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THE PLANOFLEX, A SIMPLE DEVICE FOR EVALUATING THE PLIABILITY OF FABRICS

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ABSTRACT

The Planoflex, a simple device for measuring the extent to which a fabric can be distorted in its own plane without producing wrinkles on its surface, was developed to evaluate the pliability of woven fabrics. Results of measurements on a series of cotton percales show an 88-percent correlation with their tactual pliability ratings. Comparison of the Planoflex with the Schiefer Flexometer and the Peirce Hanging-Heart Loop methods for evaluating pliability showed it to be as good as or better than these instruments with respect to the extent of the correlation between measured values and tactual pliability ratings, sensitivity to small differences in pliability, and ease of operation. The Planoflex may be used for testing all woven fabrics except those that are heavily starched.

CONTENTS

I. INTRODUCTION

During a study of the evaluation of the "hand" or "feel" of fabrics by objective means, particularly with respect to the pliability of fabrics or the ease with which they could be bent in the hands, it was observed that fabrics differed in the extent to which they could be distorted in their own planes without producing wrinkles on their surfaces. Furthermore, it was observed that the extent of this distortion for similarly constructed fabrics indicated their ease of bending. The desirability of having a method for evaluating pliability more practical and sensitive than those at present available led to further investigation of this distortion characteristic and resulted in the development of the Planoflex, which is described in this paper.

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Pliability is one of the components of hand usually judged by handling a fabric, and it depends chiefly on the ease of bending, or flexibility, of a fabric.[2] It depends also on a fabric's thickness and weight and, less directly, on its compressibility and surface friction. Since measurements of the ease of bending of fabrics by different testing methods involve these other characteristics to varying extents, the criterion of a suitable testing method, aside from its practicability and sensitivity, is the extent to which its results indicate pliability as appreciated by the hands.

Methods for evaluating pliability have been described by Peirce [1],[3] Schwarz [2, 3], Clark [4, 5], Schiefer [6], Gurley [7], and Saxl [8]. They measure either the deflection of a specimen produced by the weight of the specimen itself or the force required to produce a given deflection. The results are affected to a greater or lesser extent by the weight and thickness of the specimen. Some of the methods are not satisfactory for lightweight, soft-finished fabrics and others are considered too insensitive or too difficult to use for many purposes. The Peirce Hanging-Heart Loop method [1] and the Schiefer Flexometer method [6], representative of these two types of methods, were compared with the Planoflex method in the present work.

II. DESCRIPTION AND USE OF THE PLANOFLEX

The Planoflex is shown in figure 1. It consists of a metal base plate supported by a wooden frame, to which is fastened a movable clamp, *A*, a fixed clamp, *B*, and a hinged shelf. Clamp *A* is constrained by two connecting strips to move in an arc of 6-in. radius in such a way that it remains parallel to clamp *B*. A weight clamp, supported by the hinged shelf, is used to put the test specimen under a 2-lb tension when it is mounted.

A specimen 3 in. wide and 10 in. long, cut with the long dimension either parallel or perpendicular to the warp yarns of the fabric, is used for the test. A template may be used for cutting the specimen to size. It is essential that at least one edge of the specimen be parallel to the yarns in the lengthwise direction, a condition that is most easily obtained by gently pulling off a few yarns on one or both edges of the test specimen. A variation of $\pm \frac{1}{16}$ in. in the width of the specimen will not produce any appreciable variation in the result.

A specimen is mounted in the Planoflex as follows. One end is fastened centrally in the weight clamp, care being taken to have the crosswise yarns parallel to the edge of the clamp. Clamp *A* is moved into the position that makes the lengthwise edge of the specimen intersect corresponding points on the edges of the two clamps, *A* and *B*. Scales before the edges of these clamps assist in bringing clamp *A* into proper alinement. The test specimen is then fastened securely in clamp *A*. The hinged shelf is released and held in a vertical position by a spring clip so that the weight clamp hangs freely from the end of the specimen, subjecting it to a 2-lb tension. Then clamp *B*

[2] The terminology used in this paper is that proposed jointly by the American Society for Testing Materials and the American Association of Textile Chemists and Colorists [see Am. Dyestuff Reptr. **29**, 560 (1940)]. The term "flexibility" is used to designate the physical property of a fabric that has to do with its ease of bending. Although it is not quantitatively defined, it would be measured by some objective means. The terms "pliable" and "stiff" and their derivatives describe the ease of bending when determined by the hands, and thus involve sensitivity of touch and the ability of the nervous system to discriminate between different physical properties of the fabric.

[3] Figures in brackets indicate the literature references at the end of this paper.

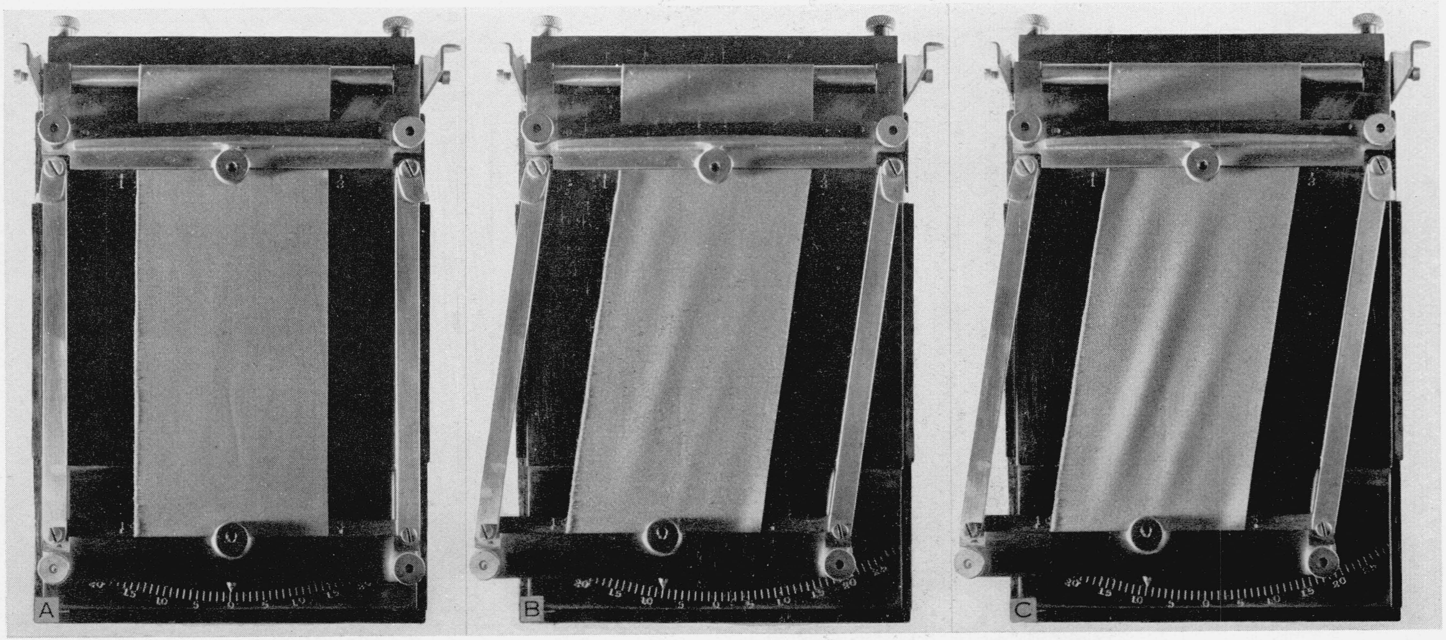

FIGURE 2.—*Appearance of specimen in Planoflex at three stages during the measurement.*

A, Specimen before deflection; *B*, wrinkles at end point; *C*, wrinkles 1 degree beyond end point.

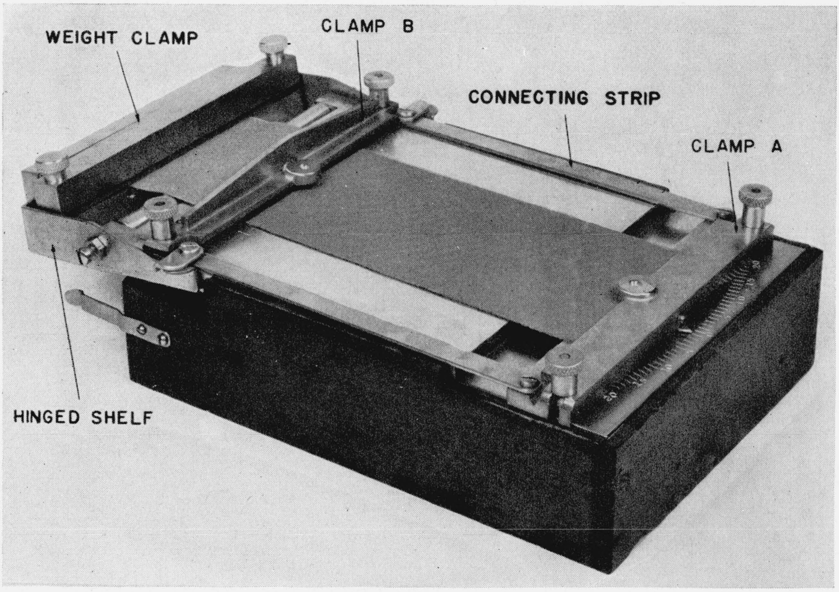

FIGURE 1.—*Planoflex.*

is tightened and the specimen is ready for test. The thumb nuts on clamps *A* and *B* are on toggle bolts, which may be swung out of the way, thus permitting easy removal and replacement of the clamp jaws.

To make the measurement, clamp *A* is moved slowly, first to the left and then to the right, to the angles at which longitudinal wrinkles first appear on the surface of the specimen. These angles, in degrees, are read on the scale below the pointer on clamp *A*. Greater precision is obtained by repeating this operation two or three times before recording the points at which longitudinal wrinkles first appear. The total angle through which the fabric can be distorted in this manner is the sum of the readings obtained on the left and on the right of the center.

The appearance of wrinkles is more readily observed if a lamp is placed about 1 ft to either side of the instrument and 6 in. above its surface. Figure 2 shows how the specimen appears at three stages during the measurement. Figure 2 (*A*) shows the appearance of a specimen before deflection. Figure 2 (*B*) shows the appearance of the same specimen when wrinkles were just visible on the leftward swing of the movable clamp. Two small wrinkles, one in the upper left-hand corner and the other in the lower right-hand corner of the specimen, appeared shortly after deflection of the specimen. These were ignored. The larger wrinkles running across the entire surface of the specimen determine the end point of the motion. Figure 2 (*C*) shows the appearance of the same specimen deflected 1 degree beyond the proper end point. The marked increase in the size of the wrinkles indicates the precision with which the end point can be determined.

The ease and precision with which wrinkles may be determined visually makes the Planoflex a very simple instrument to use. However, the end points of motion may be determined objectively, if desired, by using a scanning bar, which, when raised by a wrinkle, completes an electric circuit. Such a device was found to be satisfactory, although it has no particular advantage over the visual method of observing wrinkles.

III. RESULTS OF PLANOFLEX MEASUREMENTS AND EXPERTS' RATINGS OF PLIABILITY

Nineteen 80×80 cotton percales were used for the principal investigation. These fabrics were products of 10 different manufacturers and included printed and piece-dyed fabrics. Their warp counts averaged 86.5 threads per inch, their filling counts averaged 74.5 threads per inch and their weights averaged 4.85 square yards per pound. The variations from these average values were very small and are not believed to have affected the results.

The relative order of these fabrics, from the most pliable to the stiffest, was determined independently by each of eight textile men experienced in handling fabrics of this type. The average of the eight individual relative ratings for each fabric was taken to represent each fabric's relative pliability. The "average mean deviation"[4] of the experts' individual ratings for pliability was ±1.6 units of rating. The fabrics are listed in table 1 in the order of decreasing pliability

[4] The "average mean deviation" is used in this paper to signify the average, for all fabrics, of the average deviation from the mean of the observations for each fabric.

(increasing stiffness), as determined by the average of the experts' ratings. They were numbered to correspond with their positions in this table.

TABLE 1.—*Results of tests with Planoflex Flexometer and Hanging-Heart Loop on percales*

Fabric number	Experts' average pliability rating	Dreby Planoflex angle	Schiefer Flexometer torque	Peirce Hanging-Heart Loop bending length
		Degrees	*g-cm*	*cm*
1	1.9	12.3	101	1.54
2	3.9	12.0	111	1.74
3	4.1	11.3	122	1.80
4	4.5	10.8	120	1.57
5	4.5	10.5	122	1.63
6	5.4	8.5	123	1.49
7	6.6	10.3	117	1.55
8	8.4	16.8	109	1.62
9	8.9	8.5	122	1.76
10	10.4	7.5	143	1.76
11	11.2	6.5	147	1.66
12	11.4	7.0	168	1.82
13	12.4	11.5	122	1.58
14	14.5	4.3	166	1.67
15	15.2	3.0	184	2.07
16	15.5	6.5	194	1.73
17	15.5	3.8	207	1.83
18	17.6	1.8	230	1.82
19	18.3	4.0	214	2.13
Average mean deviation	±1.6	±0.4	±7	±0.04

The results of the measurements of the percales with the Planoflex are also given in table 1. Preliminary studies with these fabrics showed that the measurement of two specimens was adequate to obtain a reproducible average value of the angle and that it was only necessary to measure specimens cut in one direction, since the angles for specimens cut in the fillingwise and warpwise directions differed by less than 0.5 degree. Accordingly each reported value is the average of the angles observed for two specimens, both cut with the long dimension in the direction of the warp yarns, since it is easier to cut fabric specimens straight in this direction. The average deviation of the observed angles from their mean varied, depending on the magnitude of the observed angle (±0.8 degree when the observed angle was 16.8 degrees to ±0.3 degree when the observed angle was 1.8 degrees). The average mean deviation of the Planoflex results for all fabric specimens was ±0.4 degree. All the measurements were made on samples conditioned at least 24 hours in air having a relative humidity of approximately 65 percent and a temperature of approximately 70° F.

In order to determine the extent to which the results of measurements with the Planoflex correlate with the tactual ratings of pliability, the fabrics were first listed by sample number in the order determined by each of the two methods of ranking, as follows:

Planoflex	8	1	2	13	3	4	5	7	6		9	10	12	11		16	14	19	17	15	18
Experts		1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

According to the Planoflex method, fabric 8 was first, with the largest angle (16.8 degrees), and fabric 18 was last, with the smallest angle

(1.8 degrees). According to the tactual method, fabric 1 was first, with the lowest average pliability rating (1.9 units), and fabric 19 was last, with the highest average pliability rating (18.3 units). The objective order of the fabrics in each series was then correlated by the procedure described by Kendall.[5]

The correlation coefficient obtained was 72 percent. As shown by the arrangement of the fabrics above, fabrics 8 and 13 are the only ones markedly different in the two series. Without these two samples the correlation is 88 percent, indicating very good agreement between these two methods. These correlation coefficients were computed without regard to the differences between the measured values of the fabrics in each of the two series, many of which were less than the error of measurement. If consideration were given to these small differences in determining the objective order of the fabrics, it would be possible to show an even higher correlation between the Planoflex and tactual methods of evaluating pliability.

The anomalous behavior of fabrics 8 and 13 was also noted in the results of tests with the Flexometer and Hanging-Heart Loop methods, which will be given later. The agreement in results among the three test methods on the one hand and among the eight experts on the other as to the relative positions of these two fabrics in the series indicates that some characteristic or condition of these fabrics, not present in the others, has entered into the determination of their pliabilities. The differences between the number of yarns per inch, weight, thickness, coefficient of friction, resilience, and compressibility of these fabrics and the respective properties of the other fabrics have been examined, but they do not offer any explanation of the lack of agreement between measured and tactual ratings of these fabrics.

To compare the relative sensitivities of the Planoflex and the hands to the differences in pliability of these fabrics, the ratio of the spread of values obtained to their average mean deviation was determined for each series of values. This ratio is an indication of the number of distinct regions within the range of pliability exhibited by these fabrics which might be detected by the method of measurement. The data for the Planoflex gave a ratio of 37, whereas the tactual data gave a ratio of only 10. The sensitivity of the Planoflex relative to the hands may not be as great as indicated here, but it is apparent that it is considerably more sensitive.

IV. COMPARISON OF THE PLANOFLEX AND OTHER METHODS FOR EVALUATING PLIABILITY

To compare the Planoflex with other testing devices for evaluating pliability, the series of nineteen 80×80 cotton percales were measured with the Schiefer Flexometer and the Peirce Hanging-Heart Loop.

The Schiefer Flexometer is an instrument for measuring the torque exerted by a pair of specimens, so mounted as to balance out their weight, when folded to some predetermined angle. Preliminary

[5] The Kendall coefficient of correlation between two series of rankings is given by the equation $2\Sigma/n(n-1)$ where n is the number of members ranked and Σ is computed as follows: The members are put in objective order in the one series, which then determines the corresponding order of the rankings for the other series. Each member in turn of the latter sequence of rankings is compared with succeeding members in the sequence. Those pairs in the correct sequence are given a value of +1 and those in the inverted sequence are given a value of −1. The sum of these values is denoted as Σ. The method is described in detail by Schwarz and Winn [Technical Evaluation of Textile Finishing Treatments. III. Use of Rank Correlation for Comparison of Data. Am. Dyestuff Reptr. **29**, P400 (1940); Textile Research **10**, 453 (1940).]

studies showed that the geometric mean of the torques for an angle of fold in degrees equal to 430 times the thickness of the fabric in inches for warpwise and fillingwise directions gave the most satisfactory results. Four pairs of specimens of each fabric were measured, two prepared with the long dimension in the direction of the warp yarns and two with the long dimension in the direction of the filling yarns. The geometric means of the average values for warpwise and fillingwise directions are reported in table 1. The average mean deviation of the Flexometer results for all fabric specimens was ± 7 gram-centimeters.

With the Peirce Hanging-Heart Loop method, the extension of a strip of fabric in the form of a heart-shaped loop is measured, the extension being produced by the weight of the fabric itself. Four specimens of each fabric were measured, two prepared with the long dimension in the direction of the warp yarns and two with the long dimension in the direction of the filling yarns. The geometric means of the average values for warpwise and fillingwise directions are reported in table 1. The average mean deviation of the Hanging-Heart Loop results for all fabric specimens was ± 0.04 centimeter.

The correlation between the order of the fabrics determined by these two methods and the order determined by the tactual pliability ratings was determined by the Kendall method described before. For all 19 fabrics the Flexometer showed a correlation of 79 percent and the Hanging-Heart Loop, 49 percent. Fabrics 8 and 13 were displaced in the same direction relative to the other fabrics by the Flexometer results as they were by the Planoflex results, and they also accounted for most of the disagreement between the Flexometer ranking and the experts' ranking of the percales. Of the same two fabrics, only fabric 13 showed marked disagreement between the Hanging-Heart Loop ranking and the experts' ranking of the percales. When both these fabrics were removed from the series, the correlation coefficient was 88 percent for the Flexometer and 51 percent for the Hanging-Heart Loop. Thus the Planoflex and Flexometer methods are about comparable with respect to the correlation of their results with tactual pliability ratings and somewhat better than the Hanging-Heart Loop method.

To compare the sensitivities of these methods with the Planoflex and the hands, the ratio of the spread of values obtained to their average mean deviation was determined for each series of values as described before. The Flexometer data gave a ratio of 18 and the Hanging-Heart Loop data a ratio of 16, compared with 37 for the Planoflex and 10 for the hands. Each of the three testing methods is more sensitive than the hands, and the Planoflex is most sensitive.

In addition to the differences between the Planoflex, Flexometer, and Hanging-Heart Loop methods with respect to the correlation of their results with pliability and their sensitivity, there are several differences with respect to their ease and convenience of operation that are of considerable importance in applying them to routine testing. The Planoflex, insofar as it has been tested on different types of fabrics, is the only method that gives results which are for all practical purposes independent of the warpwise or fillingwise direction. All of the area of the specimen is distorted during the test, as compared with the relatively small part of the fabric specimen bent in the other tests. These conditions permit the measurement of fewer specimens to obtain a reproducible average value. The operation of cutting out and setting up a test specimen is done very easily. The instrument is direct reading. A complete test, including the preparation and measurement of three specimens of a fabric, can be completed in less than 5 minutes, excluding the time for conditioning the specimens. The mounting of the specimens for the Flexometer and their insertion in the instrument are delicate and tedious operations. The measurement itself is easily made, but there are subsequent corrections for zero points and spring calibrations that have to be made to obtain the value that is used as the measure of pliability. The Hanging-Heart Loop method utilizes the simplest apparatus. A definite technique in handling specimens for this test has to be developed to avoid erratic results. The observed values must be converted by means of the formula derived by Peirce to the quantities that indicate pliability

V. DISCUSSION OF THE BEHAVIOR OF FABRICS IN THE PLANOFLEX TEST

A consideration of the conditions involved in the Planoflex test will make more apparent the uses and limitations of the Planoflex for evaluating pliability.

The contribution of the physical properties of a specimen to its angle of distortion seems to be of two kinds.

First, there is a certain amount of free space between the yarns of the specimen that permits relative rotation of the warp yarns and the filling yarns at their intersections throughout the specimen. The free space available depends mainly on the size of the yarns and the number of yarns per inch. Since the contribution of this freedom of motion to the total angle of distortion is relatively large and practically independent of all but dimensional characteristics of the yarns, it cannot be expected that results with the Planoflex on differently constructed fabrics will be comparable.

After the free space is taken up, however, the yarns themselves are subjected to compression, as continued distortion of the specimen reduces its area. Depending on the physical characteristics of the yarns, a condition of instability is reached that results in a sudden disruption of the surface of the specimen. The ability of the yarns to give during this stage of the distortion is apparently intimately related to their flexural characteristics, since on similarly constructed fabrics the results of measurements with the Planoflex, Flexometer, and Hanging-Heart Loop are in substantial agreement. Other physical properties of the yarns, notably their surface friction and density, undoubtedly affect the extent of the distortion of the specimen. It would appear that either their effects are too small in proportion to the effects of the flexural properties or their effects complement the effect of the flexural properties in giving values that indicate pliability.

Since it is necessary to put the specimen under tension in order to obtain reproducible results, the specimen of any fabric that is too readily stretched will, after mounting, have a different construction insofar as the test is concerned than the fabric which it is supposed to represent. Thus measurements on fabrics which may have identical

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construction but which have different extensibilities will not be on a comparable basis.

VI. USES AND LIMITATIONS OF THE PLANOFLEX TEST

The Planoflex is well adapted to testing a wide variety of fabrics, as shown by measurements on the following representative types: cotton print cloths, broadcloths, poplins, organdies, twills, and sateens; rayon French crepes, twills, satins, and spun rayon fabrics of challis-like and linen-like finish; and wool and mixed wool-rayon uniform suitings and shirtings. With the exception of a very few fabrics in some of the groups, the results of measurements with the Planoflex were in agreement with the pliability ratings of these fabrics determined tactually by experts. The order of magnitude of the values obtained for the particular fabrics representing these several types is indicated in table 2.

TABLE 2.—*Range of Planoflex values for different types of fabrics*

Fabric	Range
Cottons:	*Degrees*
80×80 print cloths	2 to 16.
68×72 print cloths	10 to 25.
100×60 broadcloths	8 to 15.
100×40 poplins	12 to 23.
76×72 organdies	36 to 54.
68×76 twills	5 to 10.
65×110 sateens	2 to 30.
Rayons:	
165×72 crepes	29 to 35.
116×67 twills	36 to 42.
225×65 satins	37 to 44.
68×62 spun rayons:	
Challis-like	36 to 43.
Linen-like	31 to 35.
Wool and mixed wool-rayon:	
Uniform suitings	11 to 17.
Uniform shirtings	20 to 28.

Like other instruments for evaluating pliability, the Planoflex cannot be used indiscriminately to evaluate the relative pliabilites of fabrics of different construction. By different construction is meant different fiber construction, different yarns per inch in either direction, and different weight. Variations of ±5 percent in either the count or the weight of a group of fabrics should be considered the limits within which the results with the Planoflex are on a comparable basis. With fabrics having greater variations in these properties than the above, the results with the Planoflex should be examined carefully before any significance is attached to them. A few special fabrics, like tracing cloth, in which a heavy coating of starch has cemented warp and filling threads together, will not give measurable results on the Planoflex. Knit fabrics are too easily distorted and stretched to give values of any significance.

In addition to the use of the Planoflex for quantitatively evaluating pliability, there are two other uses to which the instrument can be applied with distinct advantage—namely, the evaluation of the effect of different finishing agents and technical control during finishing operations.

With a sensitive, reliable instrument for indicating quantitatively the effect of different finishing agents on a fabric, a finisher can select with greater certainty the better finishing agents for his purposes, not only with respect to the desirability of their effects but also with respect to the economy of their use. It should be pointed out that finishing agents have greater effects on some fabrics than on others, depending on the nature of the construction of the fabric and the magnitude of its effect on the hand in relation to the magnitude of the effect on the hand induced by the finishing agent. In addition, the relative effects of different finishing agents quite frequently vary when applied to fabrics made of different kinds of fibers. These facts make it clear that the selection of a finishing agent should be based upon the results of measurements on the same type and construction of fabric to which the agents are to be eventually applied.

The processing of fabrics involves a series of operations, each one of which may have an effect on the hand of the finished fabric. An easily made study of the effect of the different operations on the pliability of a fabric would lead to more accurate control of the operations, resulting in the production or reproduction of more uniformly finished fabrics. For this purpose an instrument, such as the Planoflex, that gives dependable results with a minimum of effort in a very short period of time would be desirable.

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