DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 153

AREA MEASUREMENT OF LEATHER

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ISSUED APRIL 24, 1920

PRICE, 10 CENTS
Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1920

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CONTENTS

I. INTRODUCTION—IMPORTANCE OF THE SUBJECT

In January, 1917, the Bureau of Standards, at the instance of the commissioner of weights and measures of the Commonwealth of Massachusetts, undertook the investigation of the methods and machines employed in the leather industry in the area measurement of hides and skins. Owing to the short time and limited staff available for the work, it was impossible to carry out the complete and exhaustive study of the field that its commercial importance would warrant. At the entrance of the United States into the war in April, 1917, the whole of the staff and facilities of the Bureau were devoted to military work, which precluded all but the briefest and most cursory consideration of the problem from that time until the end of 1918. Important and suggestive data were obtained, however, and some of these results are here presented as of possible utility in relation to further studies which may be undertaken, and of service in guiding designers and users of leather-measuring machines in their choice of mechanisms and methods. As leather-measuring machines do not enter into direct relationship with the ultimate consumer, their operation has, in general, not been given the close supervision by weights and measures officials that is accorded the more common trade measuring instruments, such as weighing scales, capacity measures, and the like. On this account, up to the time of the investigations reported in the present paper, no complete and suitable procedure for conducting tests of leather-measuring machines had been developed; no tolerances were used, nor had any comparative study of types been made.

The literature of this subject is very meager. The best material available up to the time of the investigation by the Bureau is to be found in "The Manufacture of Leather," by Davis.[1] The first edition of this book devotes a chapter of 12 pages to the subject of leather-measuring machines, including 13 figures and a list of United States patents issued in the interval 1790–1883, inclusive. The material of this chapter is almost entirely descriptive, covering both obsolete and existing types of leather-measuring machines. No information is given as to the performance possibilities or comparative operating accuracies of the different types.

In the 1897 edition of the above-named work the space devoted to leather-measuring machines is reduced to four and one-half pages by the elimination of a considerable amount of material descriptive of obsolete or undeveloped types of leather-measuring machines. In this edition, only two illustrations are given, one of a typical wheel machine and one of a pin machine. On account of the scarcity of satisfactory illustrations of leather-measuring machines, both of these are reproduced in the present paper. Like the chapter in the earlier edition, the later treatment by Davis gives no information beyond descriptions of the machines and the manufacturers' claims for them. No adequate data of the sort required by the designer nor any indication of the sources and types of error to be expected are given.

A pamphlet, "Suggestions to Sealers," issued by the department of weights and measures of the Commonwealth of Massachusetts, includes five pages regarding leather-measuring machines, comprising brief descriptions of the hand rack, the pin, wheel, and power machines, with suggestions regarding certain tests to be applied.

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[1] Henry Carey Baird & Co., Philadelphia, 1885; 2d ed., 1897.

The results of the Bureau's investigation, as comprised in the author's reports, were promptly and regularly forwarded to the Massachusetts commissioner of weights and measures, and by him transmitted to various representatives of the National Boot & Shoe Manufacturers' Association and the National Tanners' Association. The former association published in the report of the meeting of its executive committee of April 23, 1917, an extended report made by the Bureau of Standards under date of March 30, 1917, "On Certain Principles in the Design of Leather-Measuring Machines," which included a discussion of the principles of operation of the pin machine and the wheel machine, and an analysis of the sources of error of the latter, including the width of tires, spacing of wheels, overrun of wheelwork, effect of thickness of leather measured, and lost motion in the transference chains. The same association also distributed leaflets comprising the report of February 5, "On the Form and Material of Standards of Area for Testing Purposes," and that of February 12, which gives the results of an extended test upon which are based a great many of the conclusions regarding the serious inaccuracy of existing types of machines in service. The basis of this test was the measurement upon five different machines of five different calfskins ranging in area from 8.4 to 14.5 square feet. Readings were taken for each of these skins on each of the five machines, and the following tabular comparison was made with the actual areas of the five skins as determined by careful planimetric measurements conducted in the laboratories of the Bureau, careful correction being made for the shrinkage of the skins between the time of their measurement by the five measuring machines and their subsequent measurement by planimeter at the Bureau. This study also gave valuable data upon the effect of the overrun of wheelwork in occasioning serious errors of reading in excess.

Some information as to the serious difficulties met with in connection with these machines, as known to members of the leather trade, will be found in the January 18, 1917, and January 17, 1918, issues of the Shoe and Leather Reporter (Boston). In the earlier article indication is given as to the amount of variation in measurement which is commonly found in the service operation of the usual measuring machines. The comparative measurements made upon the five different machines using five different skins, as referred to above, fully confirmed these opinions, and showed that, of the five machines investigated, the average errors extended over the wide range of 4.4 per cent in excess to 0.1 per cent in deficiency.

TABLE 1.—Recapitulation of Comparative Results on Test of Five Leather-Measuring Machines, January, 1917

Serial number and actual area of skins (planimeter)	Readings of machine "A"				Readings of machine "B"			
	First reading	Second reading	Average of first and second reading	Reading at very low speed	First reading	Second reading	Average of first and second reading	Reading at very low speed
1: 12.40	12.87	13.06	12.96	12.35	12.45	12.50	12.48	12.35
2: 8.88	9.22	9.20	9.21	8.80	8.75	8.80	8.78	8.65
3: 14.46	14.87	14.90	14.88	14.35	14.40	14.55	14.48	14.40
4: 8.36	8.80	8.65	8.72	8.22	8.35	8.35	8.35	8.37
5: 12.59	13.35	13.50	13.42	12.58	12.90	12.85	12.88	12.80
Totals: 56.69	....	....	59.19	56.30	....	....	56.97	56.57
Error of machine	....	....	+2.50	−.39	....	....	+.28	−.12
Per cent error	....	....	+4.4	−.7	....	....	+.5	−.2

Serial number and actual area of skins (planimeter)	Readings of machine "C"				Readings of machine "D"			Readings of machine "E"		
	First reading	Second reading	Average of first and second reading	Reading at very low speed	First reading	Second reading	Average of first and second reading	First reading	Second reading	Average of first and second reading
1: 12.40	12.45	12.40	12.42	12.30	12.70	12.75	12.72	12.30	12.45	12.38
2: 8.88	9.05	8.95	9.00	8.80	8.95	8.80	8.88	8.90	8.80	8.85
3: 14.46	14.60	14.65	14.62	14.30	14.63	14.68	14.66	14.38	14.48	14.43
4: 8.36	8.45	8.40	8.42	8.20	8.50	8.50	8.50	8.50	8.40	8.45
5: 12.59	12.75	12.60	12.67	12.55	12.80	12.80	12.80	12.55	12.55	12.55
Totals: 56.69	....	....	57.13	56.15	....	....	57.56	....	....	56.66
Error of machine	....	....	+.44	−.54	....	....	+.87	....	....	−.03
Per cent error	....	....	+.8	−.9	....	....	+1.5	....	....	−.1

NOTE.—Areas are in square feet. A plus (+) error corresponds to a reading in excess; a minus (−) error corresponds to a reading in deficiency.

The very great commercial importance of the problem can be indicated by the statement—for which the National Boot & Shoe Manufacturers' Association and the National Tanners' Association are the authorities—that the leather annually measured upon an area basis in this country amounts to 900 000 000 square feet, worth $450 000 000. All finished leather, including boot and shoe uppers, book, enameled, and upholstery leather, are sold upon an area basis, and such hides and skins all have their selling price determined by the use of leather-measuring machines. In fact, a single machine may determine the selling price of several million dollars' worth of hides per annum. One such machine, tested during this investigation and found to have a large error in excess, determined the sale of about $2 000 000 worth per annum, and this large volume is believed to be no very unusual circumstance, since in a large leather warehouse in another city a business of $8 000 000 per annum was being handled on two and occasionally three machines. Moreover, the unit value of the leather may be very high—$1.50 per square foot or even more. The Boot & Shoe Manufacturers' Association, in one of the reports referred to above, has stated that 3 per cent variations of measurement are common. This statement becomes the more significant when it is recalled that practically this means that 3 per cent errors are common, as the investigations have shown that the variations of leather-measuring machines are almost without exception in the direction of excess measurement and the variations, therefore, distribute themselves all in the one direction from accurate measurement.

At this writing, also, the question of leather measurement is becoming prominent in England, and it is reported [2] that the standardization of the superficial measurement of leather has been discussed with the Board of Trade by a deputation representing the Federation of Curriers and Light Leather Tanners, and the Federation of Boot & Shoe Manufacturers, the former group representing the sellers and the latter the buyers. It appears that at the present time no law is in force in England by which dishonest measurement can be punished, and that little information is available regarding leather-measuring machines, while many users of such machines have no means of verifying their accuracy. The consumption of leather purchased by measurement in England is stated to be approximately 400 000 000 square feet per annum. Reference was made to the importance of protecting English buyers against inaccurately measured leather imported from abroad. Some discussion was given to the importance of the use of a template of the correct substance for carrying out tests and of adjusting the machine when changing the substance of the goods being measured. The speed of the machine was also mentioned as being important, and the statement made that the slow speed "will tend to show greater surface than when the leather is rushed through," which is, of course, an error of statement so far as our knowledge of the conditions can determine, the effect of high-speed operation

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[2] Leather Trades' Review, Mar. 26, 1919; The Leather Manufacturer, May, 1919.

being just the reverse according to our own experiments. Attention is called to the discrepancies due to shrinkage after glazing or laying in store.

The writer has just had opportunity to read the brief discussion of the leather-measurement question which appears in the annual reports of the Director of the British National Physical Laboratory, 1913–1915, which, may be briefly abstracted as follows:

> Under the direction of Mr. Attwell and at the joint request of the Board of Trade and the Federation of Light Leather Trades, an investigation into the behavior and accuracy of power-driven area-measuring machines has been undertaken, and machines in daily use tested at intervals. The secular variation in circular rubber templates, used for testing the machines, has been investigated, and attempts have been made to age such templates artificially.
>
> The investigation begun in 1913 was referred to in the succeeding annual report as having been completed, and the conclusions briefly stated therein. The first was that "the machine should be controlled by means of reliable and suitable templates which should be of approximately the same area and thickness as the skins under measurement." It appears from theoretical considerations that errors from 0.16 to 0.32 square foot must be tolerated with the different machines in use, although the errors found in practice exceeded the above figures, due largely to the fact that none of the machines was fully controlled by suitable templates. Reference is made to the necessity of providing in addition to the machine tolerance, an allowance to cover the shrinkage of the skins. It is stated that "it would appear to be impossible at present for a buyer to substantiate a claim against a seller in which the error on an individual skin did not exceed one-half square foot, or in which the mean error on a consignment did not exceed one-fourth square foot per skin. These figures might be reduced to about one-half by the use of an improved type of machine.
>
> The shrinkage of area templates made of rubber fabrics is again discussed, and shown to amount to as much as 1 per cent in 15 months in laboratory storage, and in some cases templates which have been used in the field show shrinkage amounting to nearly 2 per cent, most of which occurs in the early life of the template, suggesting artificial aging as a remedy.

So far as the number of leather-measuring machines in use is concerned, practically no data are available. We are informed, however, that about 200 such machines of all types were in use in Massachusetts alone at the beginning of 1917.

II. TYPES OF AREA-MEASURING MACHINES USED IN THE LEATHER TRADE

The types of leather-measuring machines known in the leather trade are four:

1. The hand frame—which is nothing but a screen divided into squares comprising one-fourth of square foot each, which is a superposed upon the hide to be measured and by counting of the included squares—affords a means of estimating the area to some degree of acuracy, depending upon the skill of the user. This

simple device is very little used at the present time because of its slowness and lack of precision, and the fact that it requires superior skill on the part of the measurer.

2. The pin machine, which provides for the weighing of a number of vertical rods or pins, the remaining pins in the group being relieved of communication with the weighing mechanism by the interposition of the hide being measured.

3. The wheel machine, which is the power-driven type now in most common use, and which performs the function of measurement by the traversing of the hide under a bank of uniformly spaced narrow wheels whose several rotations due to the passage of the hide are then mechanically totalized.

4. The planimeter, of which one or two special types of large capacity are available for the measurement of hides and skins. The planimeter, of course, gives a reading of area by manually tracing the outline or perimeter of the hide.

The present use of the planimeter, it is believed, is limited to very few instances, and it practically does not enter into the commercial measurement of hides and skins, but only into the determination of unit costs as involved in the number of shoe elements which can be cut from a known area. The planimeter will also be useful in standardization work, as in checking area standards used in the testing of ordinary leather-measuring, machines and, possibly, for the routine measurement of high-priced leather; its utility for the latter purpose depends upon a study of the economics of the operation, the cost of measurement being offset against the cost of the errors which may characterize competing instruments for the same purpose.

1. THE PIN MACHINE

The pin machine, which is no longer manufactured but of which a few examples built 25 years ago or more are still in operation, is illustrated in Figs. 1 and 2, and its construction and operation are as follows: A frame is supported pivotally by a knife-edge at the rear, and is so counterbalanced as to be lifted easily into and out of parallelism with the table upon which, in the first illustration, it is seen to rest. A part of the frame is connected by a cord to the load-supporting system of a suspended spring balance suitably hung in position above the table and the inclinable frame. The frame is made up of light wooden strips perforated at uniform intervals, and arranged in lines parallel to the plane of the spring balance seen in the illustration. Through each of the perforations a metal pin passes, loosely projecting some distance beyond the lower surface of the frame, and prevented from dropping through by an eye or head at its upper end. The table over which the frame is supported is made up as a grid of wooden strips perpendicular to the plane of the spring scale. The spacing of the bars in the grid is such that the pins coming through the frame above pass into the interstices and do not touch the grid itself. The lower ends of all the pins thus pass into the slots formed in the table, and all stand at the same level.

Thus, when all the pins are hanging through the slots in the table as described, their weight is carried by the suspended frame, supported in part by the pivot on which that frame turns and in part by the spring balance to which its front bar is connected. The spring balance, therefore, is in equilibrium under the load, and in this position may be said to register zero area. If, now, the frame is raised, a sheet of leather placed upon the table or grid, and the frame again lowered, so that it is parallel and close to the table though not in contact with it, those pins below which a portion of the leather is lying will be raised by it and will slide upwardly through the holes in the inclinable frame in such manner that their weight is no longer carried by it, as their weight is now received and supported by the leather rather than by the ring or head from which they are normally hung. There are thus some pins which are supported by the inclinable frame from the shouldered portion at their upper ends (the ring or head mentioned above), and some are supported by the leather, which lifts the shouldered portion out of contact with the inclinable frame by contact with their lower ends. The frame being thus relieved of the weight of the latter group of pins, the spring balance will change its reading in direct proportion to the number of pins which no longer pass into the slots of the grid but are supported by the leather, the pins being so proportioned that their weight varies inversely as their distance from the pivot about which the frame turns, so that each pin exercises the same turning effort about that fulcrum. This adjustment is accomplished by making the pins of the various rows of decreasing length and diameter, as may be convenient to gain the desired weight gradation. The spring balance, being graduated in units of area in a reverse direction from the ordinary weight graduation, gives increasing readings of area for what corresponds to decreasing values of weight of the pins supported by the frame. Simple means for changing the weight or turning moment of the inclinable frame are provided so that the

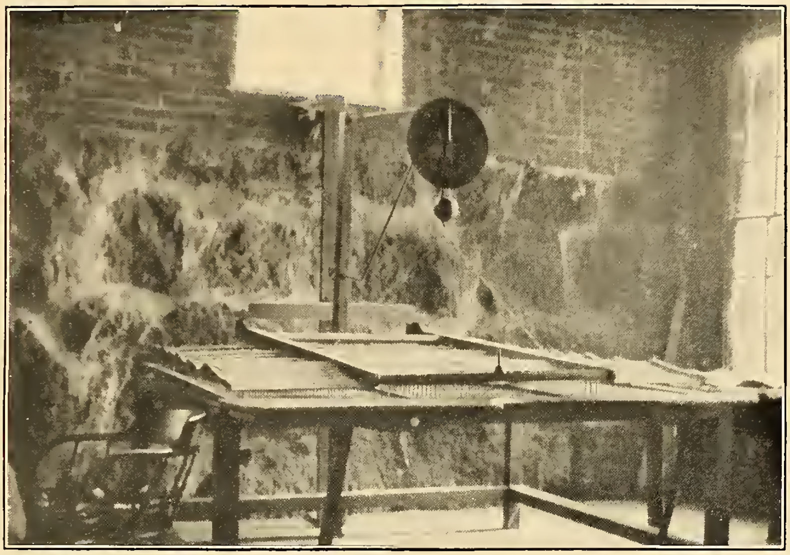

Fig. 1

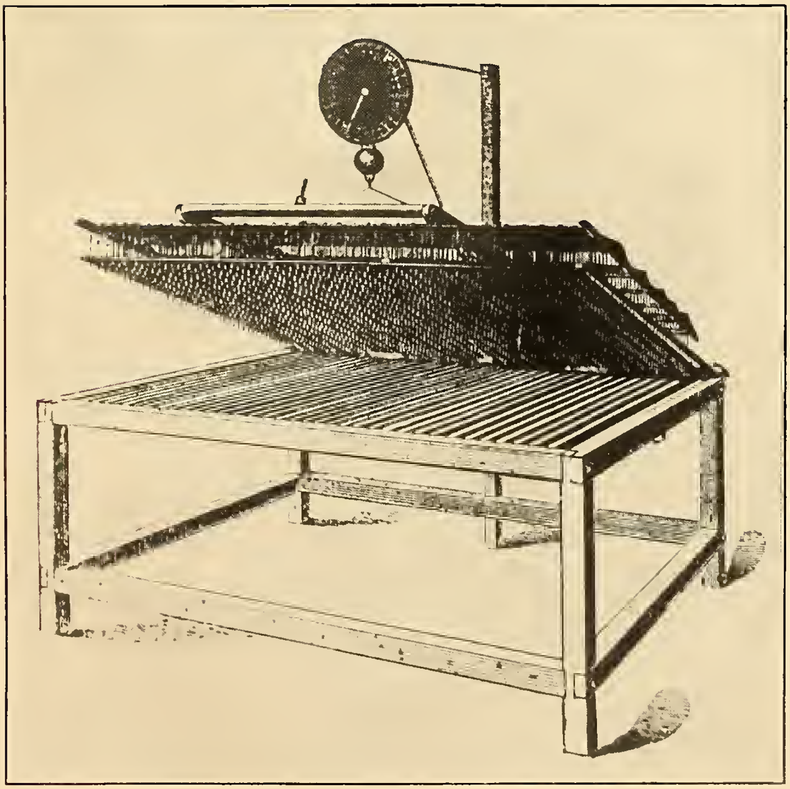

Fig. 2

scale may be made to indicate a zero reading when the pins all hang through the slots in the grid below—that is, when no leather is in place for measurement.

Obviously, if the number of pins could be indefinitely large (or, conversely, their spacing indefinitely close) an exact determination of the area to be measured would be obtainable in this way, were it not for the friction which would be introduced at the points where the pin slides against the guiding holes in the supporting frame. The degree of approximation thus increases with the closeness of the spacing of the pins in the frame. On machines of this type which were examined during the investigation, the spacing of the pins was for some unknown reason different in the two perpendicular directions, being 2 inches in a direction parallel to the plane of the spring balance shown and 1½ inches in the direction perpendicular to this plane. In practice, the friction of the pins passing through the frame, though they were very numerous, appeared to be so small as to be negligible, and no difficulty was had in obtaining readings which appeared to be quite free from errors due to this cause, as the spring balance would oscillate quite freely and for a considerable time after the frame was lowered to the table.

It would seem that if a well-constructed weighing scale is used, this type of machine should offer the possibility of very satisfactory accuracy when the pins are closely spaced. The use of a spring balance is no way essential, as almost any desired type of weighing scale can be employed for indicating the change in the weight carried by the frame.

In the book by Davis, above referred to, a machine having a similar essential principle of operation is described, but it is not known to what extent this type of machine came into use. It is the invention of Williams, Moore, and Hulburt, in 1879, and the weighing of the pins is carried out by the reception of their lower ends upon a weighing scale platform mounted below what corresponds to the grid or table described above. Under this system the pins which pass through and are not supported by the leather are allowed to exercise their effect upon the weighing scale, and the result is read upon a dial as in the device described in greater detail above. In this case, as before, the weight indicated corresponds directly to the area which is not covered by the leather, the reduction to area of leather being carried out by a reverse scale of graduations, as has been indicated. This machine is equipped with a sort of brake designed to check the oscillations of the weighing system before the reading is taken. It should be noted that in this type of construction, the pins do not touch the holes through which they pass, at the moment when the weighing operation is being performed, as in this position the pins are left resting free of their guiding holes, supported upright by flat end surfaces, either on the surface of the leather or on the surface of the weighing table below it; moreover, in this machine the pins are not required to vary in weight but are all uniform, as the system on which they are weighed is a true weighing scale having a platform moving parallel to its initial position instead of rotating about a fixed point. The indications are therefore independent of the position of the applied load.

The author has often heard the statement that the pin machine is inaccurate for the reason that it is subject to variations due to changes in the atmospheric humidity, temperature, etc., as affecting the dimensions of the wooden frame. As a matter of fact, this defect, the importance of which has doubtless been overestimated, is not peculiar to this type of machine but to the materials of its construction, and can be made quite negligible by the use of other material for the framework. In fact, it would be quite possible to use a metal framework having a small or negligible coefficient of expansion, so that the apparatus would be even less affected by temperature changes than are the existing types of wheel machines.

The advantages of the pin machine are obvious. It is simple in construction, cheap to manufacture (its cost should not exceed one-third to one-half of that of the wheel machines), it affords possibilities of very satisfactory accuracy when a sufficiently large number of pin elements are used, and it eliminates, moreover, many of the sources of error common to the wheel machines as, for example, that due to overrun of wheelwork, that due to the width of tires (the analogous error is of no moment in the pin machine, since the area of the ends of the pins can be very small), and that due to the thickness of the leather. The disadvantages principally raised in objection to this type of machine are, first, that it is slow in operation; and, second, that it does not take account of the area involved in the concavity or bellying of the hide.

So far as the first objection goes, it is believed to be overdrawn. The author, in a few observations made without special preparation, upon the use of the pin machine in comparison with the wheel machine, each in the hands of an experienced operator, found that the former required not more than 30 per cent more time per skin than the latter (pin machine, 12 seconds per skin; wheel machine, 9 seconds per skin); this despite the fact that the wheel machine was clearly overspeeded, as were most of the wheel machines observed. (See under Overrun of Wheelwork, below. As explained more fully in that section, any rational comparison of the speed of operation of the two types will require that the wheel machine be operated at a speed known to be low enough that the overrun error does not exceed a suitable small tolerance.) An item in a Peabody, Mass., newspaper refers to a competitive trial between the pin machine and the wheel machine, and actually credits a higher speed of operation to the former.

2. THE WHEEL MACHINE

(*a*) Principles of Operation.—The wheel machines operate upon a different principle, which may be briefly described by reference to the appended sketch (Fig. 3) representing any desired irregular area. Imagine that parallel lines be drawn upon such an area dividing it into strips of uniform width. The area of each strip will then be given by the product of its width into its average length and the area of the whole figure by the common width of the strips multiplied by the sum of the lengths of all the

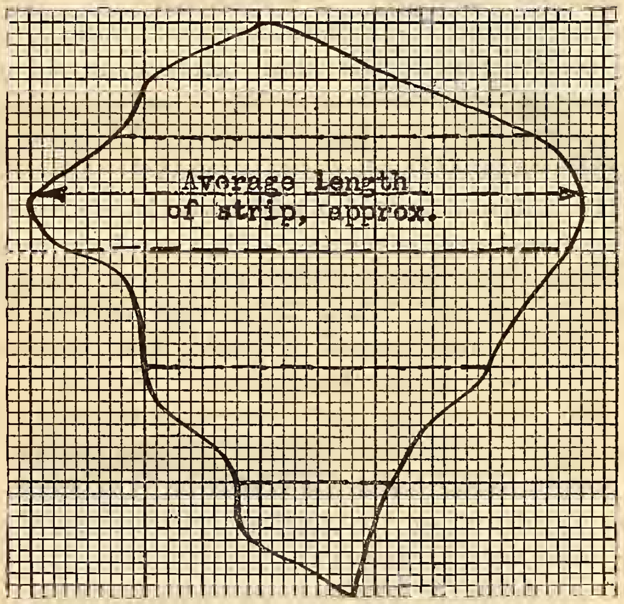

Fig. 3

strips. Now, if the irregularities of the outline to be measured are not marked by sharp discontinuities, the average length of each strip is determined approximately by the length of its middle line or median, and it is upon this assumption that the operation of the wheel-type machine is based. The measurement is carried out mechanically somewhat upon the following principle: The irregular area to be measured is drawn through the machine by a feed-roll, the construction being such that the leather in its passage produces rotation of the members of a series of parallel, uniformly spaced wheels when, and only when, leather is in contact with and passing under such wheels. Each wheel, therefore, rotates through an angle which is proportional to the length of the middle line of the strip which extends on each side of that wheel a distance equal to half the space between the wheels. If now, the rotations of the several wheels are totalized and that sum is multiplied by a constant, the result will be in units of area, and will represent an approximate integration of the irregular figure measured.

(*b*) TYPICAL DESIGNS.—(*1*) *Chain and Lever Totalizing Gear.*—In the actual construction of the wheel machine, an old model of which is shown in front elevation in Fig. 4 and in transverse section in Fig. 5, the roller *B*, which extends the full working length of the machine, rotates continuously clockwise. The wheels, *A*, which are the uniformly spaced, parallel wheels referred to above, rotate by frictional engagement with *B*, a small clearance being allowed between the pinion affixed to the axis of *A* and the segmental gear, *C*. If, now, a hide be inserted between *B* and *A*, wheel *A* is slightly lifted, the axis of *B* being fixed, and the pinion affixed to *A* at once engages the segment *C*, causing *C* to rotate clockwise until the extremity of the strip over which *A* is passing has passed out from between *A* and *B*. At this instant *A* drops back into contact with *B* and the pinion on *A* is thereby disengaged from *C*, whereupon the pawl seen in the figure prevents retrograde rotation of *C*. Segment *C*, then, in each case describes an arc proportional to the length of the median of the corresponding strip of the hide.

The travel of the several segments *C* (or in some cases complete gears, performing an identical function) is totalized by a system of chains passing over pulleys mounted on levers, the lever system being so arranged that the contribution of motion due to the winding up of individual chains on the drums affixed to the center of the

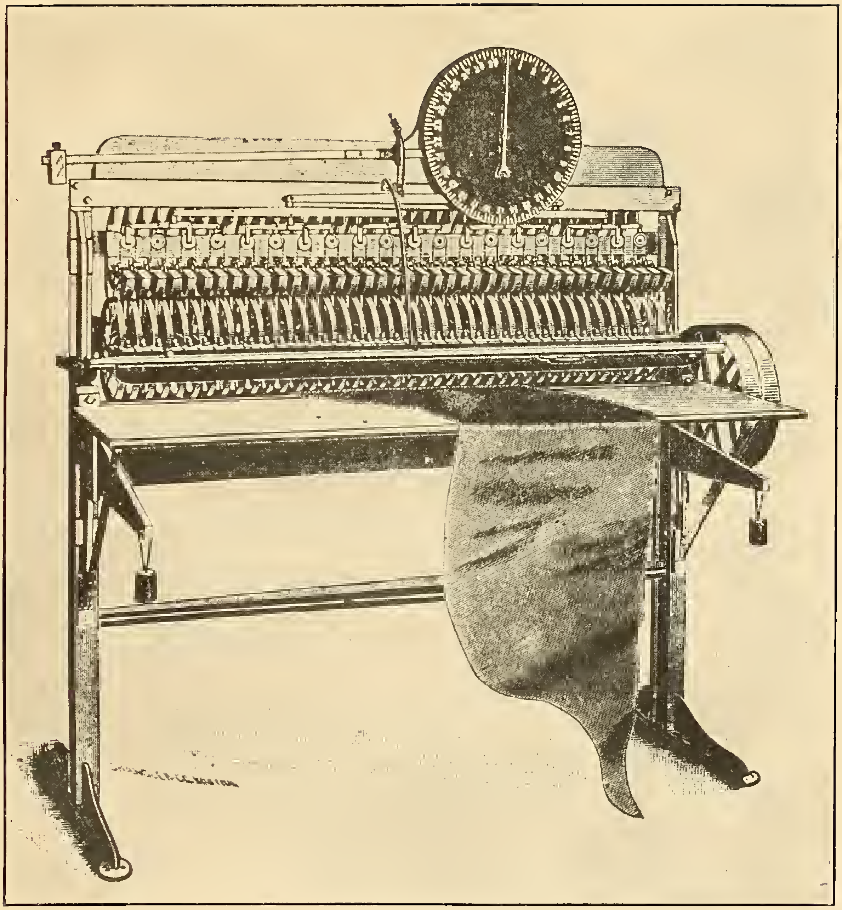

Fig. 4

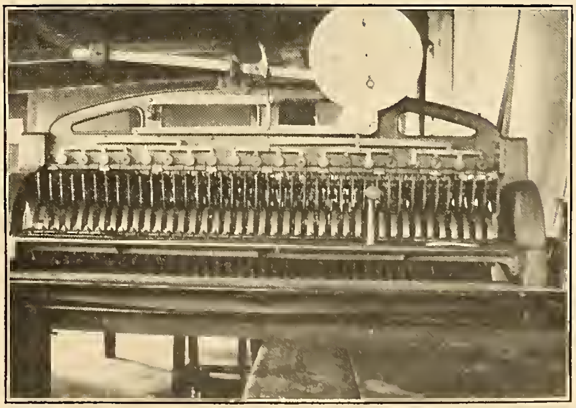

Fig. 7

segments *C*, is transmitted in reduced amount, but in equal reduction for every chain, to a single rack or segmental gear f^1 driving the pinion of the indicator at which the reading is obtained. In brief, then, the lengths of the several parallel medians of the irregu-

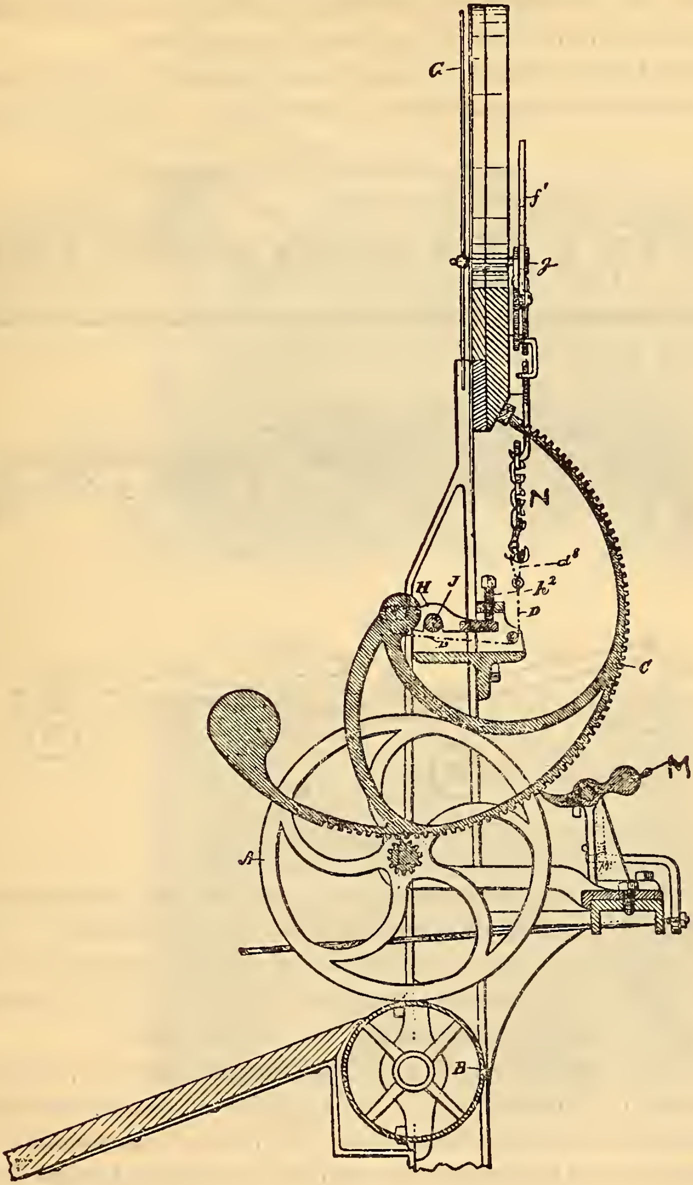

FIG. 5

A, traversing wheel carrying at its center the traversing wheel pinion; *B*, feed roll; *C*, accumulating segment (or gear); *M*, pawl restraining retrograde movement of *C* until machine is zeroized by lifting all pawls; and *N*, transference chain.

lar area are measured individually by the rotation of uniformly spaced wheels, and the amount of motion of these several wheels is totalized by a suitable lever system and, finally, through a suitable rack and pinion movement, registered upon a dial.

The next figure shows a typical lever system by which the uniform reduction of displacements is carried out. It will be observed that this leverage is so arranged as to produce the same reduction of movement of any chain when measured at the point d^{12}. Detail dimensions of the lever system by which this end is obtained need not be cited, as a suitable arrangement can always be designed upon the well-known principles of the simple lever.

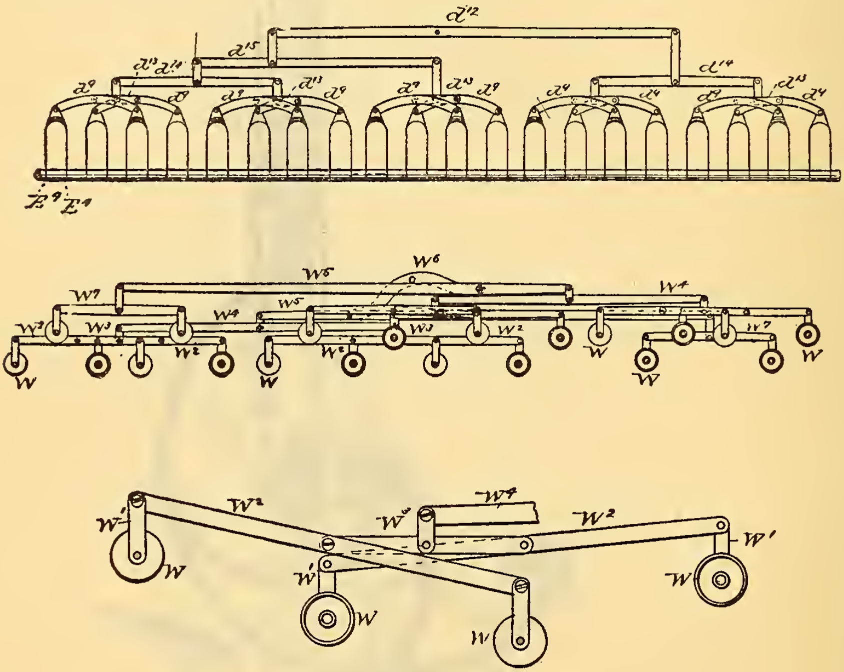

Fig. 6

When it is desired to reset the pointer to zero to permit the measurement of another skin, a bar engaging all of the pawls above mentioned is operated, disengaging the pawls from contact with the segments and permitting the segments to return to their lowermost position, propelled by their own unbalanced weight. Leather bumpers are usually included to assure uniform and shockless stoppage of the segments, as they return to their zero position. Machines of this type are usually graduated to 30 square feet by increments of one-eighth or one-fourth of a square foot. A few machines have a capacity of 60 square feet by one-fourth of a square foot.

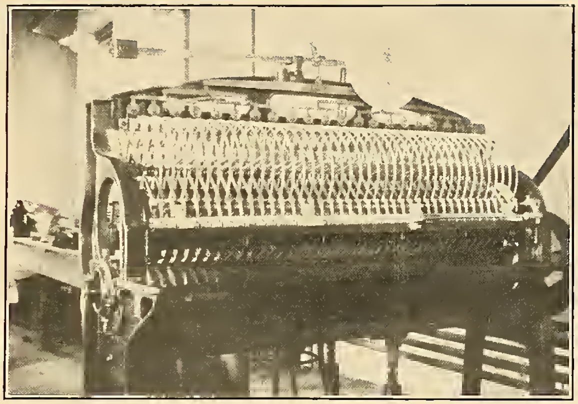

FIG. 8

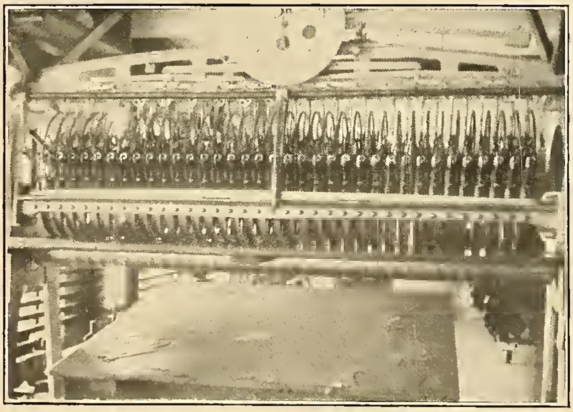

FIG. 9.—*Typical wheel type leather-measuring machines*

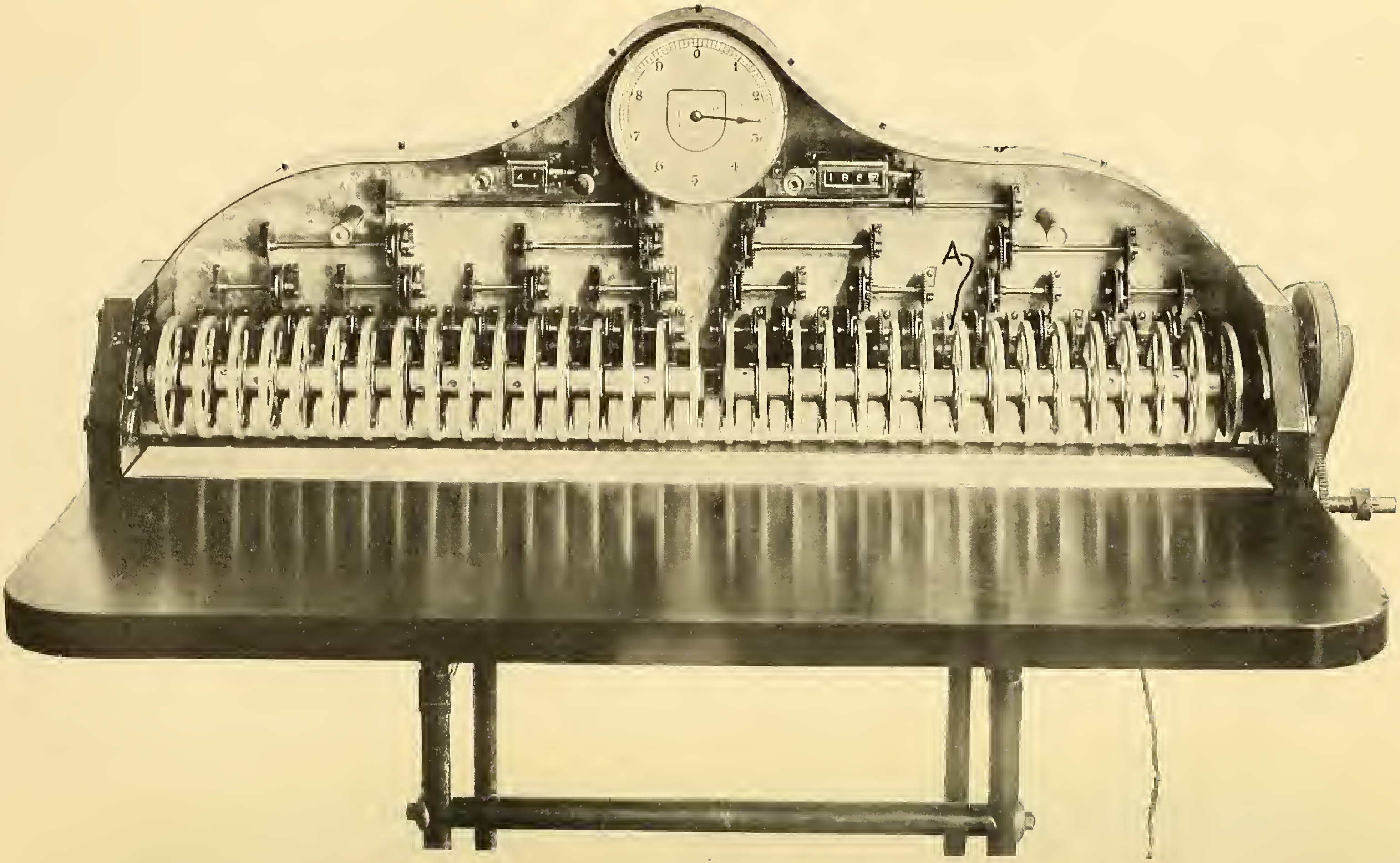

FIG. 10

In another design, operating upon this same general principle, the segments, *C*, are extended to full circles with teeth over the whole circumference. Instead of permitting these wheels to revert to the initial position, the machine is zeroized by unclutching the winding drums at the centers of these gears and restoring the drum itself to its initial position. This method is designed to eliminate the wear of the segmental gears used in the other type, which is, of course, greatest at the portions of the circumference near the initial position of engagement. The use of continuous forward rotation of the accumulating gears is, however, associated with a disadvantage, in that the use of a balanced gear definitely aggravates the error due to overrun of wheelwork, as will appear in the later discussion.

(2) *Differential Gear Totalizing System.*—Another type of totalizing train only recently developed and not yet ready for the market is based upon the principle of differential gearing. The appended Fig. 10 illustrates the arrangement used in an early model of this machine. Each measuring wheel is pivoted between a pair of narrow-tired disks which are rotated by the feed roller, and serve to smooth and direct the skin as it passes through. As in the machines using the chain-and-lever totalizing gear, the measuring wheels rise at the entrance of the skin, due to its thickness, and thereby effect engagement with accumulating gears. These gears, however, are not associated with a winding drum but engage in pairs with a differential gearing homologous to that used in the rear-axle assembly of an automobile, except that its function is fulfilled by the use of a compact arrangement of spur gears only, obviating the use of bevel gears.

To understand the manner in which this gearing is used to effect the totalization, consider an ordinary automobile of which the speed-change gears are in neutral or the clutch disengaged, the rear wheels being jacked up. If now the right-hand rear wheel is held stationary and the left wheel turned m revolutions, the clutch shaft or "propeller" shaft will rotate through some other number, say n, of revolutions, depending upon the gear ratio of the car. Similarly, if the left-hand wheel is held stationary, and the right-hand wheel rotated m revolutions, the clutch shaft will rotate through the same number n revolutions. If, however, both rear wheels are rotated in the same direction the same number of revolutions m, the propeller shaft will be found to rotate through twice as many revolutions as before, namely $2n$, and this will be the case whether the *m* revolutions described by each of the two rear wheels takes place simultaneously, or successively, or at the same or different rotational speeds. If the right-hand wheel rotates through a different number of revolutions than the left-hand wheel, the number of revolutions of the propeller shaft will be proportional to the sum of the rotations of the two wheels, also without regard to whether or not the rotations were carried out at the same time and at the same speed.

An exactly similar sort of summation takes place in the type of leather-measuring machine now under discussion. If one traversing wheel is rotated, and the other of that pair remains stationary, no leather passing under it, the intermediate totalizing shaft *A* rotates only half as far as it would were both members of the pair rotated by the same amount; and when the rotations are unequal in amount, the intermediate shaft *A* rotates by an amount which is proportional to the sum or the average of the rotations of the two members of the measuring pair.

The measuring wheels are thus grouped in pairs throughout the machine, and the intermediate totalizing shafts similarly "feed" their several rotations by pairs into superior intermediate totalizing systems, until finally after several collections and averagings, the rotation is transmitted to the dial mechanism, which receives a movement proportional to the average and hence to the summated movement of all the measuring wheels.

As in other wheel machines, a ratchet and pawl are provided to prevent retrograde rotation, which in this case would be induced by the reaction effect of adjacent gear trains. In addition to the usual dial for registering the area of the individual skins, this machine provides a counter to record the number of skins measured, this being operated by the action of resetting; and an integrating dial, to show the total area of all skins measured. In the machine shown, the measuring wheels are spaced only half as far apart as in the types already described. Other things being equal, this affords, as will appear later, a considerable improvement in the accuracy of approximation to be attained in the measurement.

Some reference has been made in conversations with the author, to a type of wheel machine in which radial pins carried in the several traversing wheels are depressed by the contact of the hide and by that depression engage a suitable accumulating mechanism. So far as is known, only one such machine has been brought into this country, and information about its operating principles and performance is very meager. It has been said however, that the particular machine imported was not successful, owing to extreme delicacy of mechanism, necessitating frequent adjustment or repair.

(*c*) SOURCES AND DETERMINATION OF ERRORS.—(*1*) *Spacing of Wheels.*—As can be easily understood without special explanation, the accuracy of approximation in the integration of an irregular area by the principles exemplified in the wheel machine is increased as the distance between the parallel measuring wheels is decreased. The practical considerations involved in the mechanical construction, such as the necessary clearance between neighboring parts and the cost of manufacture, will set a limit upon the closeness of spacing possible. The distance between centers of the rims of measuring wheels in the types of machines now commonly used, is 1½ inches.

One point of importance to be noted in connection with the errors due to insufficiently close wheel spacing is that when a tolerance of error is established upon the area measurement carried out upon the machines and a certain fraction of this error is allotted, as is requisite, to that due to the spacing of the wheels—the maximum wheel spacing permissible, to insure accuracy within this limit, can be closely calculated when a suitable outline or type of the area to be measured is determined upon and established as a standard for the purpose. H. M. Roeser, of the Bureau of Standards' staff, has given careful study to the relation of the closeness of spacing of the measuring units to the accuracy of area approximation, and is in a position to advise in detail as to the methods to be followed by the designer of a leather-measuring machine with respect to this phase of the problem. Obviously the magnitude of the error due to interval between wheels is a function of the irregularity of the outline of the hide. The more smoothly outlined the figure, the greater can be the interval between measuring wheels, for a given allowance of error, while an extremely jagged perimeter might require three or four times as many wheels per unit of machine length to permit of attaining the same degree of accuracy. Therefore, we find in this consideration, as in others to follow, a compelling reason for the adoption of a standard form of test area, a matter which fortunately raises no important practical difficulties.

(*2*) *Width of Rim.*—The next source of error is also dependent upon the shape or figure of the area measured. It will be recalled from the general discussion of this type of machine that it is the function of the measuring wheels to measure the middle ordinate of the strip which each wheel traverses. This could be done with perfect accuracy only by a wheel with an infinitely narrow contact surface or rim, and any approximation to this requirement is, of course, impracticable with present designs, because of the necessity of getting sufficient traction to drive the relatively heavy and resistant mechanism by tractive contact between the periphery of the wheel and the surface of the hide to be measured.

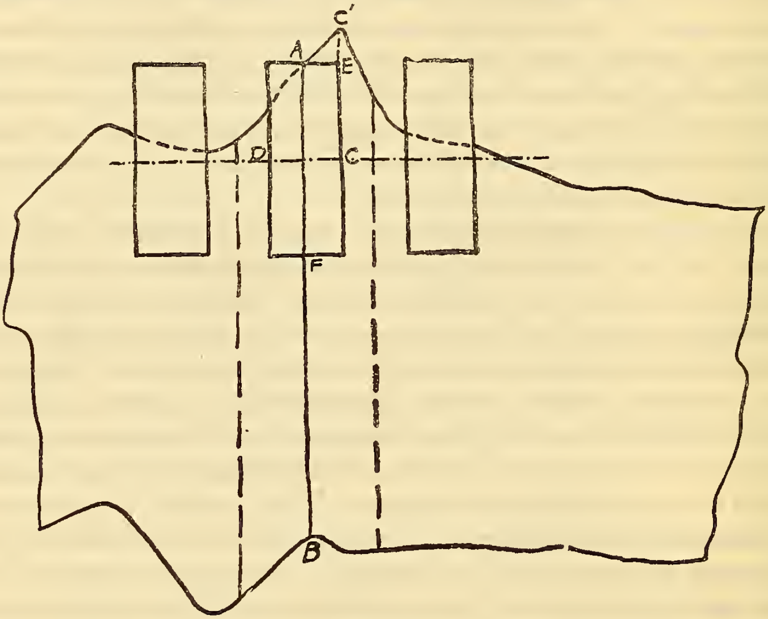

Fig. 11

Fig. 11 shows how a finite width of rim of the measuring wheel results in an exaggeration of the movement of the traversing wheels. If *AB* is the middle line of the strip which wheel *DC* is to measure, its length can be correctly measured only by a wheel which travels along the line *AB* and touches that line only. If the wheel has width, it touches a zone of which *AB* is the median, and continues to turn until every part of its tire has left contact with the hide, or in the sketch, *ADFCE* being the plan view of an exaggeratedly wide-rimmed wheel, until the point *C* of the wheel and *C′* of the hide leave contact (the thickness of the hide being neglected for the moment, this being a cause of additional delay in the completion of the traverse). Thus the ordinate of the hide is overmeasured by the amount *EC′* which represents the excess of rotation of the wheel consequent upon the existence of driving contact outside the median line of the strip.

It will be noted that this effect, which is an important one, invariably tends toward overmeasurement, and that like the preceding type of error it is the more in evidence on irregularly or jaggedly outlined hides, since on such hides the difference between the middle ordinate of any strip and the longest ordinate within the purview of the measuring wheel is enhanced. The magnitude of this error for any given width of tire, as with the wheel spacing in the preceding section, is easily calculated, and when a limit is set upon its contribution to the total error of the machine the maximum allowable width of the wheel rim is readily established, a standard form of area again being postulated for the purposes of the investigation.

As has been suggested, this type of error indicates a very definite and desirable trend in the design of leather-measuring machines, namely, that the frictional and other resistances shall be reduced to the lowest possible value, to the end that a minimum of traction shall be required to drive the measuring disks. Reduction of the driving traction will proportionately reduce the width of wheel rim required, with a consequent improvement in the performance of the machine. There is no reason whatever to suppose that the modification here suggested will offer any serious technical difficulties, although, to be sure, it does involve to some extent the simplification of mechanical detail, as it is eminently desirable that the number of moving parts be reduced in order to make available the most potent means of obtaining the desired reduction in the driving force required. The use of high normal unit pressure between the wheels and the leather to obtain the necessary traction is, of course, out of the question, as that method would involve serious danger of marking and disfiguring the finished surface of the skin.

With regard to the matter of excessive width of traversing wheel rim, it may be noted that the author had opportunity to examine one model of a leather-measuring machine in which the traversing wheels or what corresponded to them, were constructed as a bank of rolls, filling in *all* the space available, so that the exaggeration of rim width had been carried to its highest possible limit, the width of each rim thus being equal to the center to center distance between traversing wheels. This is indicative of a number of features which would permit the user of a leather-measuring machine to obtain increased reading on hides and skins, while the machine would still pass the usual accuracy tests applied. It will, of course, be understood that such a wide-rim machine as has been described would give accurate results on a rectangular test pattern, if this pattern were passed through normally, without being inclined to the common axis of the traversing wheels, though when passed through slantwise the excess of reading should be very apparent.

(3) *Overrun of Wheelwork.*—In all wheel machines, there will be some error due to the delay of the accumulating gear in picking up the velocity corresponding to the movement of the hide passing under it, since the wheel must be accelerated from rest by the pinion of the traversing wheel at the moment the latter has made contact with the hide. After the hide has passed out from contact, the accumulating wheel will tend to continue its rotation and will so rotate until its kinetic energy is absorbed by the frictional resistances of the mechanism and by such restoring or counterforces as are present, such as counterbalance weights, or unbalanced wheels or segments.

This error is quite large in some of the existing wheel machines, and it should be especially noted that it can not be considered as of small importance on the supposed ground that it will produce an error of constant amount in excess, and will, therefore, be cared for in the calibration of the machine. Even if the error were constant, either absolutely or relatively, at any speed, proper control of the machines would then require that a sensitive and reliable speed indicator or tachometer be part of the equipment. The only possible means for correction of this error, if it could be rectified rigorously, would be the setting of the pointer so that it would start back of the zero point, the retrograde shift of the zero being made equal in amount to the determined value of the overrun error. This is manifestly impracticable even under the best conditions, even if it were not for the fact that the error is not constant but a function of the outline or figure of the hide as well as of the number of wheels operative in a given measurement. The reason for this is clear; every time the traversing wheel pinion is lowered out of engagement with the accumulating gear, the latter spins forward a certain more or less definite amount, depending upon its previous rotational velocity, its moment of inertia, and the resistances of friction and gravity and other forces which oppose its movement. Now if the outline of the hide is such that a given accumulating gear is engaged and disengaged a second time in the traverse of the hide, the error is doubled, approximately, due to the second opportunity of the wheel to spin ahead of its proper final position of rotation.

Experiment has shown, as will be seen on page 24, that every increase of speed of rotation will produce an increase in the readings of area obtained, and when once the contribution to the total error or variance of the machine that is deemed permissible as resulting from this cause alone, is decided upon, the correct limiting speed of operation can readily be determined by experiment. To do this, the machine will be operated with the same standard of area or with the same series of standards, beginning with a very slow speed of operation, so low that the overrun error is quite negligible, and increasing by steps to some higher speed. A curve will then be plotted with the actual speed of rotation as abscissas, and the increase of reading over the reading corresponding to the initial very slow speed as ordinates. The value of the speed of rotation corresponding to the point where this curve crosses the horizontal line defining the permissible limit of error due to overrun effect alone will be the maximum allowable rotational speed. Its determination in the manner described will present no difficulty. If there should be any doubt as to the observance by the user of this proper maximum speed, it would be quite possible to apply a speed-limiting governor so arranged as to make the machine inoperable above the predetermined speed for which it has been adjusted.

There appear to be very considerable differences between the amounts of the overrun error of the several existing types of machines, and this can be accounted for in part by the fact that in one type the accumulating gears are in balance, and their rotation is, therefore, opposed only by frictional resistances and by the counterbalance weight provided at the dial end of the mechanism to take up backlash. On the other hand, the accumulating gears of another make are not in balance but are formed as segments, so affording a considerable restoring moment to oppose the continuance of the forward rotation. In a later modification of the latter machine, the accumulating gears, while not segmental, are nevertheless designed to be somewhat out of balance, and this has a similar though perhaps an insufficient effect. This unbalance is sufficient to, and is used to return the parts of the machine to their zero position after the completion of a measurement, which it does by causing backward rotation of the accumulating gears under the action of gravity, upon the release of the system of pawls which engage these gears.

It is the opinion of the author that the overrun error is decidedly excessive on all types of existing wheel machines, even when these machines are run at the lowest speeds now in commercial use, and there is little doubt that, in some instances, wheel machines have been deliberately overspeeded to produce overmeasurement. At least one instance has been reported of a wheel machine being regularly run at 100 per cent above its rated operating speed, a procedure which must unavoidably produce enormous errors due to overrun.

Definite numerical results on the overrun error are given in the table below, the first three machines being wheel machines—two of one make and one of another—and the last two machines being pin machines. The second column under A is significant in that it clearly bears out the statements made above in the present section, that the overrun errors are increased by a manner of use of the machine which permits the accumulating gears to be engaged and disengaged more than once in the traverse of a single skin. It will be seen that the values in column 2 for machine A are very definitely higher than those in column 1. It will be understood that in passing the skin through the machine with its long axis perpendicular to the axis of the feed roll, the wheels at the limits of the area to be measured will naturally be lifted and lowered a number of times on account of the serrated nature of these two corresponding portions of the hide perimeter.

TABLE 2.—Readings on Skin No. 6

[Test No. 20725. All readings of area in square feet]

	Actual area of skin No. 6 (planimeter)	Readings on machines designated as—								
		A			B			C	D	E
		Condition 1[a] Speed normal	Condition 2[b] Speed normal	Condition 1[a] Speed 12 r. p. m.	Speed 64 r. p. m.	Speed 30–60 r. p. m.	Speed 18 r. p. m.	Speed normal		
	8.74	8.70	9.00	8.65	8.80	8.62	8.50	8.75	9.00	8.70
	....	8.85	8.90	8.65	8.75	8.62	8.50	8.62	8.95	8.80
	....	8.80	8.88	8.62	8.75	8.75	8.62	8.65	9.00	8.70
	....	8.88	9.00	8.62	8.63	8.75	8.50	8.75	8.90	8.90
	....	8.95	8.85	....	8.82	8.75	8.52	....	8.90	8.75
	....	8.85	8.90	....	8.75	8.50	8.64	....	....	....
	....	8.90	8.80	....	8.75	8.60	8.62	....	....	....
	....	8.75	9.00	....	8.75	8.58	8.60	....	....	....
	....	8.90	9.03	....	8.75	8.62	8.50	....	....	....
	....	8.90	8.90	....	8.75	8.55	8.60	....	....	....
Average........	8.74	8.85	8.93	8.64	8.75	8.63	8.56	8.69	8.95	8.77
Error of machine....	....	+ .11	+ .18	− .10	+.01	− .11	− .18	−.05	+ .21	+.03
Per cent error........	....	+1.3	+2.2	−1.1	+.1	−1.3	−2.1	−.6	+2.4	+.3

[a] Long axis of skin parallel to axis of feed roll.
[b] Long axis of skin perpendicular to axis of feed roll.

It was noted that the error due to overrun tends to be greater (absolutely, if not relatively) the larger the skin measured. In the case of one series of measurements made with a large skin on machine *A*, the following results were obtained:

Reading of area at 14 r. p. m.	square feet	22.33
Reading of area at 59 r. p. m.	do	23.21
Difference	do	+.88
Difference in per cent		+3.9

Readings were also taken with the same machine using a rectangular sheet of leather, the area of which was determined by measurement and calculation to be 9.86 square feet. The mean of 20 readings on this machine was 10.08 square feet, the error thus being 2.2 per cent in excess at normal running speed, even for a rectangular outline, which, as has been shown, rather favors a low value of this particular error.

Additional data on this question are available in Table 1, in which it will be seen that each of the power-driven machines shows a decided change in reading when its speed is reduced from that at which it has been regularly run to a very low speed; this, of course, being proof direct that the wheel machines considered have all been run at a speed higher than is proper. The following brief analysis will show the amount of this difference:

Machine	Errors and differences in per cent of true area		
	At normal speed of operation. Average error	At slow speed of operation. Average error	Difference
A	+4.4	−0.7	5.1
B	+ .5	− .2	.7
C	+ .8	− .9	1.7

It is well to emphasize the fact that this fault can not, as has been assumed by manufacturers, be corrected in any given machine by running it at that speed which would result in a zero error in a particular skin (or test sheet), since the effect is, as has been shown, dependent upon the outline or figure of the skin, and the apparent zero error so obtained could not possibly be reproduced in succeeding measurements on other skins. As has been stated, the only remedy is to determine for each type of machine that speed at which the error due to overrun becomes equal to the partial or constituent tolerance allowable for that error.

In the absence of more exact information regarding the moments of inertia and opposing resistances of the accumulating gears of the wheel machines, the speed rating of such machines should be based not upon the number of revolutions per minute of the feed roll, as has been common, but upon the circumferential speed of that roll, thus affording a comparison of the rates of translation or traverse of the hide or skin to be measured, which is, of course, the fundamental and useful basis for comparison of operating speeds.

The author can not but believe that the emphasis placed upon speed of operation of these instruments is decidedly a fallacious one. It is his opinion that the cost of measurement, in so far as it appears in the cost of labor of the measuring machine tender, per square foot of area measured, is a factor of much less importance than the cost of inaccurate and variable measurements, or differently expressed, the cost to a tanner or shoe manufacturer of seriously deficient or excessive measurement, such as there is every reason to believe existing machines will customarily and regularly give, may be so great that the speed of performing the measurement practically drops out of consideration. It might even be economical, in the case of valuable leather, to carry out the measurements by the use of a planimeter, when it is considered that the difference between successive readings on the same machine may amount to more than 4 per cent (see Table 4), which in the case of a single skin of 15 square feet area, might amount to a money loss of nearly a dollar. When it is considered that this measurement is performed in a few seconds, it appears absurd to emphasize labor cost and to ignore the cost of machine error. Even at the present high prices for labor, a great many skins can be measured for $1, even by the most slow, painstaking, and accurate method available. The writer, whose viewpoint, to be sure, is that of one outside the leather industry, and who may, therefore, be inadvertently ignoring some essential facts or difficulties inherent in the situation, is convinced that the emphasis which has been placed upon the speed of measurement (at the cost of accuracy) is essentially a false one, and that steps should be taken to study the economics of this situation from an engineering point of view, in order to determine with assurance, to what extent slowing up of the process, if it result in enhanced accuracy of measurement, will be economical. This problem is a perfectly definite and determinate one and the studies which it will require can be conducted at very small expenditure of time and effort. It will then be possible to give proper weight to the opposing factors of speed and accuracy, which now seem to be antagonistic.

One expedient, which may already have been proposed, by which the overrun errors can be very largely eliminated, would be the use of a brake or dog so arranged as to come into operation the instant the traversing wheel has dropped back into contact with the feed roll. Within certain limits, of course, a brake of constant application, having for its purpose simply to increase the torque required to rotate the accumulating gears, would be of service. It would be necessary that it should not increase the energy required to operate the machine sufficiently so as to make slipping between the traversing wheels and the skin imminent or, collaterally, to require a widening of the rims or increase of the contact pressure of the traversing wheels. There is some doubt whether practically the application of the braking arrangement would pay, since unless constantly in operation it would unavoidably add complication to the mechanism, a result which might be sufficiently detrimental to offset the relatively small advantage to be gained. All consideration of this question by the author has seemed inescapably to lead to the one conclusion, namely, that the only effectual expedient, if wheel machines are used, is to lower the speed of traverse to the required value, however low an operating speed that may involve. Thus, if the manufacturer is required to specify the speed of operation of his machine in feet per minute of passage of leather, that speed being sufficiently low that the partial tolerance to be established upon this error will not be exceeded, then the buyer of the machine may make his decisions, drawing a proper balance between the speed of operation and the other at least equally important factors involved.

In conclusion, with respect to the three types of error just discussed, it will be seen that the wheel machines show a very definite dependence upon the outline or figure of the hide measured, or in other words, that two hides of identical area but differing outline would be differently measured by such a measuring machine, the greater reading being obtained in the case of the hide of the more irregular outline. The first two causes produce an error which is increased by increasing acuity of the angle which a part of the outline of hide makes with the plane of the corresponding measuring wheel, while the third cause is dependent upon the jaggedness of the outline in the sense that the error is increased by interruption of the hide surface by a reentrant angle of such character that the contact of the hide with a given wheel ceases for a space and is then resumed. If the hide has cut-in portions, the normals of which lie in a general direction perpendicular to the direction of the motion of the hide through the machine, the sort of action referred to will take place, in which one or more wheels are lowered out of engagement with the accumulating gears, and then later lifted so that the accumulating movement is reinitiated.

(4) *Effect of Thickness of Material.*—On most of the wheel machines in use, an error exists due to the variation of the thickness of the material being measured, which arises in this way: Assume that the traversing wheels and the feed roll are running in contact and that the pinion of the traversing wheel just fails of engagement with the corresponding accumulating gear; now, if an extremely thin piece of material, such as tissue paper, be entered into the machine, the traversing gear will be lifted at the moment the advancing edge of the sheet reaches the line connecting the center of the feed roll and the center of the traversing gear. The accumulating gear will at once start to rotate (assuming that the fit and alignment of parts of the machine under consideration are ideal, so that its accumulating gears can be engaged by an extremely small rise of the corresponding pinions). When the piece of thin material has entirely traversed the traversing wheel, it will pass out of contact with that wheel and permit it to be lowered from engagement with the remaining gears just at the instant at which the retreating edge of the sheet leaves the lines of centers of the traversing wheel and the feed roll.

Now, consider the case of a thick sheet of material, say a heavy hide of leather. The traversing wheel and the feed roll will begin to separate at the instant the sheet of material makes contact with both of them (see Fig. 12), which will occur before the advancing edge of the thick sheet reaches the line connecting the centers of the measuring wheel and the feed roll. The accumulating gear will therefore be engaged and begin to rotate as soon as the first contact and consequent lift of the traversing wheel by the sheet has occurred, and as the sheet emerges after having passed under the traversing wheel that wheel will continue to turn and the accumulating wheel will continue its engagement until the retreating edge of the sheet has passed some distance beyond the line of centers and out of contact with the feed roll and the traversing wheel. The effect of this action is that the traversing wheel will have turned through an angle which is greater than the length of the middle line of the strip which it is the function of the traversing wheel to measure, and the readings of the machine will be in excess by an amount equal to the sum of the excess rotations which have been contributed by each of the traversing wheels engaged in the measurement. It will be seen that the magnitude of this effect for each traversing wheel is a function of the diameters of the measuring wheel and the feed roll, of the engagement clearance between the traversing wheel pinion and the accumulating gear, and of the thickness of the hide, the error being greater for thicker hides.

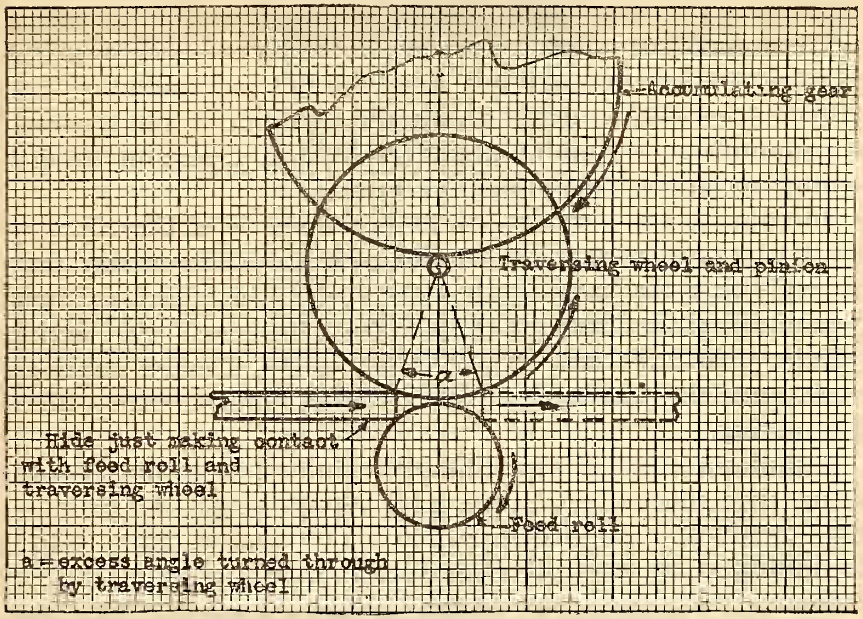

FIG. 12

The only method known to the author which will accurately and satisfactorily compensate for this error is to provide a means of lowering the feed roll so that the clearance between the pinions of the traversing wheels and the accumulating gears is made equal to the average edge thickness of the hides being measured at any one period. A graduated lowering device, so arranged that it could be operated to set an indicator at a reading to correspond to the measured thickness of the hide as determined by a suitable thickness gage would seem to serve the purpose. It is believed that some such arrangement as this is to be found on one of the foreign-made types of leather-measuring machines, of which only a few examples are in this country.

It is of course to be understood that the compensation obtained in this way can not be a perfect one on account of variations in thickness from hide to hide, and in fact in different parts of the same hide. It does not seem, moreover, that any machine using wheel contacts as its operating principle can provide complete compensation.

(5) *Variance Due to Imperfections of the Linkwork.*—The chains which operate to translate the motion of the measuring gears into rotation of the index hand at the dial are very important elements in the accuracy or rather consistency of the performance, in that if the distance between any two given links of any chain does not remain accurately constant during the operation of the machine, a variant error will be introduced, which will appear on the dial as an error in the measurement of the area.

In order to arrive at an idea as to the nature of this effect, it should be recalled that the reading of the machine at any time depends upon the total length of the chains which have not been wound up on the drums of the accumulating gears. Any action which would have the effect of changing the effective length of chain remaining unwound would, of course, proportionately affect the reading.

Consider a length of any ordinary chain suspended by one end from a rigid support, and let the exact vertical height of a point on the lowermost link, with respect to any convenient datum plane, be measured by a sensitive measuring device, as by sighting a micrometer microscope upon a fine horizontal mark or a dot or tip applied to that link. Let the height of this mark be observed and recorded. Now, it is obvious that if the chain be simply shaken, or bent or swung, and again allowed to come to rest in the vertical, the height of the reference mark will have changed, due to more or less irregular changes in the contact relationships of the several links as seen in the sketch (Fig. 13). This change in the effective length of the chain is a secondary result of the friction between the links, and produces what is termed "variance" in the indications of any instrument of whose mechanism it forms a part.[3] All types of chains are subject to this error, although, of course, its amount will vary with the type and dimensions of the particular chain under consideration. Even cords, which were once used as connectors in leather-measuring machines, show a very similar effect, due to the internal friction or elastic hysteresis

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[3] See p. 750 of B. S. Scientific Paper 328, "Variance of Measuring Instruments," by the present author.

in the fibers and strands. Another source of variance due to chain action, having a similar effect, will originate at the points where the chain makes contact with the pulleys and drums around which it wraps, as the result of a certain latitude in the disposition

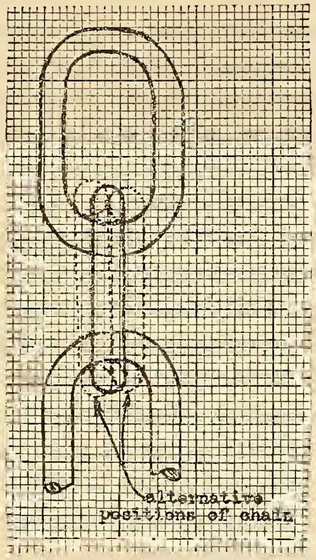

Fig. 13

of the chain laterally as it enters into contact with the pulley groove as shown in Fig. 14. This lateral variation in position has the effect of slightly altering the effective or net length of the chain with respect to its contribution to the indication at the dial.

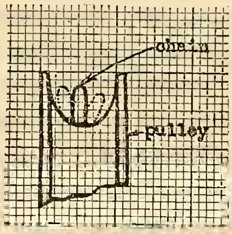

Fig. 14

The most invariant type of flexible connector available is an easily flexed, slender, flat (metallic) tape or wire, the internal friction of which will be very low, and the length of which will be correspondingly invariable. This type of connector should serve excellently for the purpose.

If a chain is used, a type should be chosen which is as little as possible subject to variability in the distance from link to link. While the individual variations from link to link may be very small in amount, nevertheless in the total length of chain involved in the numerous separate elements of a leather-measuring machine, these variations may at times sum up to a large value when reduced at the dial to an equivalent of area, as every link of every chain is liable to suffer a change in its contact relationships and so occasion a change in the effective length of the connections throughout. One machine examined uses a rather favorable type of chain, in that it is almost perfectly circular in cross section, and has a smooth, regular surface, both of which properties assure, in so far as possible, the uniform engagement of the chain with the pulleys over which it passes. This is a factor which, as has been shown, is also important in obtaining constancy of reading.

Another source of variability in the mechanism of the wheel types of leather-measuring machines is the complexity and multiplicity of connections and contacts in the linkwork generally. It is to be recalled that, in a 5-foot length machine of a common make (this being the usual working length), there are 11 pin or hinge joints in each of 5 lever systems, or a total of 55 operating joints in the averaging levers alone. In addition there are an enormous number of separate turning pairs consisting of link contacts comprised in the 40 chains involved, 40 separate bearing units supporting the accumulating gear journals, making 80 individual bearing elements, besides a small number of joints in the dial mechanism.

The importance of this variance inherent in the operation of a complicated mechanism can be judged when it is considered that, in the case of a rectangular leather sheet of 9.86 square feet area, an extreme variation or "spread" amounting to 5.1 per cent was observed in a series of 20 consecutive readings. These readings ranged between the wide limits of 9.85 and 10.35 square feet and this large value was practically duplicated in 2 sets of readings in the 20 referred to. Probably most of this variance is chargeable to the unavoidable mechanical imperfections of the mechanism or link-work, since the rectangular sheet favors maximum constancy of overrun error and a minimum variance due to the width of wheel rims, although, to be sure, under exceptional conditions the rectangular sheet might favor a high value of that portion of the variability having its source in excessively wide spacing of traversing wheels.

No instrument maker would expect such a mechanism to give satisfactorily reproducible results. In other mechanical measuring instruments, whenever high complexity of mechanism is unavoidable in carrying out the function prescribed, the utmost refinement in bearing and connector elements is provided for, when accurate results are desired—as by the use of ball bearings or conical pivots, by extremely careful fitting of parts with respect to bearing clearances, by substitution of tapes and similar flexible connectors for chains and links, etc. The necessity for modification of existing designs in these essential respects can be judged by reference to a later section, Variance, under the general heading "Determination of Machine Performance."

Another source of variance arising in the elements of the mechanism is that due to the ratchet and pawl action used in preventing reverse rotation of the accumulating gears until they are reset to the zero position. It is clear that, with teeth of finite spacing, some retrograde motion will take place before the locking position is attained. This motion is subject to the laws of chance, and the error produced is equally likely to be positive or negative so that no persistent error results, but only another manifestation of variance, that ever-present enemy of accuracy.

On one of the common leather-measuring machines there are about 550 teeth on each of the accumulating gears which serve as ratchets. As only a partial rotation of each of these wheels occurs in the traverse of a skin, it is seen that the proportionate variance due to tooth spacing is by no means negligible.

Possible expedients for reducing this error are to use (1) finer (more closely spaced) ratchet teeth, (2) "stepped" or offset multiple pawls with the existing tooth spacing, (3) the so-called toothless ratchet or clamping ratchet.[4]

The last expedient does not totally eliminate the retrograde rotation, as might be supposed, since a certain small reverse movement is required before the locking becomes operative.

The variance due to ratchet-tooth spacing, like that due to spacing of traversing wheels and the width of wheel rim, can be definitely calculated, from a knowledge of the tooth spacing and the equivalent of rotation of each accumulating gear in terms of area at the registering dial. The range of variance due to this cause, like that due to the others discussed, should be determined

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[4] References on damping ratchets: Mechanics of Engineering and Machinery, Weisbach (Klein's translation, 1890) 3, Pt. I, Sec. II, pp. 873–878; The Constructor, Reuleaux (Supplee's translation, 1904) pp. 158–162; Principles of Mechanism, Robinson, 1896, p. 296.

in advance, and restricted within a predetermined partial tolerance of error established as the maximum permissible limit of the magnitude of this effect alone.

Recapitulation: Persistent Positive Errors.—A significant fact in relation to three of the sources of error detailed above, namely, that of excessive width of traversing wheel rims; that of overrun of the traversing wheels; and that of the thickness of the material being measured; is that each tends to increase the readings above the true area, while the other two major sources of error (excessive spacing of traversing wheels and imperfections of the linkwork) are probably as likely to result in deficient as in excess measurement. On the whole, then, it may be said that any machine having any or all of the three faults in the first group named will tend to measure in excess. Any characteristic tendency of a commercial measuring device to give readings regularly in error in the same direction is to be sedulously restrained, and it is impossible to overemphasize the need for especial attention and study in the design of this apparatus, in order to eliminate wherever possible (and it usually is possible, though radical redesign may be necessitated) all individual sources of error having a persistent and positive tendency to introduce errors of a particular sign.

This whole question of increased precision in the measurement of leather, which seems imperative in the light of the data of this investigation (as well as of those of the British investigation reported by the National Physical Laboratory) seems to the author so important that he would again emphasize the disparity between the precision attained in the measurement of leather and that in the measurement of other commodities of similar or less value. The average price of copper per pound is about one-half that of leather per square foot, yet no smelter or dealer would consider using, for purposes of purchase or sale, a weighing scale having the enormous inaccuracy or variability which is characteristic of the usual leather-measuring machines. In weighing scales, instead of allowing a plus or minus variation of from 1 to 3 per cent, as has been tolerated in the case of leather-measuring machines, the variation and error combined are restricted to ±0.2 per cent or less, depending upon the type. For a weighing scale used indoors, ±0.1 per cent is the combined allowance for error and variation, after the scale has seen service. The tolerance on a new scale used indoors, is set at one-half of this value, under the assumption that a smaller tolerance should be established on new apparatus to permit of the service tolerance being maintained for a reasonable period after the apparatus has been put into use.

(6) *Secular Changes in Hides and Skins.*—The question of accurate measurement of hides and skins is complicated by the fact that the dimensions of these materials are far from permanent, in that they suffer considerable change in each direction from variations in temperature and humidity. The time available did not suffice for an analytical study of this change, but on one set of six typical calfskins received from a Massachusetts tannery, the changes in area from the time of the receipt of the skins at the Bureau was considerable, ranging in amount for the several skins from 1 to 2½ per cent approximately, in a period of 37 days.

It is by no means certain that these changes are reversible ones. It is quite probable, in fact, that a portion, at least, of the changes shown is due to a secular transformation which takes place in the material subsequent to the manufacturing process. The nature and character of this change will probably be more significant to leather technologists, and is here dismissed without further conjecture as to its causes and the degree of its dependence upon the processes of manufacture.

III. METHODS OF TESTING LEATHER-MEASURING MACHINES

1. FORM AND MATERIAL OF THE AREA STANDARD

Field calibration of leather-measuring machines requires the use of standards of area. The primary requisites for such standards are the following: (*a*) Thickness sufficient to raise into operation the traversing wheels of the usual types of leather-measuring machines; (*b*) A surface offering a reasonable tractive resistance, so as to drive the traversing wheels without appreciable slip; (*c*) An outline typical, in so far as may be, of the outline of the hides and skins usually measured; (*d*) High permanence of dimensions under (1) changes in temperature; (2) changes in humidity; (3) the distortion due to the stresses incident to use; (*e*) Durability or resistance to mechanical wear.

The first of these requires the use of a material comparable in thickness to ordinary upper leather, say 0.06 inch (1.5 mm) or more. The second requirement is fulfilled by any flexible material similar to leather or cloth having a surface giving a reasonable friction against the metals. This requirement eliminates materials like the pyroxylin plastics, such as celluloid, and very thin sheet metals, other properties of which might seem well suited to the work.

Sheets of leather, as has been shown in the foregoing section, are far from permanent in their dimensions. Leather is decidedly affected by variations in humidity, and doubtless, also, to a large degree by variations in temperature. In addition it is to be expected that the deformations to which a sheet is subjected in the testing of leather-measuring machines would alter its dimensions gradually were it made of a material having the low elastic constants and relative "plasticity" of leather.

In seeking for materials which should give promise of the best properties for this use, the following were suggested, but time has not been available to determine their physical constants in order to make certain their adaptability for this purpose. In order of their probable serviceability these two should be given consideration:

1. A pyroxylin-coated textile material of the type now much used in the manufacture of artificial leather. Rough measurements made upon a small sample of this material indicated fair permanence under changes in humidity. It is to be expected that its thermal expansivity would be high, like that of many other organic substances. A question still to be investigated in materials of this sort is the obtaining of the necessary thickness. This should offer no difficulty if the manufacturer of artificial leather does not object to coating a special, heavy fabric.

2. Rubber or composition sheet packing containing an inserted wire fabric. Material of this character, using a brass-wire fabric, is already on the market as a high-pressure steam packing.

This material can be produced in almost any desired thickness, is reasonably flexible, and should be quite durable in use.

The determination of the essential properties of either of the two materials suggested above will be a simple matter; the coefficients of expansion under varying humidity and varying temperature are easily and quickly measured.

With regard to the form of the test sheet, careful experiments have shown that the outline of the area measured affects the reading of the machine, this arising, as has already been explained, from the effects of overrun in the mechanism, the width of traversing wheel rims, and the spacing of the wheels. On this account it will not be satisfactory to test leather-measuring machines with sheets of rectangular or circular outline as was customary up to the time of the Bureau's investigation. With areas of such outline but a single engagement and a single disengagement of any given traversing wheel will take place, whereas with the ordinary skin twice as many engagements and disengagements of some wheels may occur. Moreover, a right-line perimeter does not develop the variance due to excessive width of wheel rim and to excessively large interval between wheels. That this is the case, will, of course, be quite clear from the paragraph above, concluding the discussion of the first three types of error of the wheel machines. The results of the analytical investigation of the performance of leather-measuring machines described in the first section of this paper showed clearly that the use of rectangular test sheets was resulting in the certification or acceptance by weights and measures authorities and by the manufacturers, of machines which were affording apparently satisfactory results when used with such standards of area, but which, as it developed, were subject to very large and intolerable errors when used on the irregularly outlined figures of the actual hides and skins.

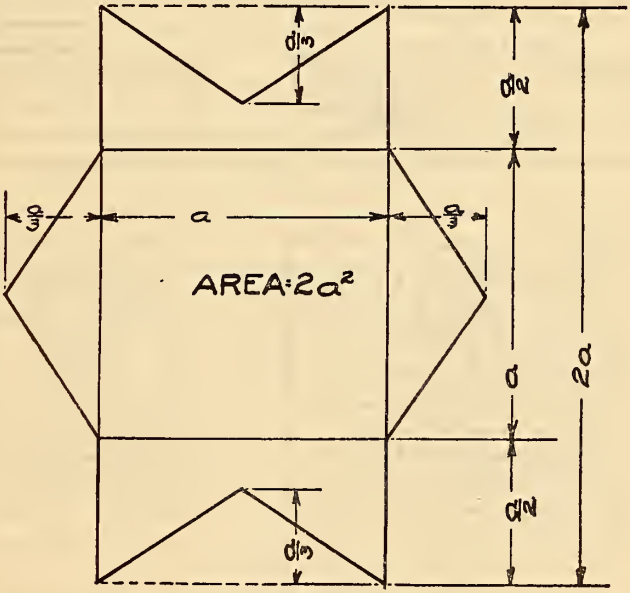

FIG. 15.—*Original form of area standard developed at Bureau of Standards, later replaced by the type shown in Fig. 16*

As a result of these deficiencies of the usual type of test sheets, an attempt was made to design an outline which would afford a rough approximation to the figure of a hide or skin, and which should, at the same time, be easy to prepare and to calibrate. With this in view, the outline defined in Fig. 15 was designed, but since that time Max Sasuly of the Bureau of Standards has suggested and laid out an outline of improved form. This, shown in Fig. 16, is equally easy to prepare, while on account of its more ob-

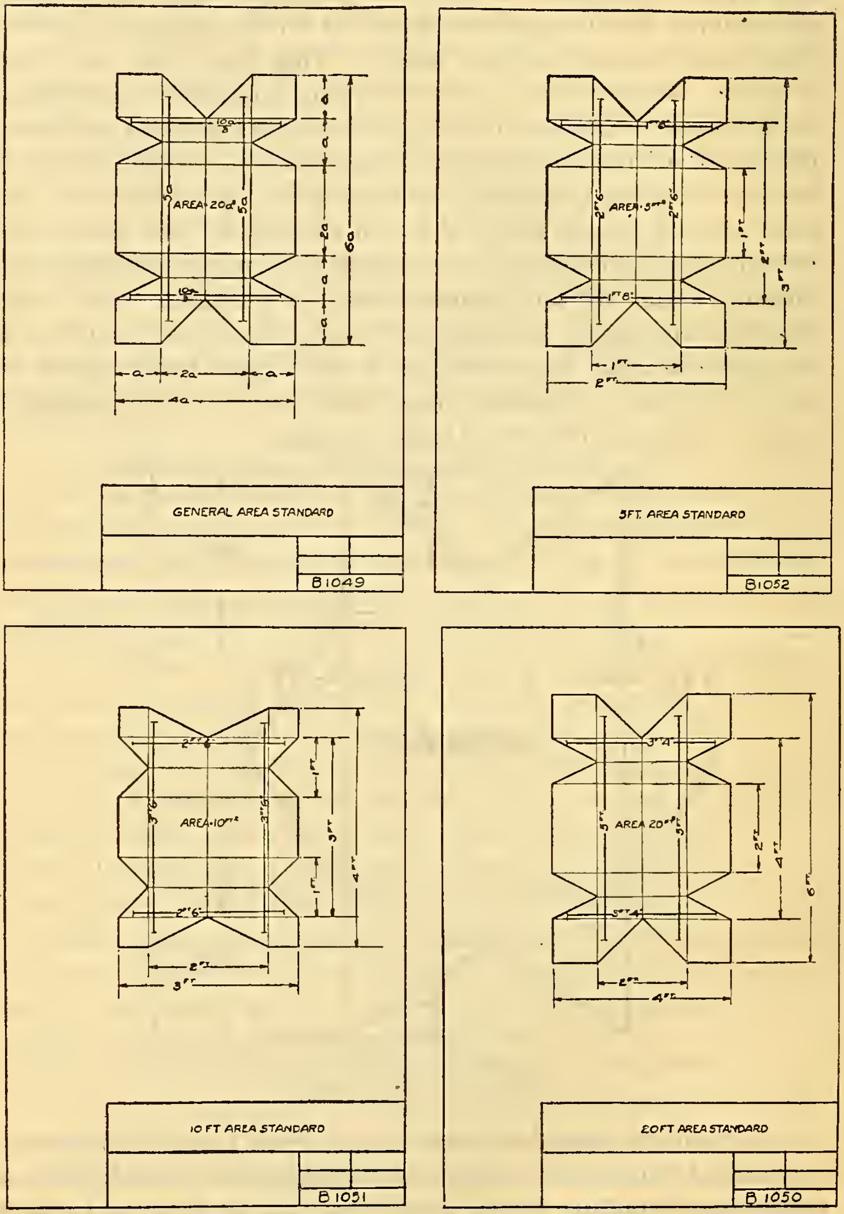

Fig. 16.—*Latest type of area standard*

As compared with that shown in Fig. 15, this has the advantages of greater durability, more effective outline characteristics, and greater ease of preparation. The first figure given is a general or type standard in which the dimensions are given algebraically; the other three are calculated for specific areas of 5, 10, and 20 square feet, respectively.

tuse angles and rectangular boundary, it is less likely to become frayed in service, and will be more readily guided through the measuring machine. It will be noted that while the outline affords the desired irregularity, the area is, nevertheless, a very simple function of its leading dimensions. The following is excerpted from the discussion which was sent out by the Bureau, accompanying blue prints defining these new standards of area, at the time the information regarding them was given to the leather trade (December, 1917):

> With reference to the question of standard patterns for testing leather-measuring machines, we would say that since our previous correspondence with you, we have developed another style of pattern which has certain advantages over the star-shaped pattern originally recommended (our report to the Massachusetts Commissioner of Weights and Measures, under date of Feb. 5, 1917). Blue prints showing the relative dimensions of this new design, and showing the particular dimensions for suitable 5, 10, and 20 square foot areas, are inclosed. One advantage of this style is that there are no projecting acute-angled corners that are liable to be bent in handling. Second, the patterns can be made from paper of common integral sizes, 2, 3, and 4 foot widths, which is more readily obtainable and has its edges cut parallel. Third, the dimensions are nearly all integral values, so that the laying off of the pattern involves no difficult measurements nor the use of special scales.
>
> You will note by the shape of the design that the pattern is most readily cut by laying off on the rectangular sheet of paper of the required size, parallel lines at distances a and $2a$ from each end, where a is one-sixth of the total length or one-fourth of the width; also two lines parallel to the sides at a distance a from the sides. The intersections of these lines with the edges then serve as the points from which six triangles are cut out of the rectangular piece of paper, the apices of these triangles being at equal distances from the edge of the paper in each case. It is not necessary for correctness of area, though it is for the sake of uniformity of outline, that these triangles be isosceles—(that is, that they have two sides and two angles equal) provided the sides meet in the lines at the distance a from the edge of the paper. The area of each triangle will be its base (either a or $2a$) times one-half the height ($\frac{1}{2}a$).
>
> In the suggested form for a 10-square foot area inclosed, the general form is varied slightly in order to use integral foot dimensions for the rectangular sheet of paper, making use of a 3-foot width of paper, and to use integral lengths for the bases of the triangles (1 and 2 feet), while the heights of the triangles are in each case 6 inches. Another feature of this design is the drawing on the pattern of four lines which may be called normal or control lines, inasmuch as they are used as a means of checking or proving the area of the pattern. Two of these lines extend lengthwise of the pattern, parallel to each other, and should have a length of about five-sixths of the length of the pattern. The other two extend across the pattern and should have a length of about ten-thirds of a. The lengths for these lines are shown in the illustrations. They should be measured at the same time as the other dimensions of the pattern are measured, and after the pattern has been cut the measurements should be marked on the pattern in each case. The exact area of the pattern as computed from measurements made at the same time should also be marked plainly on the pattern. Then, occasionally, in future use of the pattern, the control lines should be measured, preferably with a steel tape graduated to tenths of inches. The amounts by which these measured lengths differ from those shown on the pattern should be averaged for the longitudinal lines and for the transverse lines separately, and the percentage which

these amounts are of the total lengths of these two sets of lines respectively should be computed. These two percentages when added together algebraically will be the percentage by which the area of the pattern, under the conditions at that time, differs from the area marked on the pattern.

For example, suppose in the case of the 20 square foot area, the lengths of the longitudinal lines drawn on the pattern were 60.02 and 60.05 inches, respectively, at the time the pattern was made, while those of the transverse lines were 40.01 inches and 40.07 inches, respectively, and that the then calculated area of the pattern is 20.01 square feet. If, at some later use of the pattern, the lengths of the first two lines are 60.12 inches and 60.13 inches, the changes in these two lines will be 0.10 inches and 0.08 inches, respectively; giving an average increase of 0.09 inches, or 0.15 per cent. Likewise, suppose that the measured lengths of the transverse lines at this time are 40.16 inches and 40.24 inches. The changes in these lines will then be 0.15 inches and 0.17 inches, an increase of 0.16 inches or 0.4 per cent. All of these changes are increases; hence, adding together 0.15 per cent and 0.4 per cent, we have 0.55 per cent as the change in area of the pattern. In other words, the pattern will be 0.11 square feet larger under these conditions than when it was standardized; that is, its area when in use at the time of the later measurements above detailed will be 20.12 square feet.

It is desirable to have these pairs of base lines at right angles to each other as the expansion and contraction of paper with changes in humidity are different in the two directions of the sheet. Two lines in each direction are suggested, as an average of two will give more accurate results. It may be found, however, that the measurement of one line in each direction will be sufficient for most purposes. In such cases, however, the percentage change of each line should be computed in the same way and the results added together to give the percentage change in area.

For the original measurement of the pattern, it is suggested either that the parallel lines at distances a and $2a$ from the ends and sides be drawn carefully, that is, as straight and as parallel to the edges as possible, and that the distance of these lines from the edge of the paper at each side of each triangle be measured with a steel rule or tape and the mean of each pair of such measurements be used as the height of the triangle in question, provided, of course, that the triangle has been so cut that the apex lies in the line at distance a from the edge of the paper; or a straightedge may be laid in coincidence with the edge of the paper on each side of the corners of the triangle and the height of the triangle measured by means of a steel square laid against this straightedge and passing through the apex. The length and width of the sheet should, of course, be measured at both ends and sides, and the average taken in each case, and the bases of the triangles should be measured along the edge of the paper. The total area can then be found by subtracting from the rectangle of the sheet the sum of the areas of the six triangles as obtained by multiplying their bases by one-half their heights. A suggested form of computation is appended, with sample dimensions inserted to show the method of calculation used.

TABLE 3.—Sample Form of Computation of Areas of Patterns for Testing Leather-Measuring Machines

	First measurement: left side, inches	Second measurement: right side, inches	Mean area	
			Inches	Square inches
Length of rectangle	72.06	72.02.	72.04	
Width of rectangle	47.98	48.02	48.00	
Area of rectangle				3,457.92
Base triangle A	24.01			
One-half base triangle A	12.005			
Height triangle A	11.99	12.01	12.00	144.06
Base, triangle B	12.00			
One-half base, triangle B	6.00			
Height, triangle B	11.98	12.04	12.01	72.06
Base, triangle C	11.98			
One-half base, triangle C	5.99			
Height, triangle C	12.00	12.02	12.01	71.94
Base, triangle D	24.00			
One-half base, triangle D	12.00			
Height, triangle D	12.00	12.01	12.005	144.06
Base, triangle E	12.04			
One-half base, triangle E	6.02			
Height, triangle E	11.98	12.02	12.00	72.24
Base, triangle F	12.00			
One-half base, triangle F	6.00			
Height, triangle F	12.00	12.02	12.01	72.06
Total area of six triangles				576.42

Area of pattern=3467.92—576.42=2881.50 square inches=20.01 square feet.

A set of three test sheets of 5, 10, and 20 square feet area, respectively, and possibly one of 30 square feet, should be provided for the regular use of the inspector of leather-measuring machines. For the larger machines occasionally found, suitable sheets up to the 60 square feet capacity will have to be provided. It does not appear that the use of several sheets in succession, in order to obtain a calibration of the upper range of capacity, can at present be considered satisfactory, as the effect on certain of the machine errors, as involved in the traverse of a succession of separate sheets, has not been investigated. It might be suggested that a standard of area should be designed such that its perimeter would fit into that of another standard, so that two or more such standards could be passed through the measuring machine in such a way as to form a practically continuous sheet. It does not appear, however, that this is a practicable solution at the present time, and the best expedient seems to be the use of an adequate number of standards to obtain by their use singly, a calibration of the machine over its full range of graduation.

The sheets, when rolled up, may be carried in cylindrical fiberboard or metal tubes, which will serve to protect them from the weather and the rough handling incident to transportation.

2. DETERMINATION OF MACHINE PERFORMANCE

In any measuring instrument, accuracy, or accordance of the indication with the true value of the quantity measured, can be manifested in either one of two ways. (True or perfect accuracy in any measurement does not, of course, exist, and only a relatively high, or substantial exactness is implied in the present use of the term.)

1. An invariable and consistently reproducible correctness of indication on all successive determinations made at every value of the quantity being measured. This may be termed "invariant accuracy."

(2) Errors of varying magnitude and sign, which appear as deviations about the true value of the quantity being measured, such errors having, however, a mean value which, when a large number of observations are taken, becomes equal to zero. Performance of this sort may be termed "group" or "statistical" accuracy.

Unfortunately, the above distinctions have not in the past been used as the basis of discussions of measuring instrument performance, and much confusion has resulted. Instruments have been treated as simply inaccurate when in point of fact they were highly variant. The high variance may easily be of far greater importance than a high invariant inaccuracy, as it is clear that almost any instrument can be corrected, either by adjustment of its mechanism, or by suitable regraduation of its dial, to give precisely accurate readings, if only its reading at any given value of the quantity measured, is consistently reproduced in subsequent determinations. The latter condition can never, of course, be fulfilled in practice, as all instruments are subject to more or less unaccountable and unsystematic variations under the conditions of ordinary use. Thus a weighing scale used to weigh the same load repeatedly, will never give identical successive readings of the weight, but will show more or less variation about a mean reading, which latter, however, is likely to be quite a definite and stable value, becoming more definite as the number of observations entering into the average is increased.

With these considerations in mind, it is seen that in the construction of a leather-measuring machine very precise results would be assured if it were possible to eliminate practically all the variance, as the correction of the remaining inaccuracy would involve only the simple matter of regraduating the dial or changing the length of an adjustable lever or cam or similar element. The problem, then, is reduced to one of diminishing the variance to such an extent that the errors of all readings of the machine will lie within the established tolerance, or, as might perhaps be a more rational though less simple mode of specification, that the *average deviation* from exact reading shall not exceed a certain other, and, of course, smaller tolerance.

In order to select, then, from a group of several measuring machines, that type which can be expected to afford the most reliable results, the criterion should be reproducibility or invariance of reading rather than accuracy of reading in the ordinary sense of the term. As has been stated, all commercial measuring instruments are subject to sensible variation in reading, and while it is conceivably possible to adjust the average performance of the instrument over any considerable period of operation to such accuracy that no general or extensive aggregate error or economic loss would be engendered, nevertheless, to provide against large individual errors, and to prevent serious injustice in occasional, accidental cases, the basis of selection of the instrument should be the range of variation of reading at particular values of the quantity being measured, or the average deviation from the mean reading corresponding to particular values of the quantity being measured.

By way of example, it may be stated that differences as high as 4.3 per cent have been noted in the case of readings in the same series on the same area on one common type of leather-measuring machine. Two other machines gave extreme variations of 2.3 per cent and 1.3 per cent, respectively.

The accuracy of a measuring device depends upon the adjustment to which it was subjected by the maker and, within reasonable limits, the mean of its readings can by proper care at the time of test, be adjusted to be, at that time, practically coincident with the true value of the quantity measured. The deviation of successive observations from these mean readings, however, is not subject to improvement by adjustment, and in that sense is not the result of mere casual circumstances or accidents in the adjustment of the instrument.[5] It represents rather the effect of design and workmanship upon the readings, and forms, therefore, a

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[5] See "The Concept of Resilience with Respect to Indicating Instruments," by the present author; Journal of the Franklin Institute, February, 1919; pp. 166–167.

criterion by which machines of diverse types can be differentiated, as compared with the accuracy of individual readings, which is best employed to differentiate between several machines of the same type and quality.

The problem in hand, then, in the case of leather-measuring machines is to select that type which is capable of most accurately reproducing its readings in successive measurements of the same area, and such selection can be made on the basis of a group of readings given by the instrument when it is operated repeatedly, using the same area standard.

This criterion may be expressed numerically by the use of the "average deviation of the readings from the mean" which, assuming a group of readings taken by successive operations of the machine on the same area, is obtained as follows: (1) Compute the average of the observations obtained by successive measurements of the same area made under the same conditions; (2) Compute the difference between each of the several observations and the average of the group. These differences are the deviations or departures of the several observations from the mean. The sum of all the deviations divided by the number of observations is the "average deviation from the mean."

This method of analysis permits the determination also of the probability or chance that any machine will give a preassigned deviation from the mean or average value of its successive readings, and also the probability that any deviation from the mean shall be greater or less than any given amount. For example, it has been deduced that one make of machine will commit a deviation or error of 1 per cent or more, about 60 times in 1000 operations, while a certain other make will commit an error of that magnitude about 360 times in 1000 operations, these conclusions applying to determinations made with a 10-square-foot test sheet of the later Bureau of Standards' design applied with its long axis moving perpendicularly to the common axis of the traversing wheels. By this method of calculation, very definite differences in performance were developed between three makes of machines investigated, their ratings on a scale of average deviation from mean reading being represented by the series 0.34, 0.42, 1.07; the smallest number, of course, which represents the smallest average deviation from the mean, corresponding to the highest rating as to repeating accuracy. The mean errors of the same three machines were, taken in the same order as the foregoing, 0.7 per cent, 0.6 per cent, 1.5 per cent.

To repeat, it may be said that the mean error could be diminished practically to zero by a suitable change in the adjustable parts of the machines, or, more generally, by recalibration of the dial. This would leave the machines comparable strictly upon the basis of the average deviation from the mean reading, which would necessarily, of course, be combined in the final decision, with numbers expressing excellence in respect to other qualities, such as smallness of errors due to overrun, width of tires, spacing of wheels, thickness of sheet, etc. Numerical expressions for all these effects can be obtained and a combination of these numbers into one number, the several components being suitably weighted according to the importance which each is considered to possess, will then be made, affording a single significant number, which may be called the figure of merit of the machine.

The following table gives the results of a series of variance determinations made on three leather-measuring machines, showing the steps in the calculation and the nature of the numerical results arrived at:

TABLE 4.—Bureau of Standards Test of Three Leather-Measuring Machines at Danversport, Mass., Aug. 22, 1918

[All determinations made with long axis of test area moving perpendicularly to common axis of traversing wheels. Test sheet used: Bureau of Standards type (Fig. 16)]

	Machine I		Machine II	Machine III[a]			
	(b)	(c)	(b)	1	2	3	4
Successive readings of the several machines on the same area standard	....	....	....	....	10.01	....	....
	10.00	10.10	10.12	9.95	10.02	10.08	10.02
	10.02	10.24	10.05	10.08	9.97	10.20	10.02
	10.13	10.25	10.00	10.18	10.04	10.07	10.10
	10.07	9.87	10.06	10.07	10.03	10.09	10.06
	10.13	10.25	10.04	10.01	10.00	10.04	10.03
	10.13	10.05	10.07	9.97	10.00	10.09	9.93
	10.18	10.30	10.09	10.06	9.96	10.02	10.11
	10.02	10.06	10.10	10.13	10.07	10.07	10.02
	10.17	10.05	10.02	10.15	10.05	10.07	10.11
	9.93	10.10	10.13	....	10.12	....	10.03
	....	....	....	....	9.97	....	....
Mean	10.08	10.13	10.07	10.07	10.02	10.08	10.04
Mean error, per cent	.92	1.53	.68	.84	.37	.78	.57
Average deviation, per cent	.70	1.07	.34	.61	.35	.31	.43
Extreme variation, per cent	2.5	4.3	1.3	2.3	1.6	1.8	1.9

[a] 1, 2, 3, 4=Forty observations taken by the author, August, 1918.

[b] Ten observations taken by J. J. Cummings, March, 1918.

[c] Ten observations taken by the author on same machine in August, 1918.

Mean of 40 observations		10.05
Average deviation, 40 observations	per cent	.42
Extreme variation, 40 observations	do	2.70
Check measurements on the test sheet show that its actual area was	sq. feet	10.04

3. ACKNOWLEDGMENTS

In connection with this investigation it is a pleasure to acknowledge the hearty and effective cooperation which the author has received from a number of sources. H. M. Roeser, Assistant Physicist of the Bureau of Standards, who is a specialist in the theory of errors, has afforded most valuable cooperation in drafting and carrying out the methods for the calculation and numerical expression of the variability of leather-measuring machines. E. C. Laughlin, assisted by E. W. Shippee, V. A. De Castro, and T. M. Cockrill, all of the staff of the Bureau of Standards, carried out with painstaking care and accuracy, the very extensive series of measurements and calculations required to establish the areas of the six hides used as tentative reference standards in the early part of the investigation, as well as much of the computation involved in some of the later work regarding the errors due to overrun, etc. Both the National Boot & Shoe Manufacturers' Association and the National Tanners' Association have furthered the work in a most enthusiastic way, and especial mention is due, respecting the courtesies extended by W. H. Denham of the former and Walter Creese of the latter organization. J. J. Cummings, of the staff of the commissioner of weights and measures of the State of Massachusetts, lent continual assistance during the field work in Massachusetts, and took a number of observations which were needed in connection with the studies being made of the amount of the inherent variability of leather-measuring machines. Mr. Day, of the same office, also aided in the field work. To these and to the tanners, leather dealers, and shoe manufacturers who made possible the inspection of their measuring equipment and methods, and all others who have furthered the investigation, the author is happy to express appreciation on behalf of himself and the Bureau of Standards.

IV. SUMMARY

The scant literature on the subject of leather-measuring machines is reviewed, and the facts which called for the carrying on of the present investigation are reported. The importance of the problem of leather measurement from the commercial point of view is indicated, as it underlies the sale of 900,000,000 square feet, or more than $400 000 000 worth of hides and skins annually in the United States. The principles of design involved in leather-measuring machines are set forth in detail with respect to the

kinds in common use. An analysis is made of the sources of the serious errors which commonly exist in commercial leather-measuring machines of the wheel type, including the effect of width of traversing wheel rim, of overrun of the wheelwork, of varying thickness of the material measured, of imperfections and mechanical complexity in the linkwork, etc. Attention is called to the fact that a number of the sources of error definitely favor overmeasurement, so that, on the whole, the common leather-measuring machines will tend to measure constantly in excess.

A design for standards of area, which eliminates the disadvantages of the simple rectangular and circular outlines hitherto employed in the testing of leather-measuring machines, is presented, and a complete outline of procedure for the conduct of performance tests on these machines is laid down. Distinction is drawn between accuracy which is evidenced as an invariable correctness of indication, and accuracy which appears as correctness in the mean value of variant indications, and it is shown that variancy of indication may be a far more serious fault than simple inaccuracy, since the latter can be corrected for by adjustment of the machine, while the former, generally speaking, can not. The paper indicates a means of obtaining a numerical comparison of measuring machines with respect to the variancy or lack of consistency in their readings, and gives in tabular form the results of variance tests on three wheel machines, showing typical calculations of the essential factors.

WASHINGTON, August 19, 1919.

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