accurately during the exposure.

Although the last mentioned type is not widely used it is of particular interest since it is most likely to maintain a high degree of steadiness in those films which are perforated within close tolerances. It also provides an immaculate demonstration of the important relationship between film perforations and intermittent mechanisms. Because it is only possible to consider one type of mechanism in the present paper, the construction and operation of this particular machine will now be described in detail.

The general arrangement of the mechanism is shown in Figure 7. The main aperture plate supports two pilot pins, numbered 1 and 5, one above and the other below the exposing aperture. These pilot pins are rigidly fixed to the main plate and do not move. The claw pins, numbered 3 and 4, oscillate in a purely vertical direction as indicated by the arrows. The film is guided through a gate formed by two highly polished metal plates which oscillate in a purely horizontal direction.

The action of the mechanism is therefore as follows:-

The film gate, as shown at "A", Figure 7, has just moved to the left, and the film is located upon the pilot pins. The gate then continues to move to the left as seen at "B", until the back plate comes into contact with the shoulders of the aperture plate. In this manner the film is clamped rigidly in the gate channel. At the same time the claw pins commence to move in a downward direction. It is during this part of the cycle that the film is exposed. The claw pins complete their downward movement and the gate then moves to the right, as seen at "C", so transferring the film from the pilot pins on to the claw pins. It is important to note that the nose of the pilot pins projects sufficiently to overlap the nose of the claw pins and, because of this, the film is always under control by one or both sets of pins. The claw pins now move in an upward direction, as seen at "D", and so advance the film by a distance equal to one pitch. The gate then moves to the left, as seen at "E", and transfers the film from the claw pins on to the pilot pins. The cycle is then repeated.

The pilot pins are separated by a distance equal to 5 perforation intervals, or 4 pictures. It is because of this control over a considerable length of film, and also due to the accuracy with which the pilot pins fit the perforations, that it is possible to dispense with the conventional edge guides in the film gate. The film is therefore freely suspended on the pilot or claw pins except for that part of the cycle during which the gate is closed and the film comes under pressure from the aperture plate. It should be noted that the pilot pins are of different sizes. Pin No. 1 is known as the full-fitting pilot, while pin No. 5 is the tolerance pilot and is suitably reduced in thickness to accommodate the permissible tolerances on a section of film four frames in length.

Before considering the degree of unsteadiness which may be produced by such a mechanism it is necessary to establish the maximum dimensions and correct positions of the pilot and claw pins. The centre diagram in Figure 8 shows a plan view of these pins and their relationship with a theoretically perfect piece of film. The shaded area marked "1" indicates the full-fitting pilot pin and is surrounded by a framework representing a perfectly formed perforation. However, the recommended perforation width (that is the larger dimension, measured across the film) is 0.0720-in., plus or minus 0.0004-in. The maximum width this pin may attain is therefore limited to 0.0716-in. Similarly, the height of the perforation is limited to 0.0500-in., plus or minus 0.0004-in. and, therefore, the height of the pilot pin must not exceed 0.0496-in.

Let us now assume that the upper face of this pilot pin, shown at "A", Figure 8, shall be the base line in setting out the position and size of the remaining pins. The second and third shaded areas will then represent the position of the claw pins when at the top of their stroke. Similarly, the third and fourth shaded areas will represent the position of the claw pins when at the bottom of their stroke.

Line "B" represents a distance equal to one pitch, and is taken from the perforation in engagement with the full-fitting pilot pin to the bottom of the second perforation, as indicated by line "C". However, we know that, in order to permit Uniformity and other variations in the film, perforating recommendations permit line "C" to move towards line "A" by 0.0005-in. This condition is shown in the right-hand diagram. We have also just recognised a further tolerance, namely on the perforation or "hole size". This tolerance permits line "C" to move a further 0.0004-in. towards line "A". Thus a pin in position "2" must be capable of accepting a film in which the lower edge of the perforation, as shown at "C", may be 0.0009-in. nearer to the base line "A" than would obtain in the case of a theoratically perfect piece of film.

It must be remembered that the recommendations also permit a positive tolerance, that is to say, the dimensions may also be larger than the standard. This condition is shown in the left-hand diagram. The upper edge of the pin in position "2" must therefore be 0.0009-in. further away from the base line "A" than would be necessary to accommodate a perfect piece of film.

The height of a pin in position "2" is therefore equal to the theoratical height of a perfect perforation, minus the total tolerances required on each side of that perforation, that is to say, it is 0.0500-in., minus 0.0018-in., or 0.0482-in.

In a similar manner it is possible to calculate the dimensions of any pin required to fit any perforation a given distance from the base line "A". It is only necessary to apply the formula shown in Figure 8 and from which the height of the tolerance pin No. 5 has been calculated. Thus, by subtracting from the height of a perfect perforation, the total tolerances permitted on the "hole size" plus the total tolerances permitted on a perforation removed by four frame intervals from the base line "A" (to accommodate the permissible uniformity errors, etc.) we see that the tolerance pin "5" will be 0.0452-in. in height.

Under these conditions the printer will successfully pass any film which is perforated within the tolerances permitted for errors of Uniformity. As seen at the right of Figure 8, any film in which the overall pitch between pins "1" and "5" is shortened to the minimum length permitted will still pass successfully through the machine. Similarly, as seen at the left of Figure 8, any film in which the overall pitch between pins "1" and "5" is increased to the maximum length permitted will also pass successfully through the machine. However, it does not necessarily follow that all such films will be free from unsteadiness on the screen.

The next important point to note is that the width of both pilot pins, measured in the horizontal direction, should be equal and sufficiently reduced below the minimum permissible width of the perforation to accommodate all films perforated within the recommendations.

The effect of the 16mm intermittent mechanism on Picture Steadiness.

It is now possible to forecast the relationship between the perforations in the film and the position of the pictures printed on this machine. Firstly, considering only a simple case in which the film has been perforated with the maximum permissible Uniformity Error, but which does not contain any appreciable Squareness Error, it may be assumed that the film is always being located about the full-fitting pilot pin.

Figure 9 shows four successive stages in the passage through a printing machine of a film in which the maximum permissible Uniformity Error is present. The relative positions of the full-fitting pilot pin and the exposing aperture are also clearly shown. Those dimensions marked "A" represent perforations separated by the maximum permissible amount, while those marked "B" represent perforations separated by the minimum permissible amount. It should be noticed that here again the well known grouping of three perforations, which characterises "Uniformity Error", is present.

The distance between "C", the top of the fixed pilot pin, and "D", the lower edge of the exposing aperture, is, of course, fixed. The distance between "C" and point "E", the centre of the perforation level with the aperture "D", will be a varying amount dependent upon the combination of film pitches present. For example, in Case 1 the distance "C-E" is equal to "2A", or the distance between two frame intervals, each separated by the maximum permissible amount. In Case 2, when the film has moved forward one frame, the distance "C-E" is equal to "A plus B", or the distance between one frame interval separated by the maximum permissible amount plus the distance between one frame interval separated by the minimum permissible amount. In Case 3, when the film has moved forward two frames, the distance "C-E" is equal to "B plus A" and is, therefore, similar to Case 2. Lastly, when the film has moved forward three frames, as in Case 4, distance "C-E" is again equal to "2A" and if, therefore, similar to Case 1.

By subtracting "C-E" from "C-D" it is possible to forecast the relationship between the printed frame "D" and its corresponding perforation "E". Such a calculation has been made, and is shown pictorially in Figure 10.

In this figure only the lower half of each frame has been shown and the film pitch has been foreshortened in order to avoid confusion. It is seen that every third frame is misplaced with respect to its corresponding perforation by 0.001-in., while the remaining two frames are absolutely in line with their corresponding perforations. This has occurred since, in the example given, the two spaces between those perforations formed at one blow of the punch were raised to the upper permissible limit, and the space made by carrying the film forward was decreased to the lower permissible limit. If the arrangement had been reversed, then the two successive frames would be misplaced by 0.001-in., and only every third frame would be absolutely in line with its corresponding perforation.

It should be noted that, where the two frames are in line with their respective perforations, as shown in the figure, the upper film pitch is short and the lower film pitch is long, this feature will be referred to again when we come to consider the unsteadiness caused by the projector mechanism and, more particularly, the relative positions of the intermittent mechanism and the projector aperture.

The Effect of "Squareness Error" on Printed Picture Position.

A rather more complicated case in which the film has been perforated with the maximum permissible amount of "Squareness Error", but which is relatively free from "Uniformity error", will not be considered. Figure 11 shows four successive stages in the passage of a film of this type through a printing machine. The relative positions of the full-fitting pilot pin "1" and the printing aperture "D" are, of course, fixed, and it should be remembered that this machine is not fitted with film edge guides in the printing gate. The film will therefore be free to move laterally until the first and fifth perforations are in line with the pilot pins.

As the film moves through the machine the edge "A-B" will not remain parallel with a straight line passing through the centre of the pilot pins, marked "1" and "5", but will be continually oscillating to three angles, dependent upon the perforations which happen to be in engagement with the pilot pins.

In the first case shown in Figure 11, dimension "C" will be 0.0006-in. smaller than standard, but dimension "E" will be correct. In case "2" dimension "C" will be correct, but dimension "E" will be 0.0006-in. greater than standard. In case "3" dimension "C" will be 0.0006-in. greater than standard and dimension "E" will be 0.0006-in. smaller than standard. Lastly, in case "4", the conditions of case "1" will be repeated and dimension "C" will be 0.0006-in. smaller than standard

An exaggerated picture of the three positions in which successive frames will be printed under these conditions is shown in Figure 12. It will be seen that during two successive movements the frames are printed at substantially the same angle to the film edge and only vary in their distance from that edge. However, in the third frame the angle is equally severe, but in the reverse direction. If, without introducing flicker, the speed of a projector could be reduced to enable a study of this movement to be made, it would be seen that the picture would first move to the left and then appear to rotate in an anticlockwise direction about the lower left-hand corner.

This diagram also shows that this type of pilot pin registration helps to reduce the apparent effect of any "squareness error" which may be present in the film. This will be readily appreciated by comparing the angle between the film edge and the vertical frame boundary with the angle between the film edge and a line through the centres of the three perforations made at one operation. This ability to reduce the error is, of course, due to the relatively large distance between the pilot pins.

It is now possible to calculate the amount of movement between a fixed base line, such as the printing aperture, and any point within the exposed frames. Figure 13 shows the relative positions of three successive frames, superimposed upon the printing aperture. The degree of displacement shown does not bear any relationship to the picture area and has been intentionally exaggerated.

It can be shown that, with a film containing the maximum permissible "Squareness error", the amount of relative movement from frame to frame, when printed on a machine of this type, will be of the following order:- At the top left-hand corner the displacement will be approximately 0.001-in. At the top right-hand corner approximately 0.0006-in. At the bottom left-hand corner approximately 0.0009-in. and, at the bottom right-hand corner, approximately 0.0001-in. It is also possible to show that the motion at the centre of the picture will be approximately 0.0005-in.

<u>The 35mm negative and the 35mm Intermittent Mechanism.</u>

It is now possible to consider the accuracy with which the reduced image of the 35mm negative is presented to the 16mm aperture. Such accuracy will, of course, depend upon three factors. Firstly, upon the accuracy of the perforations in the original 35mm "shooting" negative. Secondly, upon the accuracy of the mechanisms used to produce the duplicate negative used in the printing machine and, thirdly, upon the accuracy of the 35mm intermittent mechanism in the printing machine.

For many years the professional film studios have employed many trick effects to enhance their film plays. The success of the majority of such effects eventually depends upon the accuracy with which one film can be located with respect to another. One such effect is, in principle, very similar to reduction printing. It is the "background projection shot" in which a print of some distant or inaccessible scene is projected upon a translucent screen and in front of which the actors and cameras are placed.

Obviously any variations in the position of the projected background with respect to the foreground action would be immediately apparent to persons viewing the composite print.

When this effect was first introduced unsteadiness in the "combined" negative frequently occurred and, as a result, two main difficulties became apparent. The first of these was the inaccuracy of the 35mm film perforations and the second, and certainly the most important, was the lack of standardisation between the equipment used in the various studios. These difficulties occurred in America as far back as 1933, when standardisation in professional equipment had not reached its present high level.

Perhaps the greatest contribution to the solution of this problem was to standardise the intermittent mechanisms used and to employ pilot pins arranged to locate the film by the same perforations both in the cameras and the background projectors.

Unsteadiness is rarely encountered in present-day background projection work and, since many of the problems involved in this type of work are also present in the reduction printing process, it was a natural development to employ a similar intermittent mechanism in the 35mm head of the printing machine.

It is therefore most unlikely that unsteadiness in reduction printing will be traced to errors occurring in a 35mm "projection head" which has been designed correctly and has been accurately manufactured. For these reasons the 35mm intermittent mechanism used in the machine which has been described, will not be discussed in detail but, it should be remembered that, in principle, the mechanism is similar to that used in the 16mm "head".

There are, however, differences between 35mm and 16mm films and mechanisms which must not be overlooked. Firstly, 35mm film is perforated by machines which make four perforations along the length of the film in one operation and, of course, the distance so occupied is equal to the amount by which the film must be moved to advance it by one frame or picture. This condition is seen in Figure 14, in which a perforating punch is shown in relationship with the perforations made by that punch. It should be noticed that the film pitch, indicated at "D" is not equal to that indicated at "E" and, it will be remembered, such a condition denotes the presence of "uniformity errors".

From this figure it is seen that, since the film will always be moved forward by a distance equal to four perforations, the relationship between the pilot pins "A" and the perforations will always remain constant. For example, if, as shown in the diagram, the pilot pins "A" are in engagement with the perforations made by punch legs "E", this relationship will be maintained throughout the entire roll of film. In this manner the possibility of unsteadiness, due to perforating "uniformity" or "squareness" errors, is greatly reduced.

Thus the distance between the perforations located on the pilot pins "A" and the printed aperture "C" will always remain substantially constant, although a uniformity error is present. This uniformity error will only become noticeable if the film is used for double exposure or trick work in which it is located by the pilot pins on perforations "B" during one operation and, for example, on perforations "F" during a subsequent operation (possibly on a different piece of equipment). Film used for this type of work is always carefully marked by the camera operator to indicate the perforations which must be used to engage with the pilot pins and claw pins during each operation.

At this point one may well ask why more than one perforation should be made at one operation during the manufacture of 16mm film. If single punching machines were used it would be necessary to employ three times the number of machines to obtain the same output and, to maintain the same "punch speed". Alternatively the speed of the machines would have to be increased to three times their normal rate of operation. The accuracy with which any perforations can be made largely depends upon the speed of the perforating head and, if this were increased beyond its intended rate, the expected increase in accuracy would not be obtained.

Clearly the only certain means which may be employed to reduce these errors is to standardise the distances between the exposing and projecting apertures, the claws and the pilot pins.

The Effect of the 16mm Projector Mechanism on Picture Steadiness.

It is now possible to consider the final cause of unsteadiness in reduction printing, namely, the intermittent mechanism in the 16mm projector. Most 16mm projectors use some form of "claw" intermittent, although several machines have employed a modified "beater" movement and at least one projector employs an eight-sided maltese cross.

To attempt to give a detailed description of the many 16mm projector intermittent mechanisms at present in use would be to start an independent paper. It is, however, necessary to point out that the distance between the projecting aperture and the claw pins, when at the top of their stroke, may still vary between one and five frames, according to the particular type of projector in use.

From previous considerations of the 16mm pilot pins in the printing machine it will be readily appreciated that such wide variations in design have been known to cause a film to appear relatively steady on one machine and to appear exceptionally unsteady on a second machine. The explanation of such an occurance is, of course, that in the first case the distance between the claw pins and the projecting aperture was similar to the claw-to-aperture distance in the printing machine while, in the second case, it may have been two or three frames greater or smaller.

Figure 15 shows a section of film perforated with the maximum permissible "uniformity error" and being printed on a machine similar to the one which has been described. In the position shown at "A" the film is located about the full fitting pilot pins "C" and frame "D" is being exposed. If this film is now placed on five different projectors, so that frame "D" is in the projecting aperture at the moment when each claw comes to the end of its stroke, frame "D" will be placed in any of three positions.

In the first machine the claw engages with the perforation which is level with the lower frame line when at the top of its stroke. This will cause frame "D" to be placed in the projecting aperture in true relationship with the printing aperture. If the film is placed in the second projector, in which the claw is two frames distant from the projecting aperture, frame "D" will be placed 0.0005-in. higher than the theoretically correct position. When used in the third projector, in which the claw is three frames distant from the projecting aperture, frame "D" will be placed 0.0010-in. higher than the correct position. Projectors four and five will place frame "D" in similar positions to projectors two and three respectively.

It will be remembered that the example shown only takes into account the most simple type of errors, but it is sufficient to demonstrate the great need for standardisation of this important section of the projector mechanism.

Because of the wide variety of intermittent mechanism still in use little would be gained from a study of any particular machine. The more useful method of approach is to consider the maximum permissible tolerance which may be allowed in any such mechanism. In this connection Townsley states that projector steadiness tolerance should be from 0.2 to 0.3 percent of the picture width. This may be taken to indicate a maximum tolerance of plus or minus 0.0005-in. on the position in which the claw mechanism will place successive perforations, that is, a total tolerance of 0.0010-in. between the relative positions of successive perforations.

If a claw mechanism were designed with this accuracy, and was arranged to stroke, or "pull down", over that pitch adjacent to the actual frame located in the projecting aperture, only three additive errors would effect the steadiness of the projected picture. These errors would be, (1) the errors in the film perforations, (2) the errors introduced by the reduction printing process and, (3) the errors introduced by the manufacturing tolerances permitted on the projector intermittent mechanism.

Such a projector should also be designed to guide the film accurately through the picture gate by using spring loaded edge guides, similar in principle to those used in the perforating machines. Unfortunately the majority of 16mm projectors are not fitted with really adequate edge-guides and, as a result, the film may move laterally in a most unpredictable fashion.

Figure 16 shows at "A" the amount of picture movement obtained by printing a film which contains the maximum permissible "squareness error" on a machine of the type previously described. If this film is then projected on a machine built to the accuracy suggested, and having the claw mechanism placed adjacent to the projecting aperture, the combined screen picture unsteadiness, as measured in the projector gate, will be as seen at "B", Figure 16.

It is interesting to compare these figures with those given at the beginning of this paper - when it was mentioned that recommended tolerances for 35mm projection, were as follows:-

(1) That the unsteadiness of the centre of the picture, measured in the projector gate, shall not exceed a total jump of 0.0010-in.

(2) That the unsteadiness of the corners of the picture, measured in the projector gate, shall not exceed a total jump of 0.0020-in.

It should be noticed that the unsteadiness of the centre of the 16mm picture may be 50% greater than that at the centre of the 35mm film, while the unsteadiness at the corners of the 16mm picture will not exceed that permitted on 35mm film. This larger error at the centre of the 16mm picture is, of course, due to the fact that 16mm sound film is located by a single perforation on one side of that film, thus causing the picture to hinge about one point.

The actual unsteadiness, as measured on the screen, will depend upon the magnification used although, when the position of the audience is in accordance with the recommendations previously quoted, such unsteadiness will appear equally acute at all magnifications.

However, assuming an average 16mm screen to be 6 feet in width, that is, assuming a magnification of 176 times, the greatest movement due to unsteadiness at the corners of the frame, and measured at the screen surface, will be approximately 3/16th of an inch.

CONCLUSIONS.

(1) The degree of picture unsteadiness seen in Figure 16 is obtained with film which is perforated to the maximum permissible tolerances.

(2) It has been assumed that the position of the average audience viewing any picture will be as recommended by the Projection Practice Committee of the Society of Motion Picture Engineers.

(3) No standard dimension has as yet been given by any organisation for the measurement of "squareness" error in 16mm sound film, and a suggested method of measuring this error has been given in this paper. This proposal is covered by the following statement:-

> "Dimension "E" is provided to measure two characteristics: (a) the average margin between the perforations and the film edge and, (b) the squareness or degree of parallelism between perforations and the film edge. When considering "average margin" dimension "E" is permitted an overall tolerance of plus or minus 0.002-in. whereas, when considering squareness or parallelism, variations throughout a series of measurements taken between at least four consecutive perforations and the film edge must be considered - and such readings must remain within plus or minus 0.0006-in. or each other regardless of their average magnitude."

(4) The picture unsteadiness shown has been calculated for only one type of printing machine. This particular machine was chosen because it tends to reduce the apparent effect of "squareness" error in film perforating. However, it should be remembered that a different degree of picture unsteadiness would undoubtedly be obtained with other types of printing machines.

(5) Any unsteadiness on the 16mm screen will appear at least 2.1 times greater than an equal amount of unsteadiness on the 35mm screen if both are viewed under recommended conditions.

(6) The picture unsteadiness calculated in this paper has been based on two important assumptions regarding the projector mechanism. The first is that the claw pins are engaging with those perforations adjacent to the picture which is being projected. The second assumption is that the claw pins will be capable of repeating their action accurately and that the various gate tensions, edge guides, etc. will all play their part in placing successive perforations within plus or minus 0.0005-in. of their true position.

(7) Lastly, the possibility of increasing the general quality of 16mm projection and reducing the degree of unsteadiness is shown also to be dependent upon the claw-to-gate distance in the projector mechanism.

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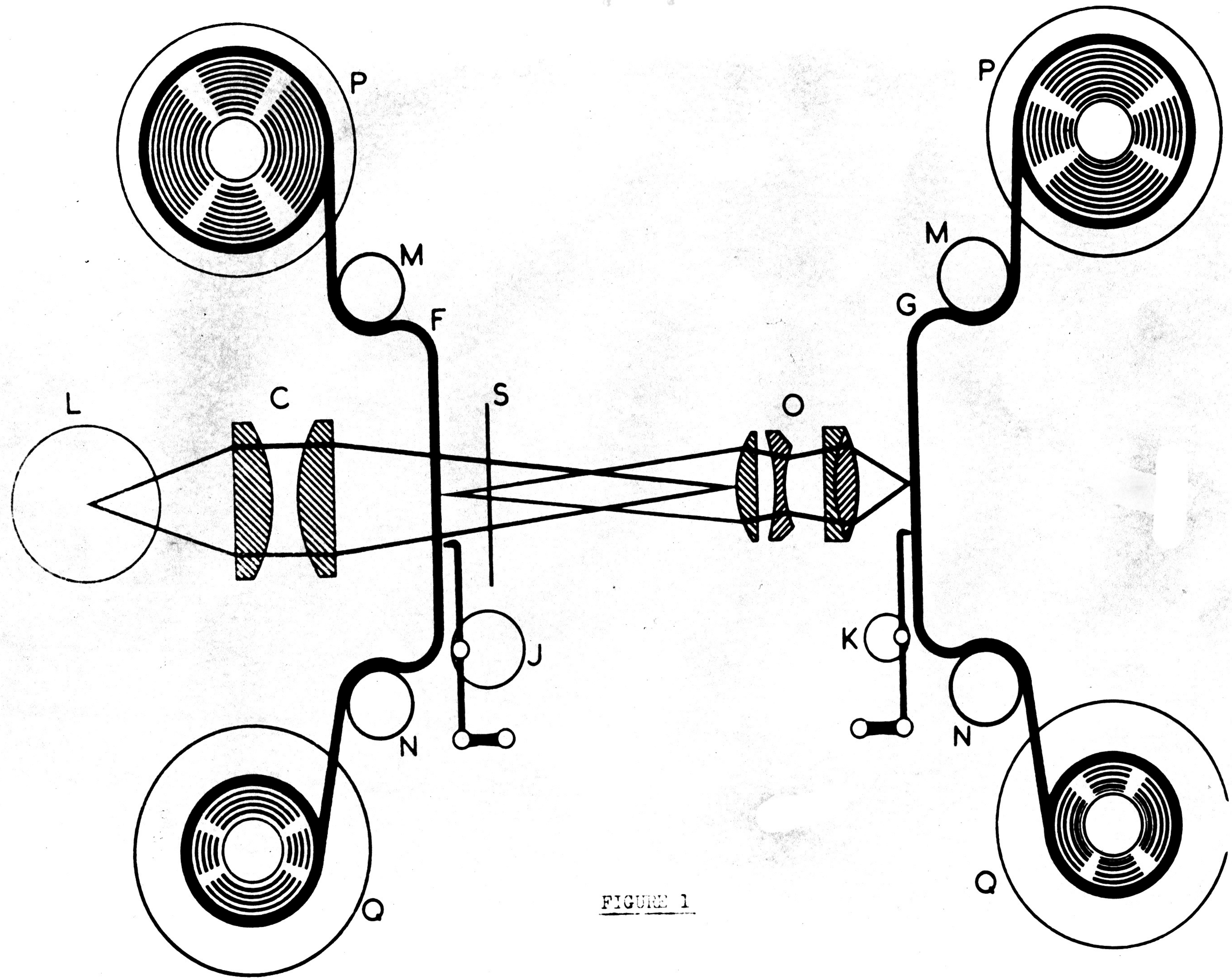
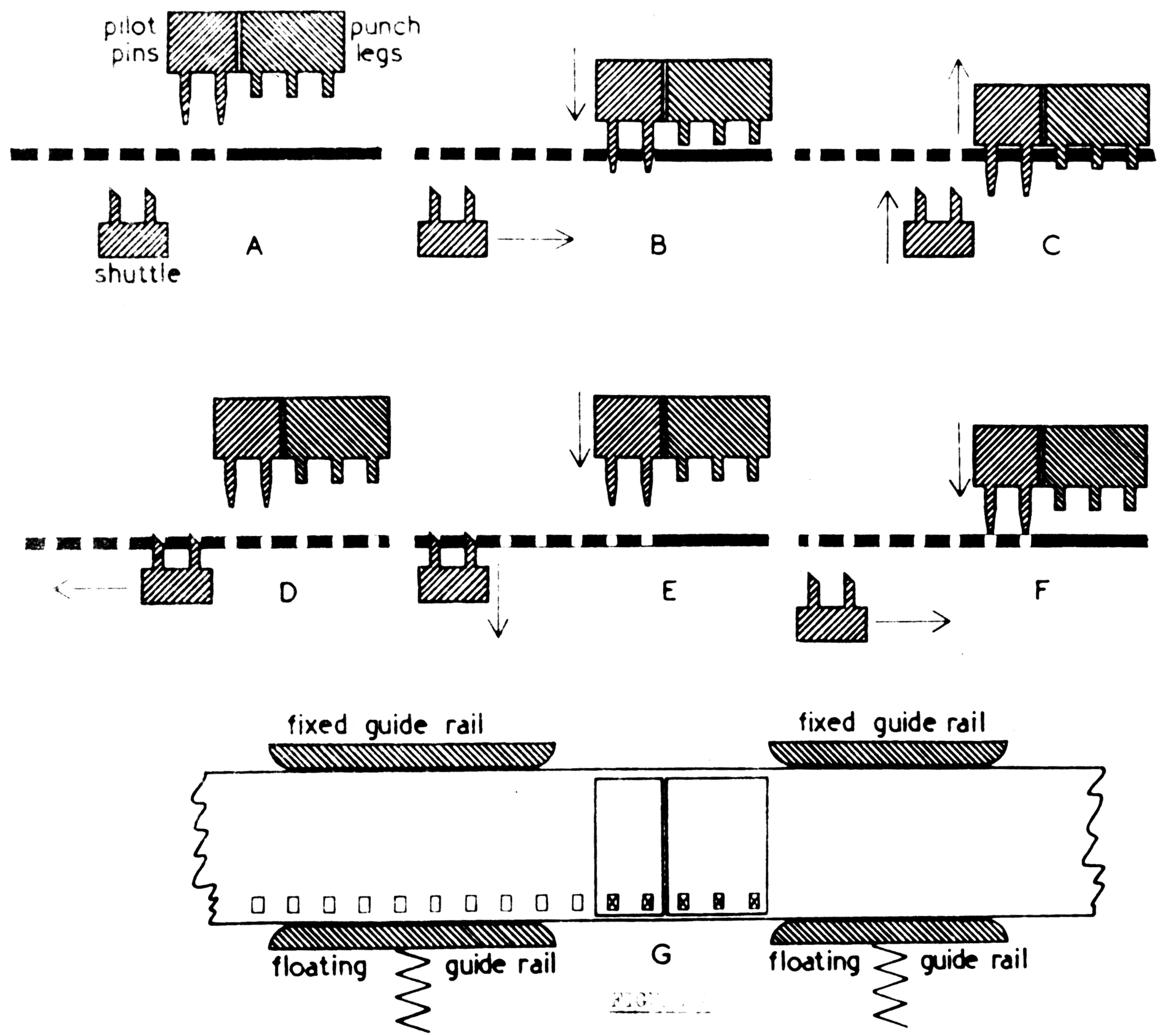


FIGURE 1


pilot pins
punch legs
shuttle
A
B
C
D
E
F
fixed guide rail
fixed guide rail
floating guide rail
floating guide rail
G

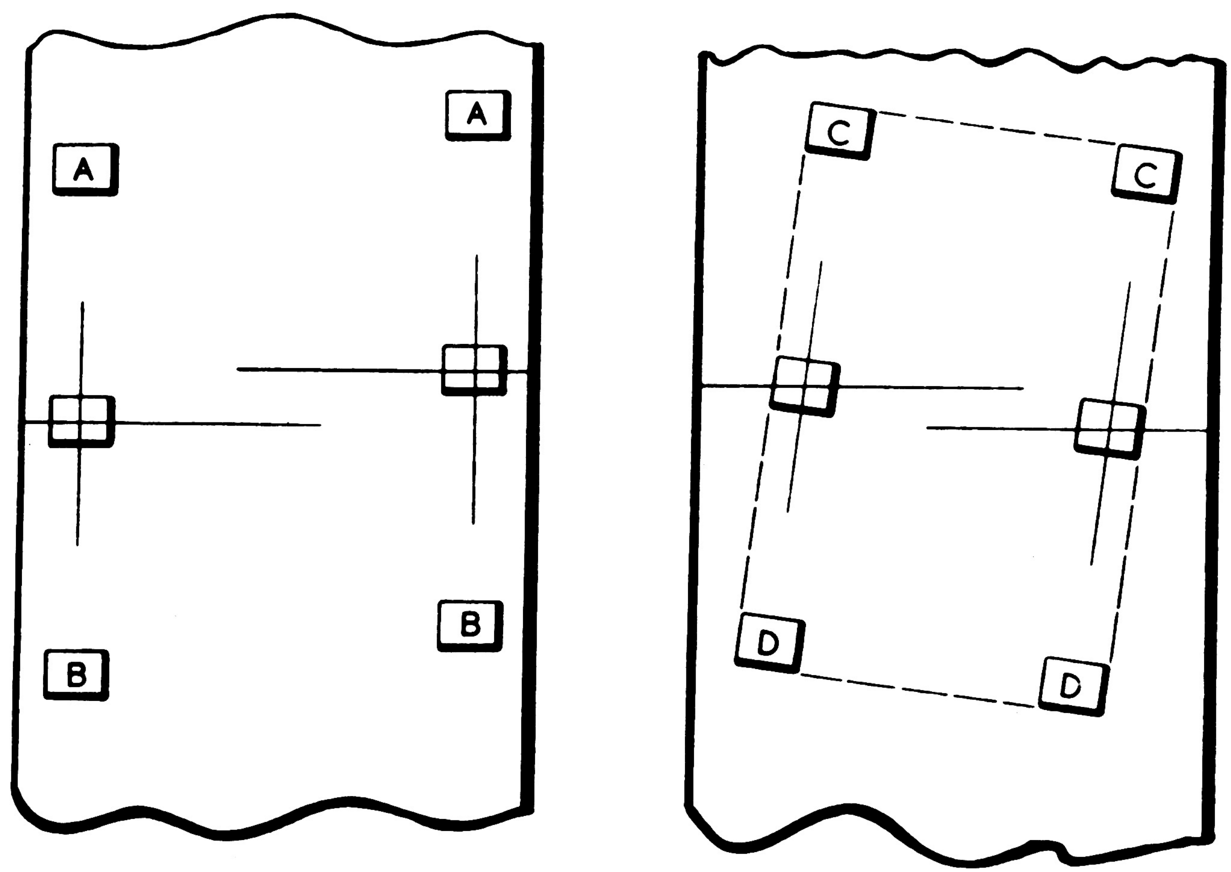
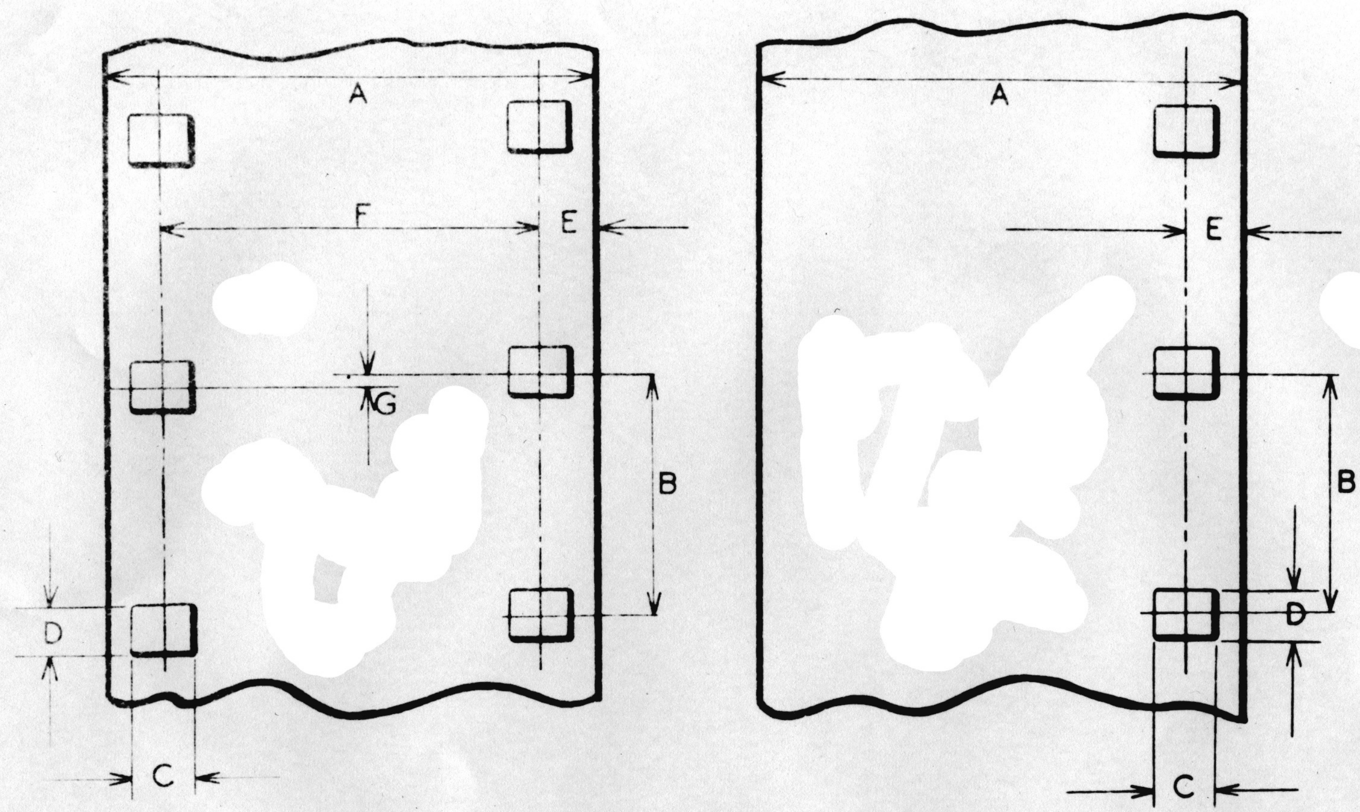
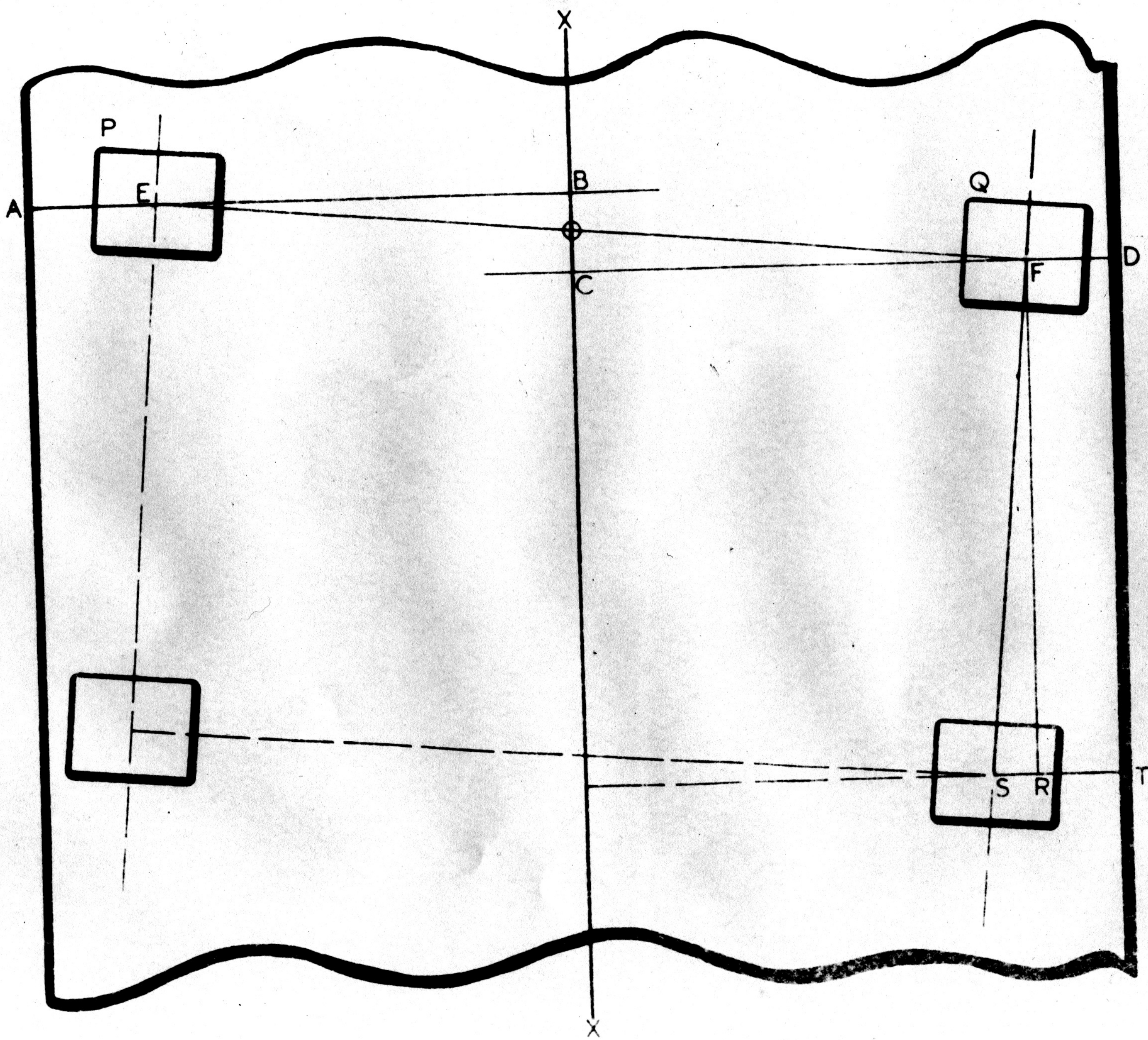


FIGURE 3



DIMENSION	INCH STANDARD	TOLERANCES
A	0·6300	+ 0·0000
		− 0·0020
B	0·3000	± 0·0005
C	0·0720	± 0·0004
D	0·0500	± 0·0004
E	0·0720	± 0·0020
F	0·4850	± 0·0010
G	NOT TO EXCEED	0·0010

FIGURE 4


X
P
B
Q
A
E
D
F
C
S
R
T
X

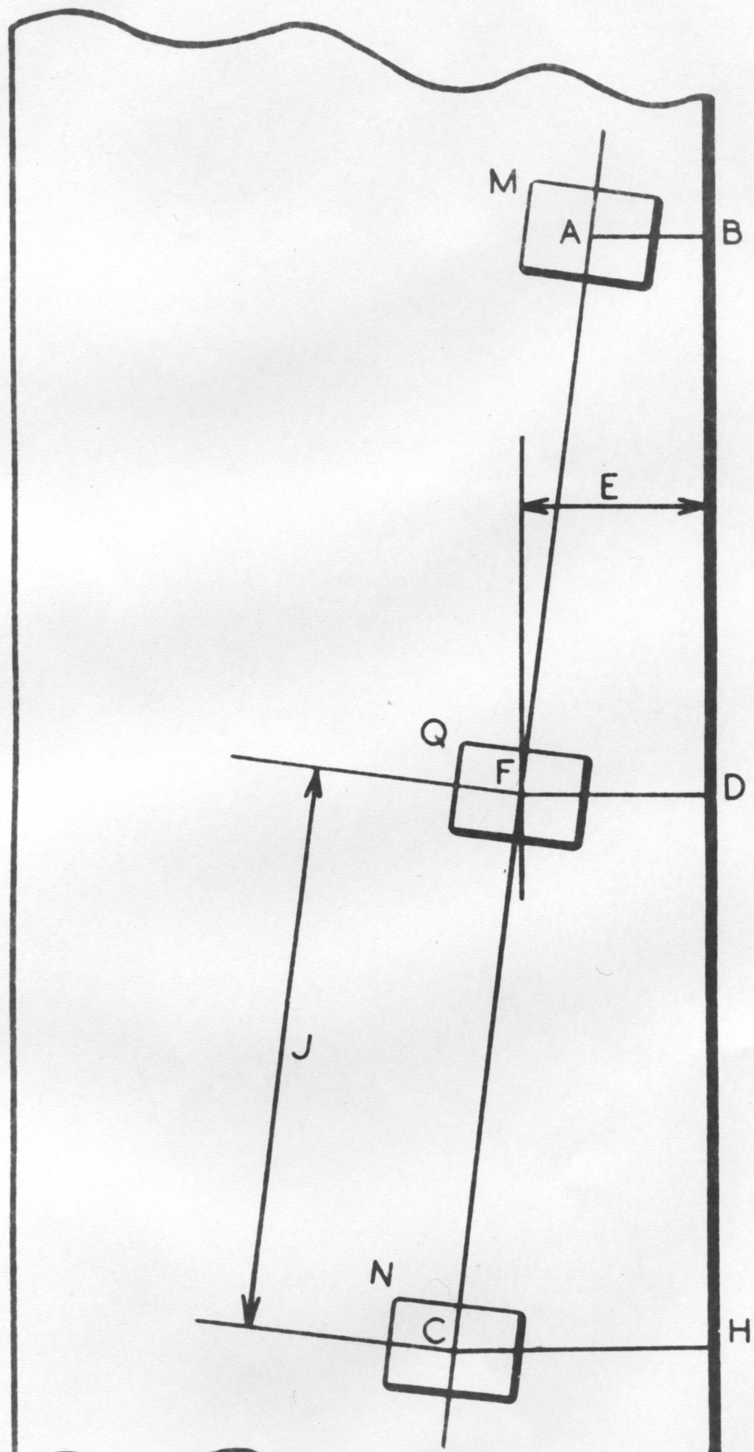


FIGURE 6

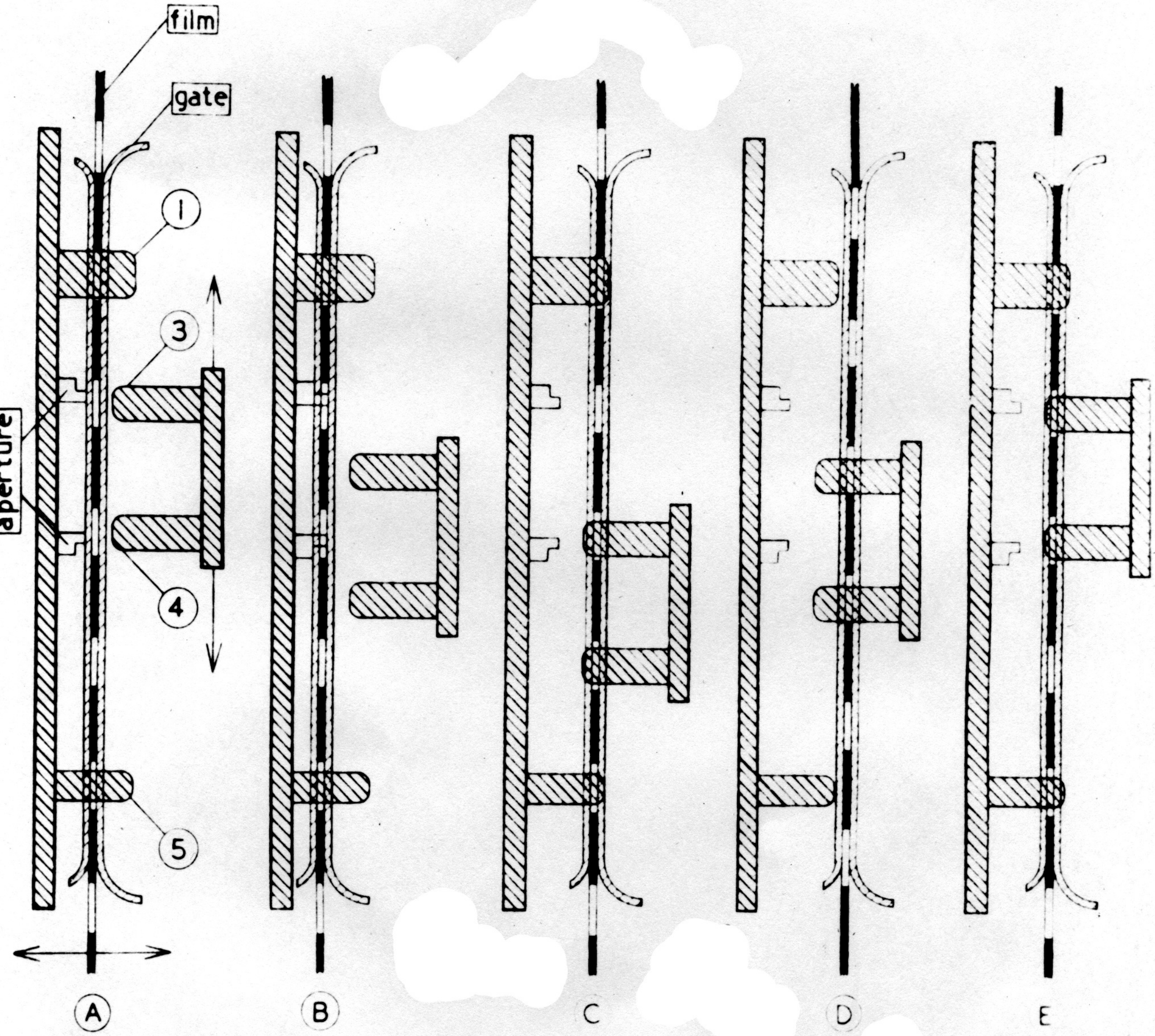


FIGURE 7

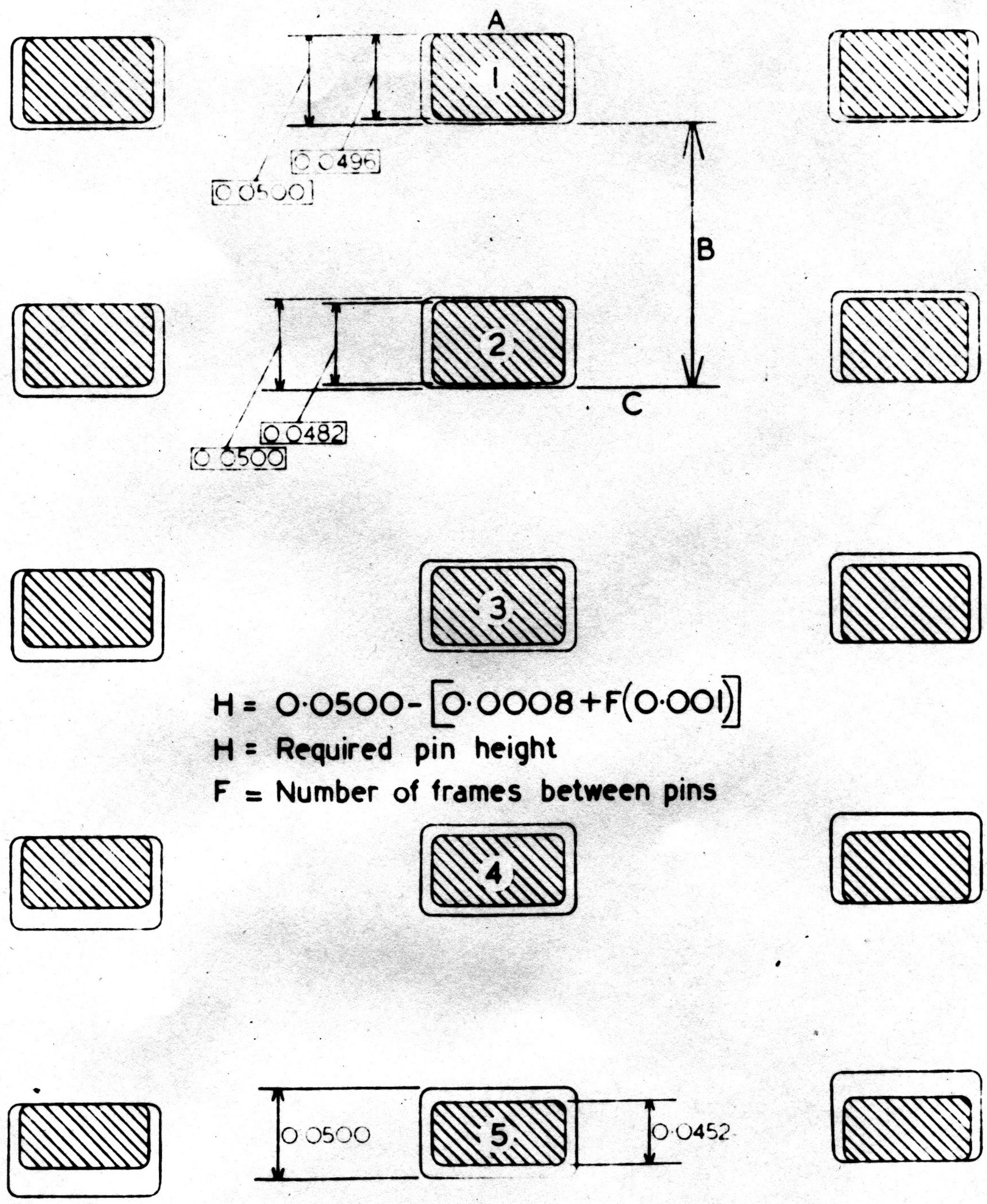

A
1
0.0496
0.0500
B
2
C
0.0482
0.0500
3
H = 0.0500 - [0.0008 + F(0.001)]
H = Required pin height
F = Number of frames between pins
4
0.0500
5
0.0452

FIGURE 8

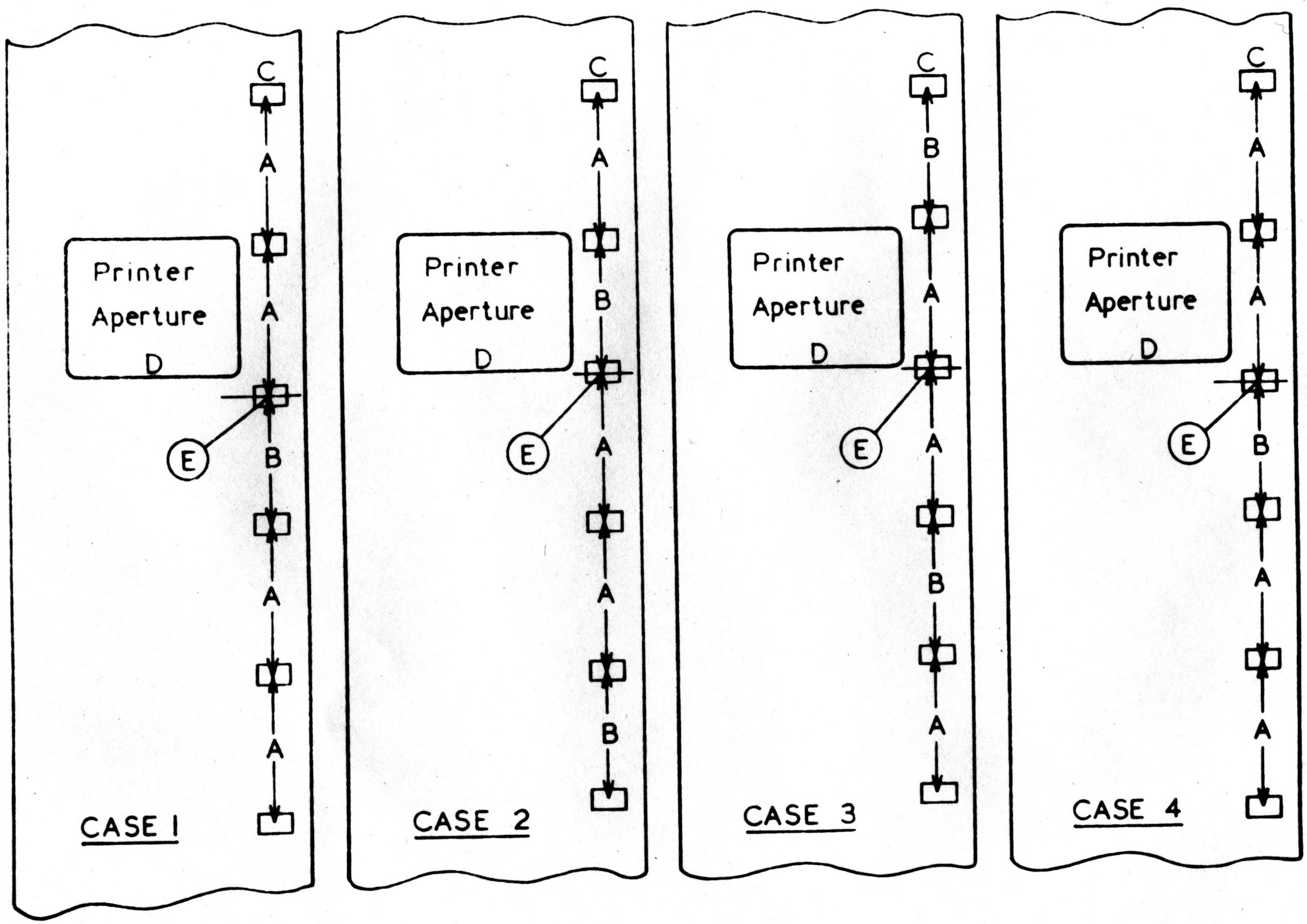

C
A
A
B
A
A
Printer
Aperture
D
E
CASE I
C
A
B
A
A
B
Printer
Aperture
D
E
CASE 2
C
B
A
A
B
A
Printer
Aperture
D
E
CASE 3
C
A
A
B
A
A
Printer
Aperture
D
E
CASE 4

FIGURE 9

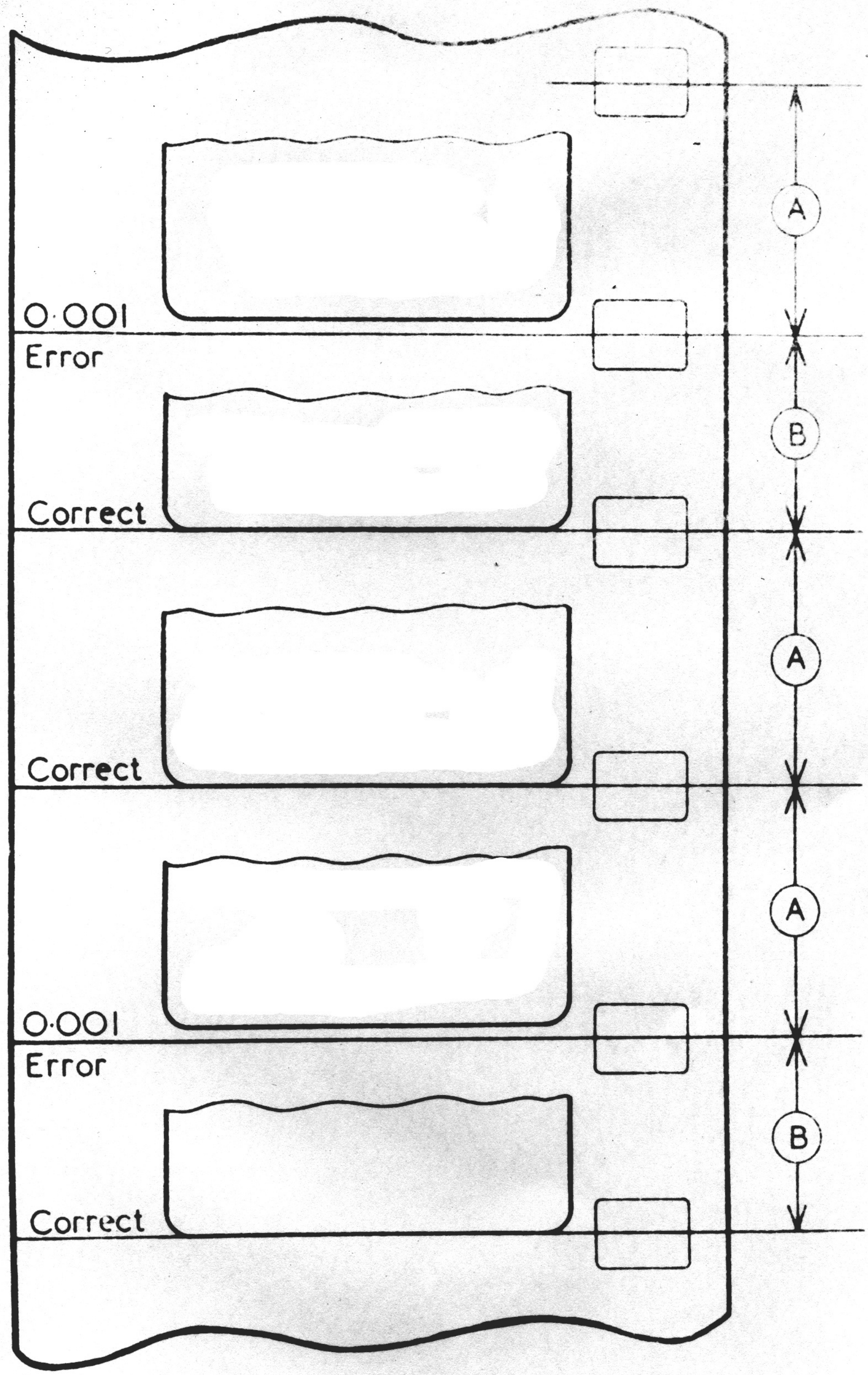


FIGURE 10

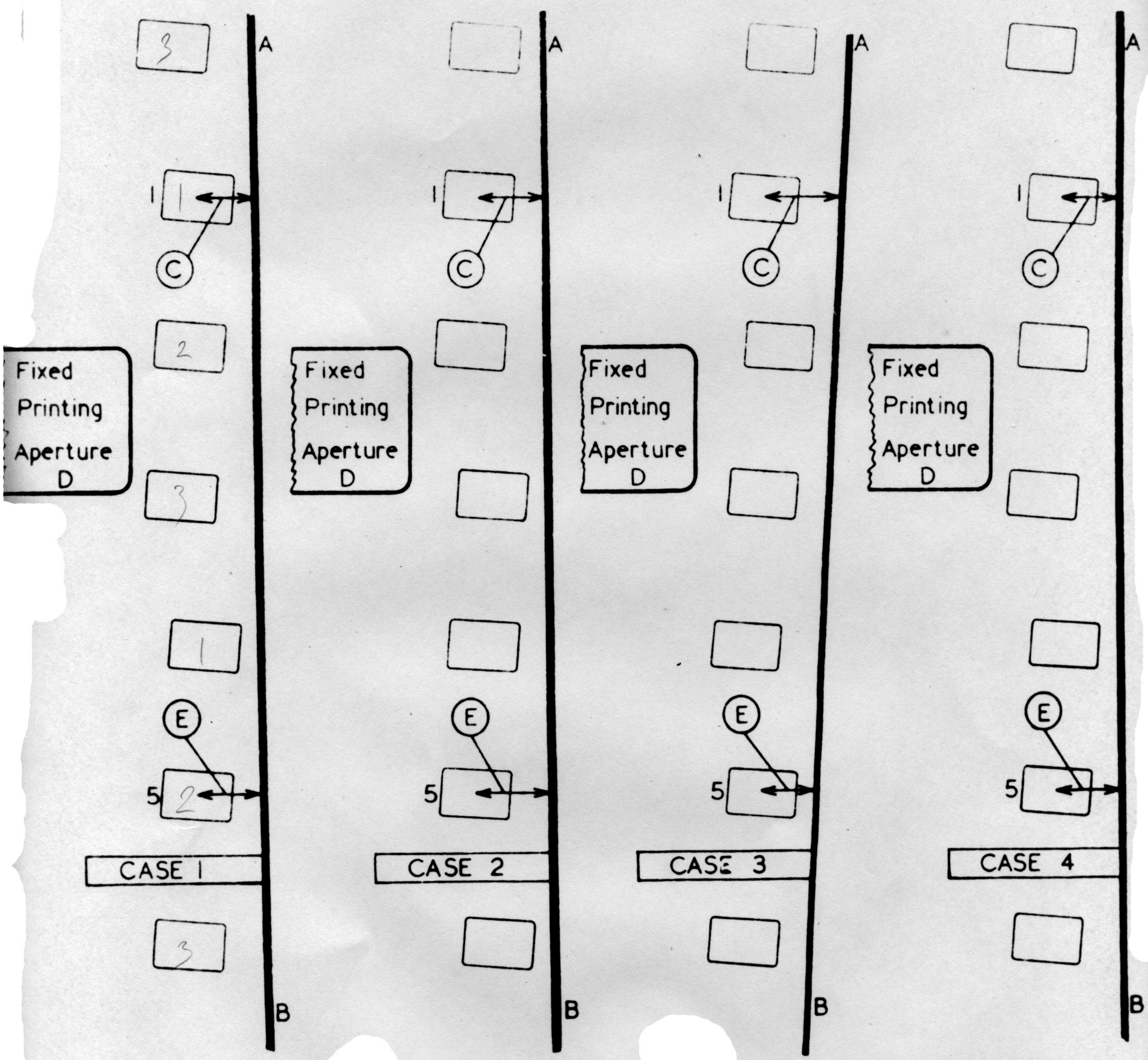


FIGURE 11

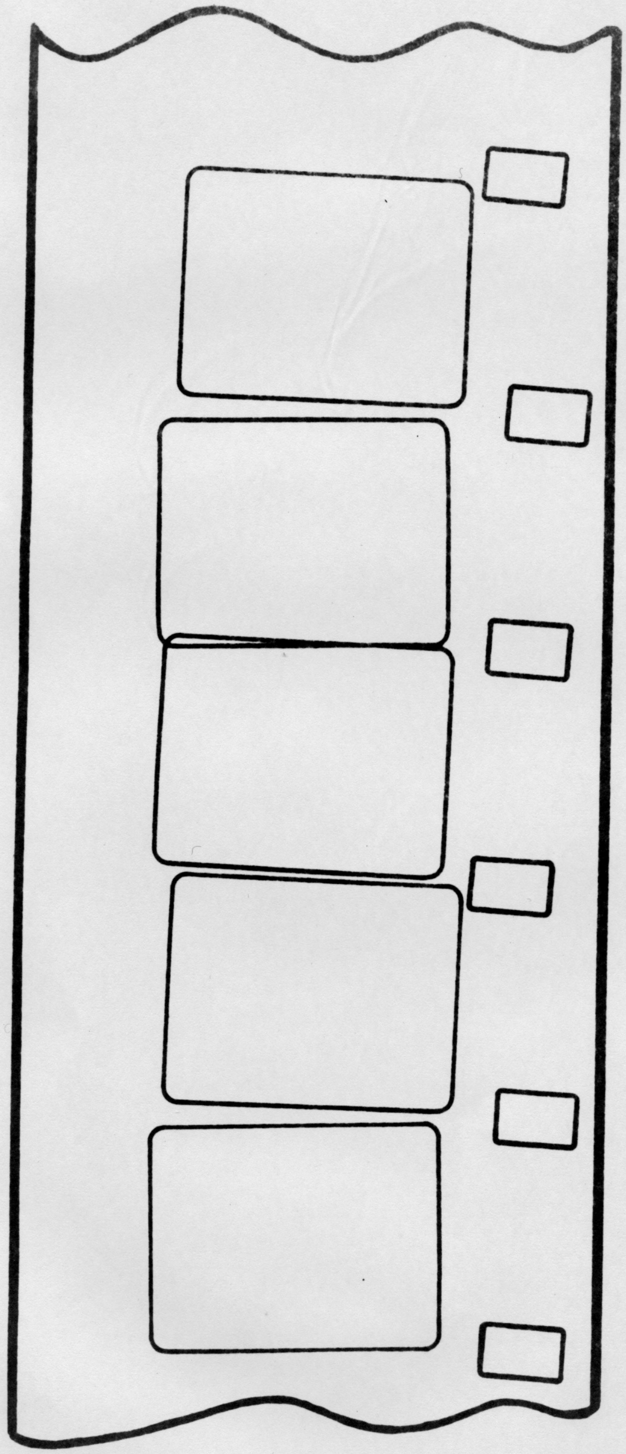


FIGURE 12

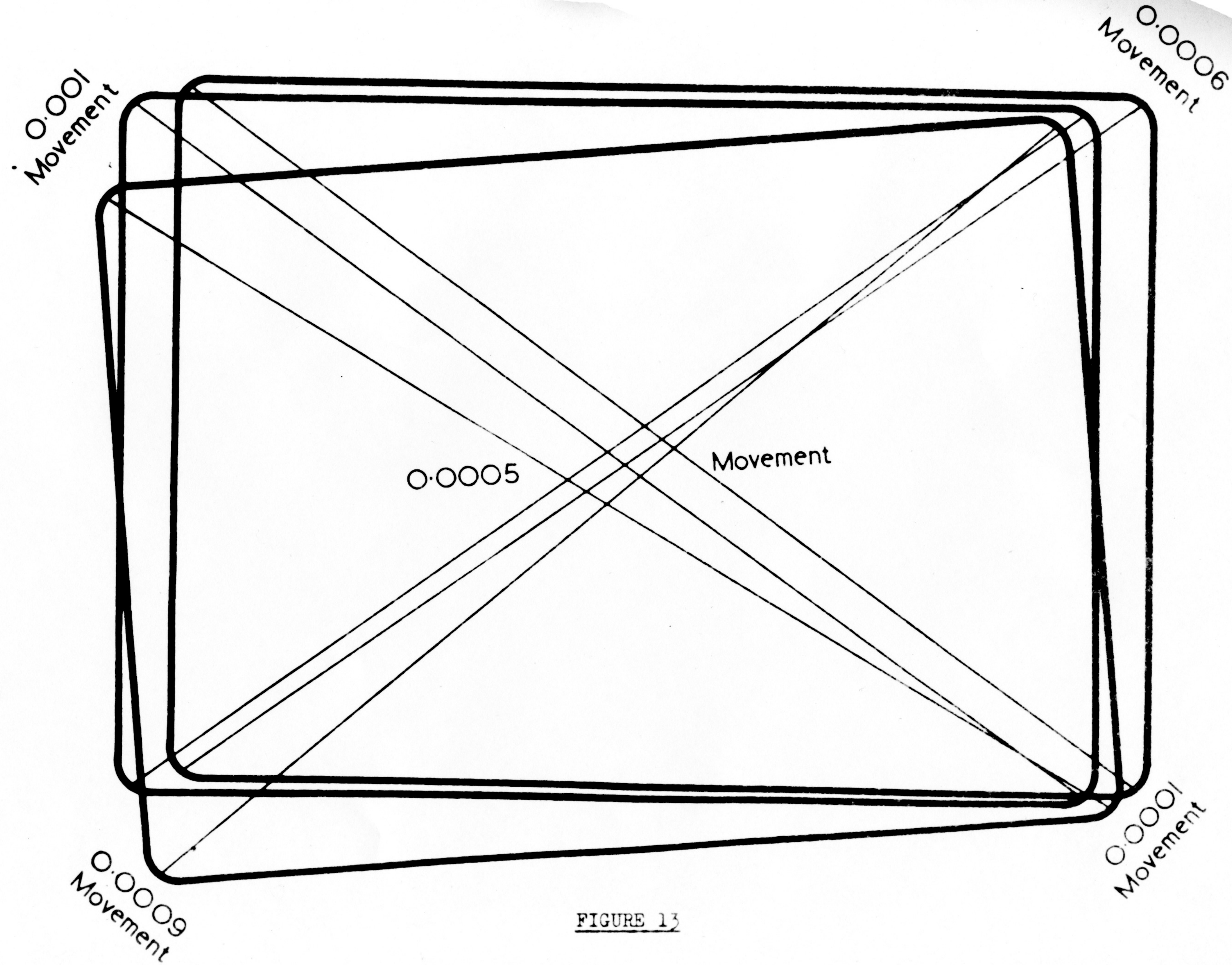
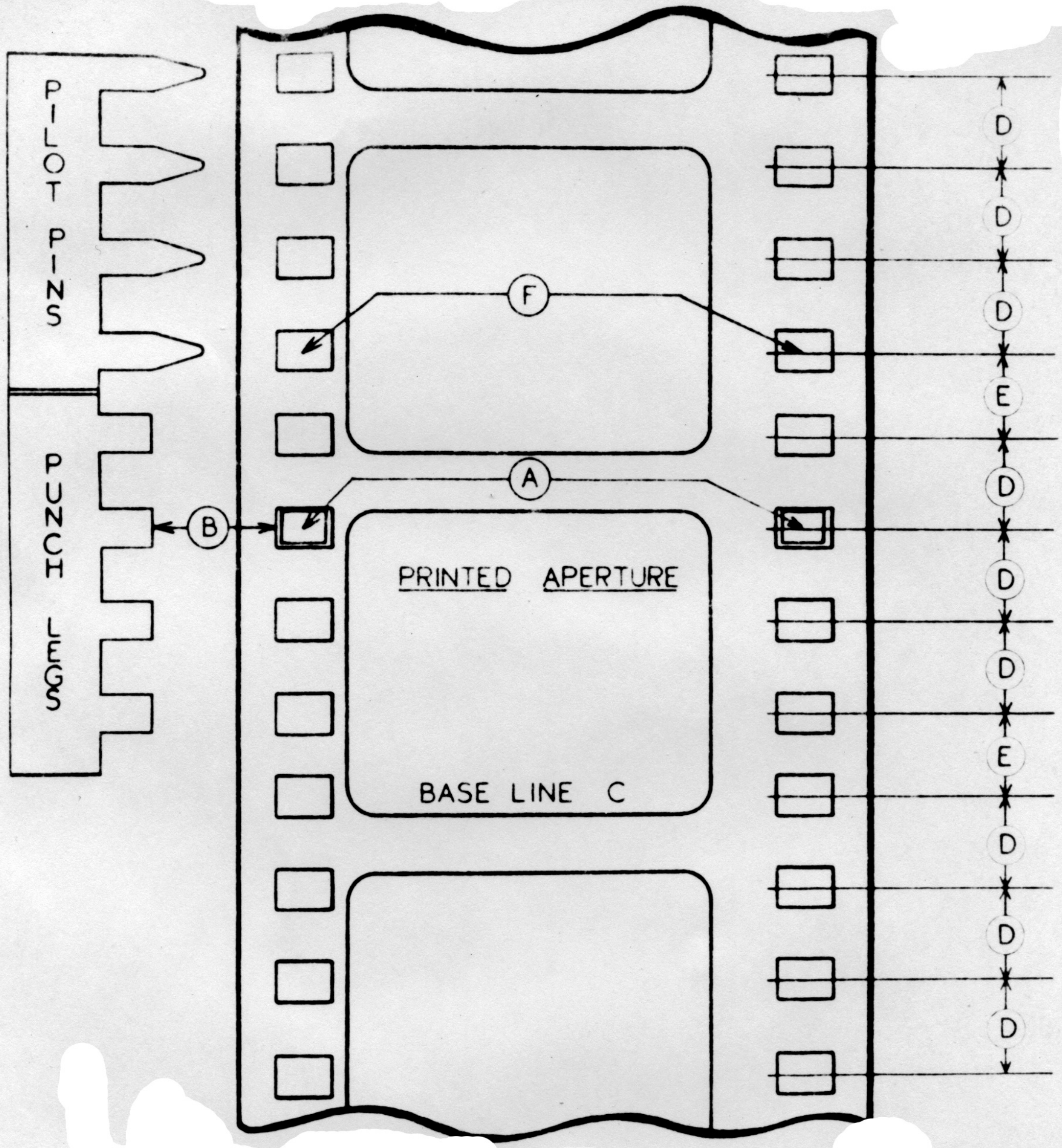

0·0006
Movement
0·001
Movement
0·0005
Movement
0·0009
Movement
0·0001
Movement

FIGURE 13



PILOT PINS
PUNCH LEGS
B
F
A
PRINTED APERTURE
BASE LINE C
D
D
D
E
D
D
D
E
D
D
D

FIGURE 14

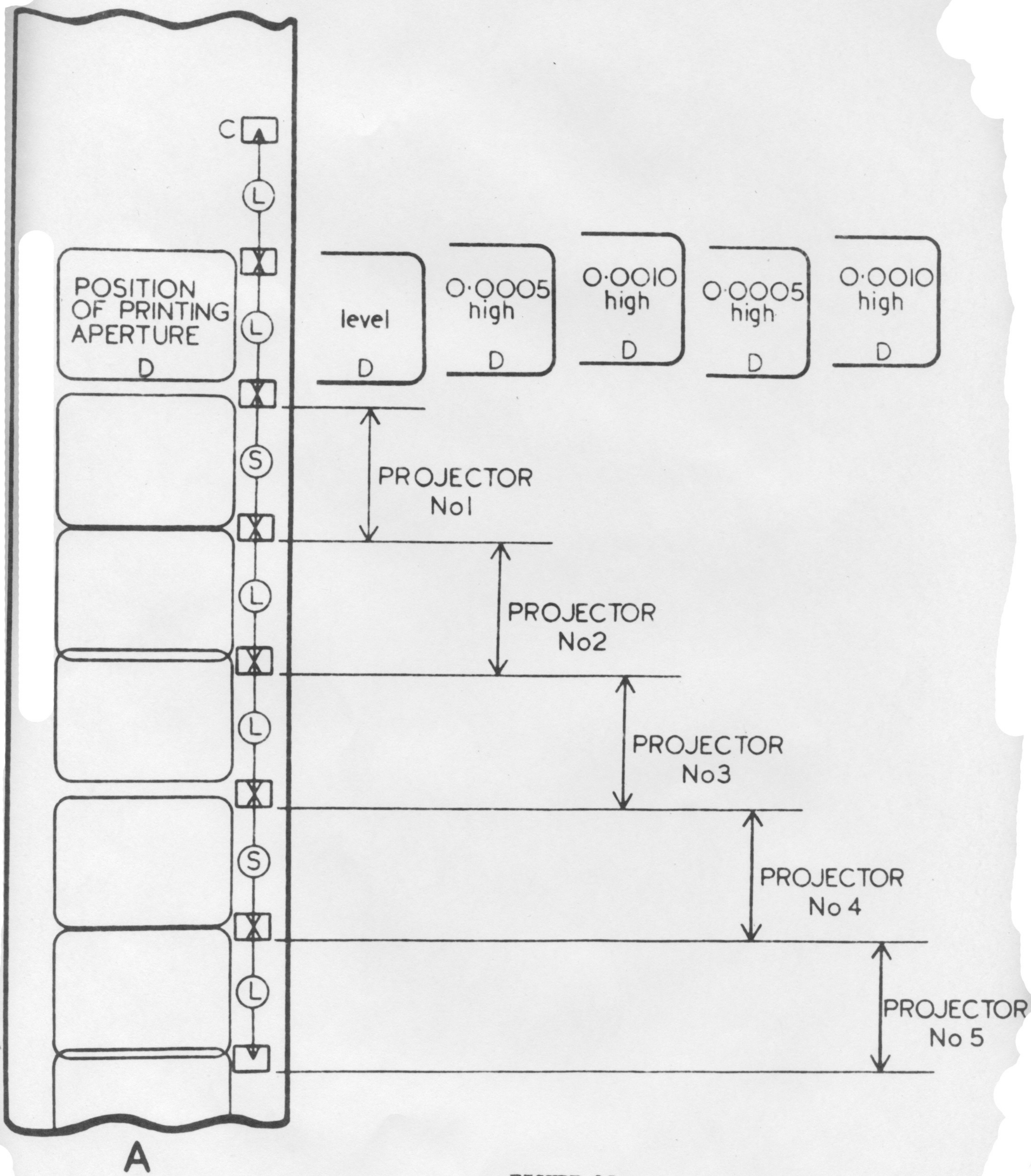

C
L
POSITION OF PRINTING APERTURE
D
level
D
0·0005 high
D
0·0010 high
D
0·0005 high
D
0·0010 high
D
S
PROJECTOR No1
L
PROJECTOR No2
L
PROJECTOR No3
S
PROJECTOR No 4
L
PROJECTOR No 5
A

FIGURE 15

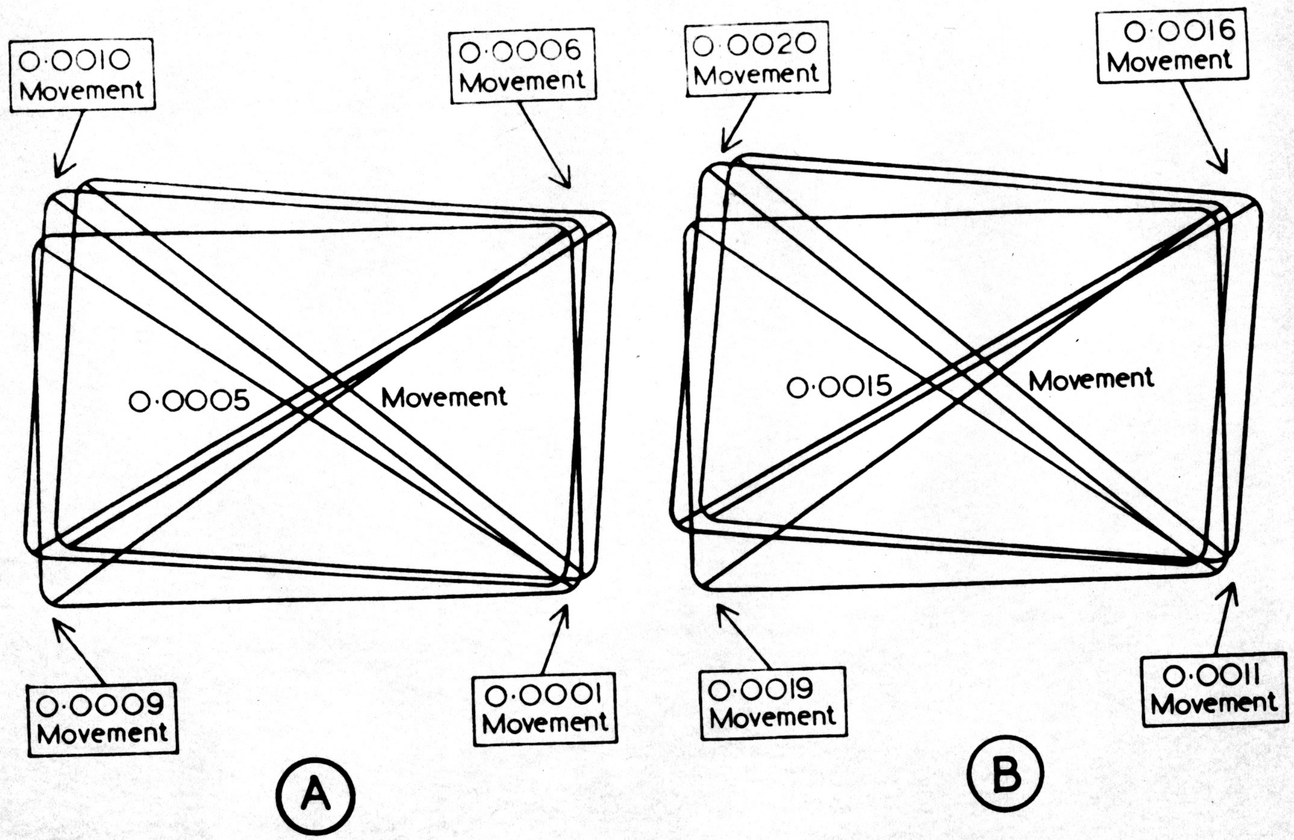

0·0010 Movement
0·0006 Movement
0·0005
Movement
0·0009 Movement
0·0001 Movement
A
0·0020 Movement
0·0016 Movement
0·0015
Movement
0·0019 Movement
0·0011 Movement
B

FIGURE 16