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CALIBRATION AND ADJUSTMENT OF THE SCHOPPER FOLDING TESTER

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CALIBRATION AND ADJUSTMENT OF THE SCHOPPER FOLDING TESTER

By F. T. Carson and L. W. Snyder

ABSTRACT

The Schopper folding tester, which is designed to test the bending endurance of paper and its resistance to such types of wear as involve creasing and folding, is so constructed that a number of mechanical variables are introduced by reason of the several rollers and other working parts which are driven by the specimen being tested. These mechanical variables affect the folding results in much the same manner as do errors in adjusting the tension applied to the specimen during the test, and apparently can in general be expressed as equivalent effective tension. The tension on the specimen is very critical, the effect on the folding results being inversely proportional to something like the tenth power of the tension, according to available data.

Owing to the necessity of frequent confirmation of the amount of applied tension, devices have been developed for facilitating the adjustment. A new device is described which permits calibration and adjustment of the springs without disturbing the assembly of the tester. This is a balanced bell-crank lever supported by a knife-edge in such manner that the springs may be calibrated against dead weight with a minimum of inconvenience.

A method is outlined for measuring the friction of the rollers and an effort is made to emphasize the magnitude of this influence upon the folding results.

CONTENTS

I. INTRODUCTION

Many uses of paper involve bending, creasing, folding, and such types of wear. The ability of paper to withstand such wear in service has come to be recognized as one of its most important properties. Thousands of tons of paper are bought each year by the Government departments alone on specifications in which the folding resistance is considered the most important physical property. This test has been used as the chief criterion of the quality of currency paper in the investigation carried out in attempting to improve the quality of this material. It is coming to be used in mill control also where constant hygrometric conditions are available.

Of the several types of apparatus which have been devised for testing this property of paper, the Schopper folding tester is most generally used. The structure and principle of the tester may readily be understood by reference to Figures 1 and 5. The specimen of

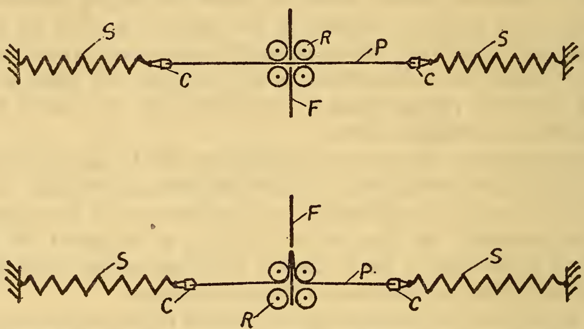

FIG. 1.—*Diagrammatic representation of the working principle of the Schopper folding tester*

paper is folded by means of a thin, slotted reciprocating blade, *F*, which passes back and forth between the rollers, *R*, arranged in a quadrant about the central position of the slot in the folding blade. The strip of paper, *P*, threaded through the slot in the blade, is folded about the rounded edges of the slot, first one way and then the other, as the blade moves back and forth. During this process the specimen is kept under tension by means of springs, *S*, attached to the clamps, *C*, which grip the ends of the specimen. The paper is thus folded repeatedly until it weakens sufficiently to rupture at the crease under the influence of this tension.

Not only is this test affected by variable factors inherent in the specimen, such as moisture content and the dimensions of the specimen, but it is also influenced very materially by comparatively slight changes in a number of mechanical elements in the make-up of the folding tester itself, such as differences in the thickness, shape, or condition of the edges of the slot in the blade over which the paper is folded, wear in the clamp-spring linkage, changes in the adjustment or condition of the quadrantal rollers and of the rollers supporting the clamps, or any other change affecting the tension of the specimen. The tester might be criticized on several scores, but that is not within the scope of this article. The purpose of this publication is to review briefly such data as are available on the effect of these mechanical variables on the folding results, drawing such inferences as seem justifiable, and to describe a means of calibrating and adjusting the instrument with especial reference to a new device, shown in Figure 5, for adjusting the tension of the clamp springs quickly and easily without disturbing the assembly of the tester.

II. EFFECT OF THE MECHANICAL VARIABLES

1. AVAILABLE DATA

Data on the effect of the mechanical variables of the Schopper folding tester are comparatively meager and somewhat contradictory. The study of these variables and the collection of adequate data are a formidable task, owing to the great variability of individual results and the slowness of the test. Unless a very large number of tests are made the conclusions are of little value, and few investigators have felt justified in giving the necessary time to systematic study of the problem since Herzberg's rather exhaustive study a quarter of a century ago.

The effects of these mechanical variables have been studied by Herzberg [1] in Germany and by Veitch, Sammet and Reed,[2] and Kiely [3] in this country. All agree that the folding results are influenced to a considerable extent by the adjustment and condition of the working parts and by differences in tension applied to the specimen, although there is some difference of opinion as to the magnitude of some of these influences. There are something like a dozen distinct working parts whose dimensions, adjustment, and condition influence the folding results to a greater or less extent.

The user has control over the adjustment and condition of these working parts, but, of course, has no control over their dimensions. The dimensions are determined in the manufacture of the instruments, and in those instruments examined these dimensions appear to be sufficiently uniform. However, the instruments show evidence of having been made very largely by hand operations and probably without the use of jigs in machining, for the parts are not interchangeable, screws having different threads are used on different machines for the same purpose, and in two new machines recently examined there was an easily noticeable difference in the throw of the driving crank. Hence, it can not be assumed that in every case the dimensions of like parts are exactly the same.

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[1] Mittheilungen a. d. Königlichen Technischen Versuchsanstalten, **19**, p. 161; 1901.

[2] Paper, **20**, No. 12, p. 13; May 30, 1917.

[3] Paper Trade J., **76**, No. 19, p. 45; May 10, 1923.

2. FOLDING BLADE AND LINKAGE

Apparently no experiments have been made on the influence of the dimensions of the folding blade. This member is about half a millimeter in thickness, and differs by as much as 10 per cent in different instruments. However, the form and condition of the edges of the slot probably have a considerable influence on the results. These edges determine largely the form and severity of the crease. If they are not properly rounded or if they become pitted or rough as a result of rusting, the rupture will be hastened by such abrading edges. Lack of parallelism of these edges with the plane of the paper likewise lowers the results, since the tension in such a case is not evenly distributed across the specimen and premature tearing results. Very considerable errors in results have been traced to such defects. The folding blade is housed in the central block of the tester where it is not readily examined and, hence, may sometimes escape blame justly due it. The two halves of the blade are attached to the crosshead extension only by the lower ends, and sometimes get sprung out of their normal position without the fact being apparent except upon removing the crosshead and the attached blade.

In folding the specimen the folding blade travels approximately 1 cm each side of the neutral position. This distance is determined by the throw of the crank. Slight differences in the total travel of the folding blade on different instruments are not so important as having the blade on a given machine travel equal distances each side of the neutral position. The tension on the specimen is adjusted to a definite value corresponding to the outermost position of the folding blade. This results in a certain minimum tension corresponding to the neutral position of the folding blade characteristic of each instrument, but unavoidably different for different instruments. Unless differences in crank throw are great enough to overshadow the normal unavoidable variation in minimum tension, such differences are unimportant. However, if, as a result of wear in the linkage between driving wheel and folding blade, the travel becomes unequal on the two sides of the neutral position, appreciable error may result from the unequal tensions corresponding to the outermost positions of the folding blade. This defect in an old instrument can usually be remedied by replacing the crank pin and connecting-rod pin by oversize pins.

3. QUADRANTAL ROLLERS

The four vertical rollers quadrantally situated about the central position of the slit in the folding blade are mounted in pairs on each side of the folding blade. Each pair may be shifted in the direction normal to the folding blade, but there is no adjustment in the direction of the movement of the folding blade.

The clearance between the folding blade and the rollers on either side is usually adjusted to 0.38 mm (0.015 inch). Most papers which are tested with this instrument occupy from one-third to two-thirds of this clearance while being folded. Hence, although the crease is formed as the specimen is pushed between the rollers, the paper is not pressed tightly against the folding blade by the rollers. Except in the case of heavier paper, which occupies practically all the clearance, small differences in roller clearance probably do not influence greatly the severity of the crease. The chief effect of changes in the adjustment of the vertical rollers appears to be to alter the tension on the specimen. This would seem to be the only effect which could result from differences in the clearance between rollers in the space occupied by the specimen in its neutral position. There is some disagreement as to the effect of different adjustments of the roller clearance in the direction normal to the folding blade. Herzberg reported appreciable differences in results due to very small differences in this adjustment. As pointed out by Veitch, Sammet and Reed it is not clear from Herzberg's report whether or not the springs were recalibrated after each new adjustment of the roller clearance. These investigators report no appreciable differences in results due to small changes in roller clearance provided the springs are recalibrated after each new adjustment. This finding is confirmed by Miss Kiely. All agree, however, that considerable changes in the adjustment of the roller clearance are followed by considerable changes in results. It is easily appreciated how this can be, since the adjustment of these rollers determines the length of the path in which the paper lies when the folding blade is in its outermost position. The shorter this path the smaller will be the difference between the maximum and the minimum tension; that is, the higher will be the minimum tension. As will be brought out later the minimum tension probably has a more important bearing upon the folding result than is usually ascribed to it. Any considerable differences in the diameters of the rollers would have a similar effect on the length of path of the paper for given clearances between rollers.

Although every effort should be made to adjust the roller clearances as precisely as possible and particularly to see that the rollers are symmetrically arranged about the central position of the slot in the folding blade, it is scarcely possible to make the adjustments closer than two or three thousandths of an inch, since there is no micrometer adjustment and the measurement must be made with leaf gauges. It is particularly difficult to adjust accurately the clearance between the folding blade and the vertical rollers because the slight play in the crosshead permits the folding blade to be shifted a few thousandths of an inch either side of its normal position. But such small differences in clearance or diameter can have no appreciable effect on the results, since the maximum tension is adjusted after all other adjustments have been made, and the few grams change in the minimum tension is inconsequential in view of the fact that values for minimum tension from 780 to 815 g have been observed in different instruments having rollers in proper adjustment.

Lack of parallelism of these quadrantal rollers gives rise to much the same effect as that due to lack of parallelism of the edges of the folding blades.

It is, of course, necessary to keep these rollers in good condition and well oiled, a requisite applicable equally to all friction surfaces driven by the folding specimen. The friction of these vertical rollers is considerable, and adds to the effective tension on the specimen. This effect will be considered further along in this paper and data will be given showing its magnitude.

4. SUPPORTING ROLLERS

The condition of the rollers which support the moving jaws may have an appreciable effect upon the results. The old-style knife-edge rollers quickly wear flat on the periphery and sometimes groove the plate against which they rest. As a result a considerable amount of friction develops which has the effect of increasing the tension during the outward stroke and decreasing it during the inward stroke. A cylindrical type of roller has been developed by E. O. Reed, of the Government Printing Office, and is now being furnished as regular equipment by the makers of the tester. This type has proved to be much more satisfactory than the old-style knife-edge supporting rollers.

5. TENSION ON THE CLAMP SPRINGS

As has been seen, changes in adjustment of most of the mechanical variables are tantamount to changes in the tension applied to the specimen, and the magnitude of such influences may be inferred from the effect of differences in tension. This adjustment is therefore the most important one to be made and is one which must be frequently verified in order to prevent error in the results, since this tension may change as a result of wear or other less obvious causes.

As previously stated, the tension is adjusted to a definite value corresponding to the outermost travel of the folding blade, this value being 1 kg in most practice. A minimum tension of about 0.8 kg, more or less, then corresponds to the neutral position of the folding blade. The specimen is subjected to tension of all values between these limits four times for each double fold. Experience and such data as are available indicate that the adjustment of the tension on the specimen is very critical. Comparatively small differences in the tension give rise to relatively large differences in the folding results.

But, important as is this adjustment, few data are available purporting to show experimentally the magnitude of the effect of differences in tension. The user of the folding tester is largely dependent upon Herzberg's work previously referred to for experimental data on the effect of tension.

Herzberg made folding tests on nine samples of paper varying the tension on the specimen from 1 down to 0.7 kg. The range of folding values of these samples under standard conditions was from 2 double folds to a little over 200 double folds. This corresponds to the lower grades of paper which are customarily tested for folding endurance and scarcely represents the gamut of folding papers, some of which withstand several thousand folds. It represents, however, practically the only study of any consequence of the effect of tension. This range of papers was chosen, no doubt, in order to conserve time, as it would take a very long time to complete tests on this number of samples, making enough individual tests at each tension value for a reliable average when the paper folds several thousand times before breaking under 1 kg tension, and many times that much at the lower tensions.

From all his data Herzberg obtained average values for each of the four tension values and plotted a curve which is shown by the full line in Figure 2. This graph suggests a curve of the exponential type. In order to get a better idea of the manner in which the folding value changes with tension let the simplest possible relation consistent with the form of the curve be assumed; namely, that the folding value varies inversely as some power of the tension, or in mathematical symbols

$$F=\frac{F_1 T_1^n}{T^n}=\frac{F_1}{T^n}$$

if T_1 is taken equal to 1 kg. In this equation F is the folding value corresponding to tension T when F_1 is the folding value corresponding to 1 kg. (T_1). Hence

$$n=\frac{\log F_1-\log F}{\log T}$$

The broken-line curve of Figure 2 is drawn with $n=7$ for comparison with Herzberg's curve. If a tangent (dash-dot line of fig. 2) is drawn to Herzberg's curve at the point where the tension is 1 kg it is seen that for this part of the curve a change in tension of 1 g corresponds to a change of approximately 1 per cent in the folding value, or a change of one-tenth of 1 per cent in tension produces a change of 1 per cent in the folding value. In this case when $T=0.999$, $F=101$ (with $F_1=100$).

$$n=\frac{\log 100-\log 101}{\log 0.999}=10$$

It may, therefore, be concluded that for this immediate region in which the variation in tension takes place in practice, the folding value, according to Herzberg's data, varies on the average inversely as the tenth power of the tension on the specimen. However, the magnitude of this effect depends very much on the kind of paper being tested. The least effect which Herzberg obtained in this series of tests gives n a value between 1 and 2 for one of the papers. Since $n=10$ is an average value for all the tests for the region in the imme-

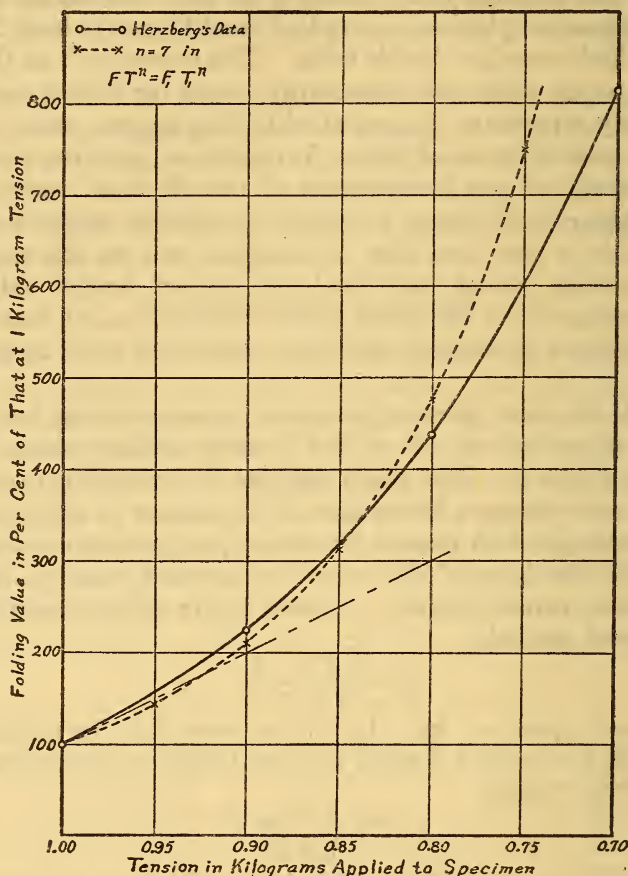

FIG. 2.—*Graphic representation of the effect of tension on the folding results*

diate vicinity of $T=1$ kg, there were other values of n greater than 10. Although the relation between tension and folding value can not be given a definite single value for all kinds of paper, nevertheless it is plain that the adjustment of the tension is very critical and must be kept as nearly as possible to the assigned value (1 kg) in order that reliable results may be obtained.

In adjusting the tension on the springs it is necessary to determine the deflection of each spring corresponding to the point of maximum travel of the folding blade and subsequently to adjust the springs under a load of 1 kg until this deflection is obtained. It is, therefore, convenient to determine the error in folding results due to maladjustment of the tension on the specimen in terms of the error in the deflection of the springs at maximum travel of the folding blade. A load-deflection diagram was made of one of the springs and it was found that a change of 1 g in tension corresponds to a change of 0.0356 mm (0.0014 inch) in the deflection of the spring. This corresponds well with Herzberg's figure of 0.035 mm (0.00138 inch) per gram. Hence, an error of one-thousandth inch in deflection results in an error of approximately 0.7 g in tension, or 0.7 per cent in the folding value, according to the data of Herzberg. If it be assumed that an error of two or three thousandths inch may be reasonably expected in the adjustment of the rollers, in the travel of the folding blade either side of the central position, or in the adjustment of the clamp springs, the resulting error in the folding value should be no more than about 2 per cent. As is evident from other data, this is well within the attainable precision of the tester in practice. According to the data of Veitch, Sammet and Reed, whose work appears to have been carefully carried out, the mean of 10 tests may, under carefully controlled conditions, be reproduced to within about 10 per cent on the average on the same instrument or on different instruments. Some of their recorded means, however, showed deviations of more than 20 per cent, and in average usage where the conditions are not so carefully controlled the deviations may be much greater.

(*a*) Effect of Minimum Tension.—Whenever the effect of tension is referred to in the literature on the folding test the discussion revolves about the maximum tension. Although at first thought it seems obvious that the maximum tension must have a greater influence upon the folding value than the minimum tension, there is reason to believe that the minimum tension, whose value varies over a considerable range, is not so inconsequential as is commonly assumed. With all other adjustments standardized it is impossible to have both the maximum and minimum values of tension satisfy a standardized value unless all springs could be made exactly alike; that is, so as to have exactly the same load-deflection diagram. In practice the maximum tension is set at 1 kg and the minimum tension follows as a consequence of all the other standardized conditions, its absolute value being necessarily neglected. The other obvious alternative would be to adjust the minimum tension to a standard value and let the maximum be what it will. The crease is formed under the influence of the minimum tension and at this time the fibers are most free to untangle and cause the strip to rupture, whereas at maximum tension the fibers are presumably in the positions assumed at the time the crease was formed, since at maximum tension there is no further bending of the paper in the neighborhood of the crease. Under this maximum tension of 1 kg the fibers are almost static with respect to each other and the effect on the strength of the paper of their friction on one another and on the folding blade is enhanced by this fact. On the other hand, under the minimum tension of approximately 0.8 kg the fibers are taking up new positions with respect to one another owing to the creasing of the paper and the influence of felting friction on the strength of the paper is least as a result of this fact. Now it is a question of whether this condition within the paper favoring rupture or the slightly greater external stress at maximum tension is the more influential in bringing about the rupture. Perhaps some light could be thrown on the question by studying with motion pictures or a suitable recording device the place along the stroke of the folding blade where the rupture most often occurs; that is, whether it occurs more often near the outermost or the innermost position of the folding blade. An investigation in which a definite setting of the minimum tension is compared to a definite setting of the maximum tension would be desirable and most interesting. However, owing to the notoriously large deviations of individual results from an average, and because of the slowness of the test, a very large number of observations would be required on many different kinds of paper in order to establish definite conclusions.

III. ADJUSTMENT OF THE CLAMP SPRINGS

1. VERTICAL SUSPENSION METHOD

The method of adjusting the tension on the clamp springs which is most commonly used was described by Herzberg as early as 1901. According to this method one of the clamps, together with the spring housing and the supporting standard, is removed from the tester. This removed unit is taken apart so as to obtain the weight of the clamp. It is not stated whether the weight of the spring is considered. Strictly speaking, half the weight of the spring should be added to the weight of the clamp. The unit is then reassembled and clamped in a vertical position with the clamp downward. A weight is then attached to the clamp, whose weight, plus the weight of the clamp, is equal to 1 kg. The fixed end of the spring is then moved by turning a knurled nut on the end of an attached shaft until a previously determined deflection interval corresponding to the outermost travel of the folding blade is obtained. In this manner it is assured by dead-weight calibration that the specimen is subjected to a tension of 1 kg when the folding blade has attained its maximum outward travel. As originally described this method makes use of marks on the pyramidal clamp stems to indicate the necessary deflection corresponding to maximum tension during the test. If the roller adjust-

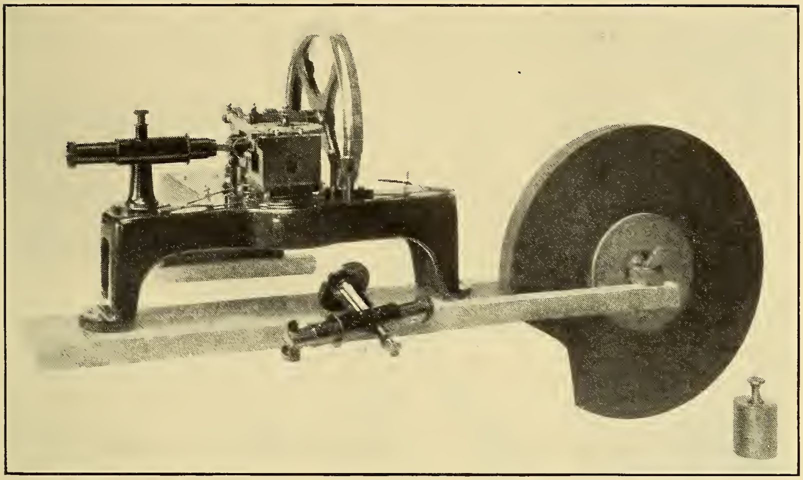

FIG. 3.—*Frictionless pulley used in calibrating the Schopper folding tester*

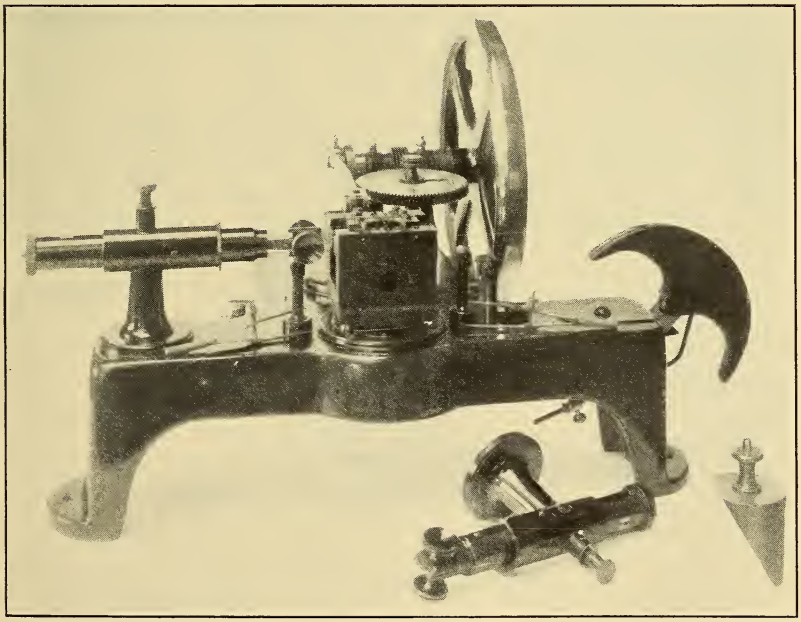

FIG. 4.—*Compact form of frictionless pulley used in calibrating the Schopper folding tester*

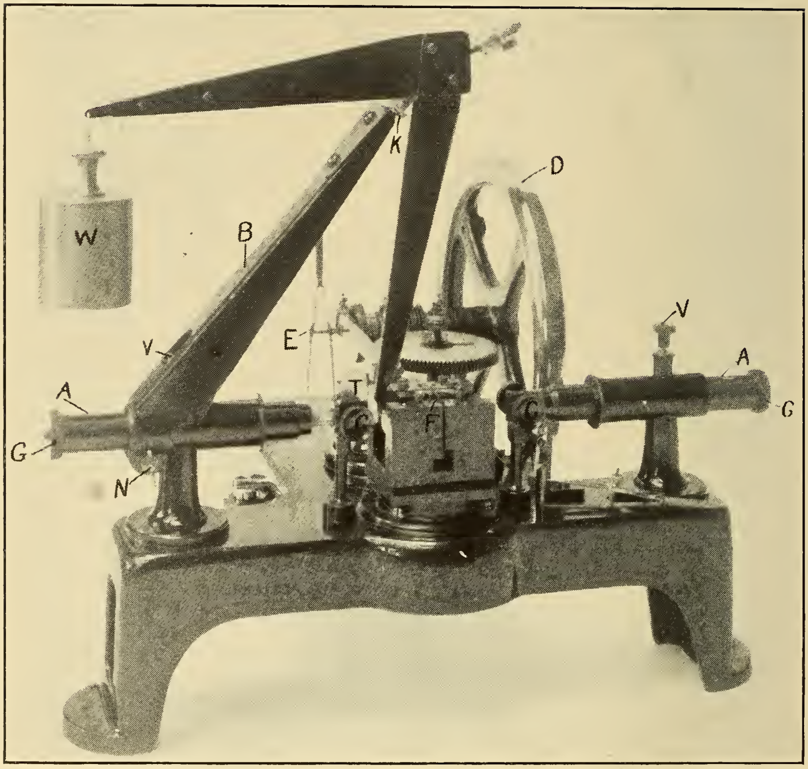

Fig. 5.—*Balanced bell-crank lever used in calibrating the Schopper folding tester*

ment is changed, or the folding blade replaced by one with slightly different width of slot, or play in the working parts results from wear, these marks have to be made anew. It is not long until a veritable grating on the clamp stem results and the proper reference line becomes a matter of considerable uncertainty. This procedure has sometimes been modified by using inside calipers to span the interval between fixed and movable shoulders of the clamp in order to make these scribed lines unnecessary.

This method of adjustment if carefully done is sufficiently accurate, but it has several disadvantages. Chief among these is the necessity of removing the clamp and housing and taking out the clamp in order to get its weight. Another disadvantage is that the freely suspended stressed spring tends to respond to vibration, such as that from machinery running in the building, which makes it difficult to bring the vibrating clamp to rest in order to measure the deflection. It is especially difficult to use inside calipers under such conditions. In adjusting the freely suspended clamp unit no account is taken of the friction of the supporting rollers when the clamp is operated in its normal horizontal position. As a result of these difficulties many folding testers are being used without proper periodic calibration.

2. CALIBRATION IN PLACE

(*a*) Frictionless Pulley.—In order to facilitate the calibration and make the adjustment of the clamp springs in their normal operating position the Bureau of Standards has for several years used the frictionless pulley as a means of applying dead-weight load to the horizontally moving clamp. In using such a pulley one clamp unit is removed out of the way and a fine wire is fastened in the other clamp, passed over the pulley, and attached to a 1 kg weight. One form of knife-edge pulley is shown in Figure 3. The purpose of such a large pulley is to minimize the friction and wear of knife-edge and bearing. However, since it was found necessary to calibrate the springs for only one position (that corresponding to a tension of 1 kg), the necessary movement of the pulley is very small, and hence a smaller pulley may be used. The more compact form shown in Figure 4 has its bearing attached in place of the removed clamp unit, the counterbalance being permitted to project through an aperture in the casting which forms the base of the folding tester; but with either form it is necessary to remove one of the clamp units in order to calibrate the other.

(*b*) Balanced Bell-Crank Lever.—An apparatus has now been devised by means of which the clamp springs may be calibrated and adjusted in place without the necessity of removing any part of the folding tester. This device is shown in Figure 5. It is essentially a counterbalanced bell-crank lever having its center of gravity on the knife-edge, *K*. The knife-edge bearing is at the end of the bracket, *B*.

This bracket is slipped over the tube in which the spring housing moves and clamped in place by means of the thumb nut, *N*. A recess inside fits about the shell of the vertical pin, *V*, which holds the movable spring housing in its outer position, thus insuring that the bracket is always clamped in the same position. The two arms, *KH* and *KM* (fig. 6) of the bell-crank lever are of equal length and are at right angles to each other. Figure 6 shows this arrangement diagrammatically. In this illustration are also shown the thin metal tab, *T*, which is clamped in the jaw, and the connecting link, *L*. A

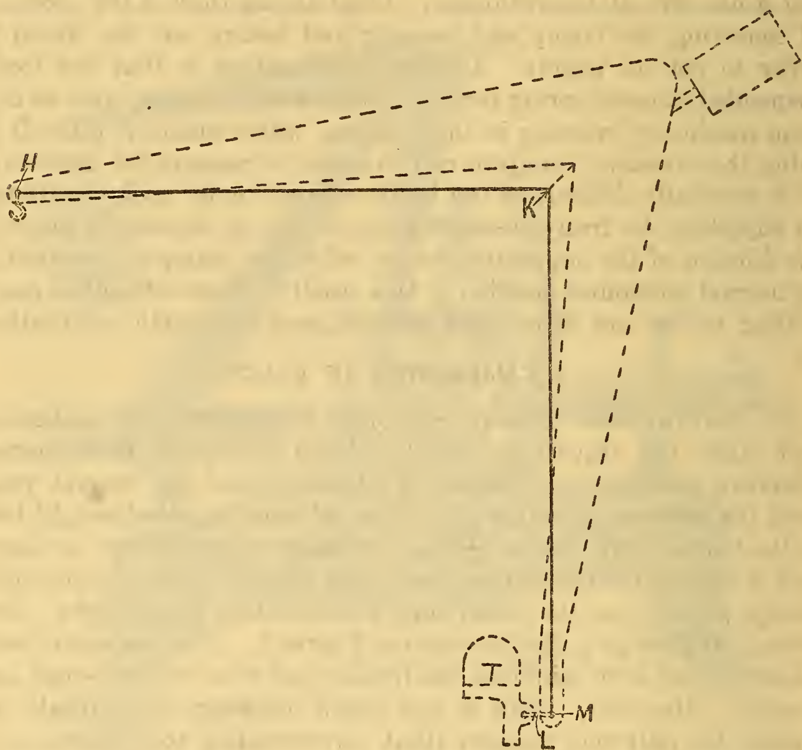

Fig. 6.—*Diagrammatic representation of the balanced bell-crank lever used in calibrating the Schopper folding tester*

hook is fastened to the end of the horizontal arm to which the 1 kg weight, *W*, is hung.

The calibration is carried out as follows, after making certain that all working parts are in good order and that the quadrantal rollers are properly adjusted and symmetrically arranged about the central position of the slot in the folding blade.

At the end of each spring housing, on the shoulder of the clamp-stem guide, a very small punch mark (a mere pin prick) is made. A second punch mark (or a fine-lined cross) is made on the shoulder of each clamp stem. The two marks on each clamp unit serve as reference marks for determining the displacement of the clamps, resulting from the deflection of the springs.

The two vertical pins, *V* (fig. 5), on top of the clamp-spring housing *A*, are lifted, allowing the spring housings to move toward each other as far as possible. The driving wheel, *D*, is rotated until the slot in the folding blade is in its central position directly in line with the two clamps.

A strong specimen about 0.13 mm (0.005 inch) thick, such as a piece of 28-pound bond or a strip of celluloid cut from a photographic film, is clamped in the jaws so that it lies smooth and straight between the clamps. The driving wheel is now rotated a quarter revolution, bringing the folding blade to its outermost position. The spring housings are then pulled out until the pins drop into position holding the housings in their outermost positions. By thus pulling out the housings after the crease is formed the distance by which the clamps are pulled away from the spring housings is made approximately the same on the two sides.

The distance is now spanned between the reference marks on the shoulders of the two clamps, using a separate pair of draftsman's bow dividers for each interval, so that the interval may be reproduced later in adjusting the springs when under the proper tension. These spanned intervals determine the position of each clamp with respect to its spring housing when the specimen is under the greatest tension to which it is subjected during the folding cycle. In spanning this interval it is convenient to place the point of one leg of the bow dividers in the punch mark on the shoulder of the housing and touch the point of the other leg lightly to the movable clamp while making the adjustment.

The pins are now released and the housing allowed to move inward again, after which the driving wheel is turned a half revolution until the folding blade is again in its outermost position, but this time antipodal to the previous position. The housings are then pulled out again until the pins drop into place. The spanned interval between reference marks on the two clamps should now be the same as for the original setting of the dividers. If this is not the case it probably indicates wear in the crank pin, which should be corrected by replacement with an oversized pin. It is necessary that the travel of each clamp—that is, the deflection increment of each spring—be the same for the two antipodal positions of the folding blade, otherwise the maximum tension to which the specimen is subjected each half revolution of the driving wheel will have a different value for the two half cycles.

In order to adjust the tension of the spring in either clamp unit the base of the bracket, *B*, is slipped over the tube in which the spring housing moves and is clamped in position, the bell-crank lever is put in place with the knife-edge on its bearing, the metal tab at the end of the vertical arm is fastened in the clamp, a 1 kg weight is hung on the hook at the end of the horizontal arm, and the spring is adjusted by turning the knurled nut, *G*, at the end of the spring housing until the distance between the reference marks is exactly that of the original adjustment of the dividers, *E*, for that clamp. In making the adjustment the instrument should be tapped lightly to bring the stressed clamp to a stable position. The operation is then repeated on the other clamp unit.

It sometimes happens that the two springs attached to the two clamps are not twin springs; that is, equal increments in deflection do not correspond to equal increments in tension for the two springs. If this is true, even though the springs are adjusted to give the same maximum tension with the folding blade in its outermost position, the specimen will shift so as to equalize the tension of the two springs as soon as it is free to do so when the slot in the folding blade is in the central position, since equal decrements in deflection give rise to unequal decrements in tension. When the specimen is again folded the maximum tension on the two ends of the specimen will no longer be the same. A similar condition may arise from nonsymmetrical arrangement of the quadrantal rollers. In order to test for this condition after the adjustment is completed, a specimen is clamped in place, the spring housings are pulled out (before the driving wheel is rotated), the driving wheel is turned a quarter revolution until the folding blade is in its outermost position and the distances between reference marks are spanned with the respective dividers. If the intervals are those demanded by the original settings of the respective dividers the tester is ready for use. If one interval is greater and the other correspondingly less than it should be the springs are not twins and can not be properly adjusted (assuming the rollers symmetrically placed). The only remedy is to replace the springs with matched springs.

There arises in this connection the question of the allowable error in adjusting the tension of the springs. Accepting Herzberg's figure of 1 per cent error in results per gram error in tension, and taking the experimental value of approximately 1 g change in tension for a change of 0.0356 mm (0.0014 inch) in deflection, and remembering that the reproducibility of results under the best of conditions is not better than 10 per cent, it follows that an error of thirty-six hundredths mm (fourteen-thousandths inch) made in the deflection interval in the adjustment of the tension of the springs would result in an error no greater than the normal testing error. If the calibration is carefully done the error due to maladjustment of the springs should not exceed 1 or 2 per cent in the folding results.

Another question which arises is that of the sensitivity and accuracy of the calibrating device, and how the results may be affected by irregularities in construction and in the use of the device. Experiments have shown the device to be sensitive to half a gram when loaded with 1 kg, which corresponds, according to Herzberg's figure, to one-half of 1 per cent in the folding results. Each arm of the bell-crank lever is about 16.5 cm (6.5 inches) in length. From this and previously mentioned data it is calculated that a difference of over sixteen-hundredths mm (six-thousandths inch) in the length of the two arms is required to produce an error of 1 per cent in the results. When the calibrating device comes to a position of stability under a load of 1 kg the end of the vertical lever is always within a few hundredths of a centimeter directly below the point of suspension. Even if it were half a centimeter out of place it would be raised only about one-tenth mm (four-thousandths inch) which amounts to only a few seconds change in the angle between the lever and the stressed spring. Hence, the error which might arise from the use of a device of this nature is entirely negligible.

3. RELATION OF ROLLER FRICTION TO THE ADJUSTMENT OF THE CLAMP SPRINGS

(*a*) Supporting Rollers.—By means of the device for calibrating the clamp springs in place it is possible also to measure the static friction of the supporting rollers and thus to get a good idea of the effect which the friction of the supporting rollers has on the folding results. If the weight is lifted and released very carefully the deflection interval will be less in proportion to the amount of roller friction. By comparing this deflection interval with that obtained in the normal procedure when the apparatus is tapped in order to bring the clamp to a stable position the difference in the two deflection intervals is obtained. From this and the established relations between deflection and tension and between tension and folding results the effect of roller friction on the folding results may be determined. In the case of the cylindrical rollers this has been found to be very small, but in the case of worn knife-edge rollers the effect is sometimes considerable. Friction equivalent to as much as 30 g added tension has been observed on a worn knife-edge roller and about a tenth this amount on the cylindrical-type roller.

(*b*) Quadrantal Rollers.—The friction of the vertical quadrantal rollers is usually assumed to be negligible, but that this assumption is far from the truth is shown by measurements made with the arrangement shown in Figure 7 combined with the procedure outlined above. A strip of paper is clamped by one end in one of the clamps, passed around one of the vertical rollers and subjected to a tension of 1 kg by means of the pulley arrangement shown in Figure 7. By a procedure similar to (*a*) above the difference in deflection interval which characterizes the friction of the vertical roller is determined, and from this measurement the tension equivalent of the friction is determined.

In the case of four testers, the rollers of which had just been cleaned and oiled, the friction of the individual rollers was found to be from 50 to 100 g, or from 5 to 10 per cent of the normal tension on the specimen. According to Herzberg's data this difference in effective tension should affect the folding results by some 50 to 100 per cent. The friction of a given roller is a fairly definite quantity, but since this friction differs from roller to roller it seems that it should be considered in the calibration and adjustment of the spring tension.

The rolling friction is, of course, less than the static friction. But the rollers are idle half the time and each time the crease is reversed a pair of rollers is set in motion from rest, so that twice each cycle the full static friction comes into play. The rollers also come to rest momentarily when the folding blade reaches its outermost point of travel. There is a question as to whether the spring tension should be adjusted to a definite amount, neglecting the friction of the rollers, as is now customarily done, or whether they should be adjusted so that the total effective tension on the specimen is a definite amount, including the roller friction. The latter procedure would seem desirable, but would be difficult if not impossible owing to the fact that the friction is not equal in the two rollers of a given pair which affect the same spring.

IV. CONCLUSIONS

1. The condition and adjustment of the working parts driven by the specimen being folded affect the folding results, in that poor condition or maladjustment of these parts cause unequal distribution of stresses, or more often give rise to differences in the effective tension on the specimen.

2. Small errors in adjustments are for the most part inconsequential, but errors in adjustments amounting to more than about 5 g in tension become serious. The friction in the rollers, particularly in the vertical quadrantal rollers, may be considerable. Static friction in the quadrantal rollers equivalent to 50 to 100 g tension appears to be unavoidable.

3. Since comparatively small errors in tension produce relatively large errors in folding results, it is advisable frequently to confirm the adjustment of the spring tension. This is most conveniently done by means of the balanced bell-crank lever described.

WASHINGTON, June 1, 1927.

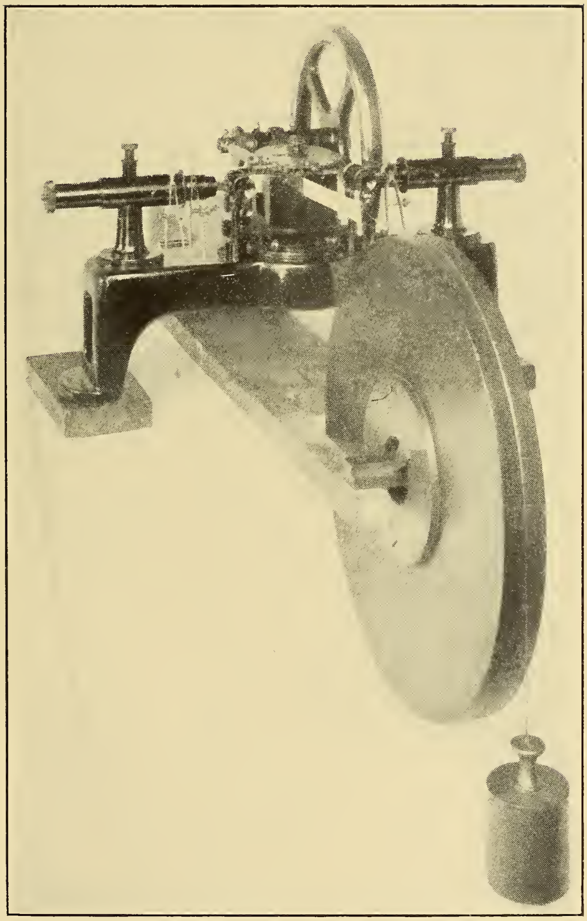

Fig. 7.—*Method of measuring roller friction*