OCT 20 1921

DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 199

METHOD FOR PRECISION TEST OF LARGE CAPACITY SCALES

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SEPTEMBER 24, 1921

PRICE, 5 CENTS
Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

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METHOD FOR PRECISION TEST OF LARGE CAPACITY SCALES

By C. A. Briggs and E. D. Gordon

ABSTRACT

This paper outlines a scientific and systematic method used by the Bureau of Standards for testing railroad master and grain hopper scales. A pointer and scale are arranged for reading the position of the beam, and the errors of the scale are determined from observations made upon the freely swinging beam. The procedure of the test is explained with the aid of a record form and computation sheet which was developed in connection with the successful application of the method in the field. In the interest of a uniform and efficient method the scheme outlined is recommended for adoption by those who have occasion to carry out tests on large scales where accuracy of a high order is required.

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1. INTRODUCTION

In making tests of unusual accuracy on compound lever scales, such as grain hopper and master scales, it is the practice of the Bureau of Standards to employ a method for determining the position of equilibrium of the beam similar to that generally used in laboratories on equal-arm precision balances. This method was introduced by one of the authors when the work of standardizing large weights and master scales was first undertaken, and as the

result of several years' application in the field it has now reached an improved routine form. The chief feature of this method is that observations are made by means of a pointer attached to the trig loop, readings being made on a ruled scale mounted on the freely swinging beam.

The application of this method in the field has aroused the interest of the practical scale man engaged in regular scale testing, and practically all who have seen tests carried out in this manner have expressed their desire to become familiar with it, so that they can use it for their own work when the occasion arises. It is in response to this demand for a detailed explanation of the scheme that this description has been prepared and issued.

2. NOT SUGGESTED FOR GENERAL USE IN ORDINARY TESTING

This method is not suggested for use in the ordinary testing of railroad track or motor truck scales or for routine work of this character. It has yet to be determined, however, to what extent this plan can be used to advantage in the regular testing of grain hopper scales. At first it was thought that it should not be used for the latter, but more recent considerations have suggested that it may be desirable to use the method to some extent in this work.

3. ADVANTAGES OF THE METHOD.

The advantages of the method are several: First, it permits tests of scales to be conducted in a systematic and scientific manner. A complete record is made of all observations, so that nothing is left to uncertain or delayed entries. Second, the personal equation and unconscious prejudices of the observer are reduced to a minimum. Third, results may be checked as the observations are made, so that omissions become very apparent and mistakes can generally be discovered and often corrected with reasonable reliability. Fourth, the method in practiced hands enables the test to be carried out much more rapidly than is the case where the ordinary plan is used. It is not necessary to add or remove small weights until by repeated trials the beam comes to a position of equilibrium in the middle of the loop, but the weights required to bring this balance about can be determined from computations derived from observations on the swing of the beam for only two different applications of small weights. The saving of time is particularly important in scales requiring the greatest accuracy, as in these scales changes which take place during the test, on account of the effects of temperature varia-

tions and from a slow settling of the parts, may cause an appreciable part of the total error. Fifth, further advantage lies in the fact that when disturbing conditions are present, as air currents and drafts, it is possible to obtain data which otherwise could not be secured—the readings of the pointer can be watched and recorded and quiet intervals can be recognized and used.

4. DISADVANTAGES OF THE METHOD

The disadvantages are that computations have to be made before the results are available in definite figures, and under the conditions of the test the very fact that time is saved and the work permitted to proceed rapidly may develop a tendency to delay working out the data. This is particularly true in the case of those who have used the method for a short time only and who have not the practice necessary to make the required computations quickly while the test is being made. A slide rule is an almost indispensable item of the equipment, and ability to use it with accuracy and speed is necessary. The very thoroughness with which the test can be carried out also entails a large amount of clerical work.

5. REST POINT DEFINED

The term "rest point" will be defined as the position in which the beam would come to rest if the effects of friction were eliminated. It is the position about which the beam oscillates as a center when vibrating freely.

6. MEANS FOR MEASURING THE POSITION OF THE BEAM

Consider a ruled scale mounted vertically on the beam near the end in a manner such that the position of the beam in its play in the loop can be read by means of a pointer attached to the trig loop or stand. This is shown in Fig. 1. Any position of the beam—as, for instance, the position of equilibrium or rest point—can now be expressed in terms of the reading of the pointer on the ruled scale. The method outlined in this paper for making the observations is based on this fact.

7. SENSIBILITY RECIPROCAL

Likewise, the sensibility reciprocal of the beam, or *sr*, as it will be written, can be expressed as the change in the load required on the platform to change the position of equilibrium of the beam one division as read on the graduated scale. In the particular

method outlined in this paper for making the tests with a maximum economy of time the corresponding value needed for the computations is the weight required to change the position of equilibrium of the beam one-half a division, or one-half the *sr*. This is a consequence of the scheme employed for making the computations in which the rest point is taken as the sum of the readings of the two extreme positions of the beam as it swings freely. This is to render it unnecessary to divide by 2, thereby simplifying the computations, as will be more fully discussed later.

If the weighing mechanism is working properly, the *sr* will be practically constant for any particular load for all positions of the beam.

8. COMPUTING WEIGHT REQUIRED FOR PERFECT BALANCE

Consider the pointer and ruled scale so arranged that when the beam is in a horizontal position in the center of the loop, as for a perfect balance, the reading is 20. Suppose, further, that for a certain load the position of equilibrium of the beam is given by reading 16, and that the ruled scale is arranged to give increasing readings as the beam changes from a low position to a high position. Let also the *sr* be 2 pounds per division. In this case the pointer is 4 divisions below the center of the loop or the mid-position of its play; that is, 16 is 4 divisions below 20. In this case it is easy to see that 4×2, or 8 pounds additional weight, would be required on the platform to bring the beam to a perfect balance, where it would read 20.

From this it can be understood that when the *sr* is known and the position of equilibrium is determined in reference to the ruled scale it is possible to compute the change in weight required on the platform to perfect the balance, and it is unnecessary to take the time and trouble actually to change the weight on the platform.

9. DERIVATION OF DATA FROM MOVING BEAM

In what has just been outlined reference has been made to the reading of the pointer which corresponds to the position of equilibrium or rest point, as it is termed. An apparent way of obtaining such a reading would be to allow the beam to come to rest and then to make the reading. This, however, would not give practical results, as in many cases the position assumed by the pointer would be affected by friction. If friction were not appreciable, the beam would be a very long time in coming to rest.

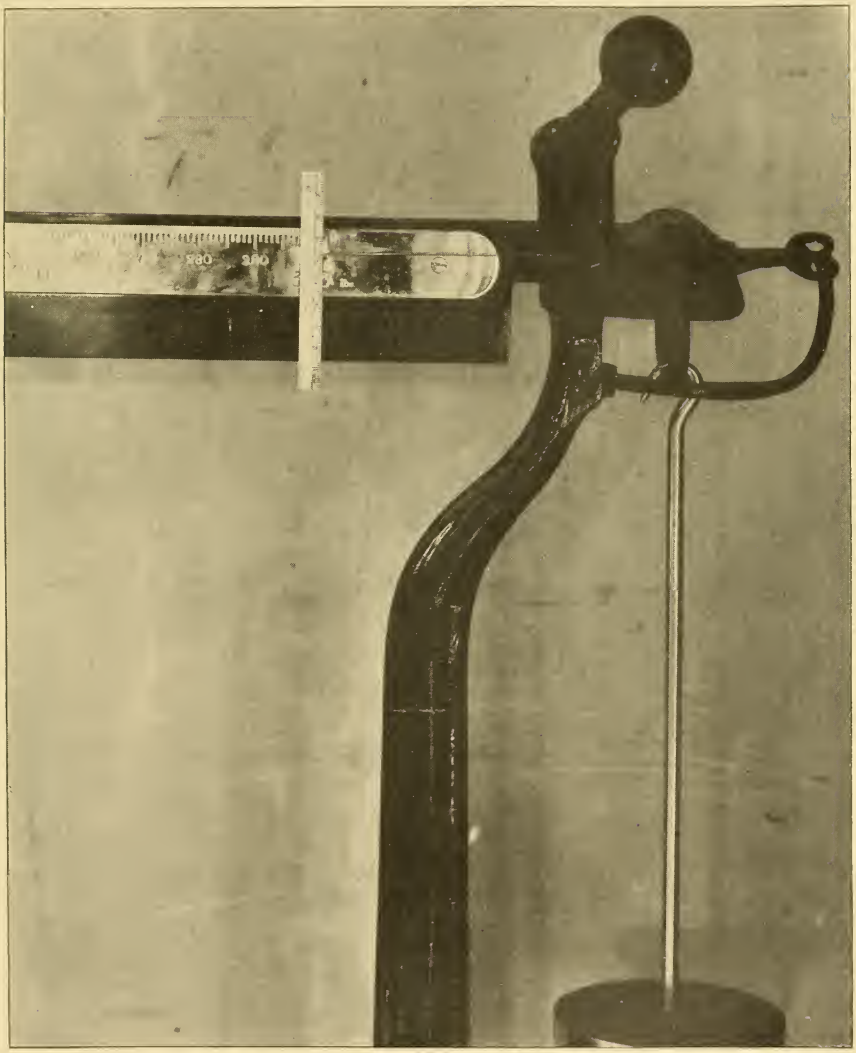

FIG. 1.—*View showing pointer attached to trig loop reading on ruled scale mounted on the beam, ready for conducting precision test of a scale*

Suppose that the movement of the pointer over the scale is observed and that there is no friction present. The beam will then swing up and down indefinitely, and the position of equilibrium will be midway between the upper and lower readings of the pointer on the ruled scale. Under these conditions the value can be obtained by taking the upper and lower extreme readings, adding them, and dividing by 2.

10. METHOD FOR ELIMINATING THE EFFECTS OF FRICTION

The friction which affects the movement of the beam during its swing can be eliminated by a simple method. The average of the readings from two successive swings in one direction is taken and added to the reading of the swing occurring between in the other direction. This result divided by 2 gives the rest point as it would be read with a stationary beam if friction were eliminated.

For example, in the following table we have:

	Readings	
	Down	Up
	(1)... [6.1]	(2)....17.3
	(3)....6.4	(4)....17.0
Averages	6.4	17.2

where the first value 6.1 is not used except as a check on the second value just below. The readings occur in the order indicated by the numbers in parentheses. The rest point in this case is given by $(6.4+17.2) \div 2 = 11.8$, and the value 11.8 is the reading that the beam would assume if it came to rest at its position of equilibrium with effects of friction eliminated. This is illustrated in Fig. 2.

When the damping is large or for other cases where the taking of extraordinary pains is justified, the rest point can be determined by taking the average of a series of readings on one side and combining them with the average of a series of readings coming in between on the other. Thus, for illustration, in the following readings we have:

	Readings	
	Down	Up
	6.1	17.3
	6.4	17.0
	6.7	16.7
	7.0	....
Averages	6.6	17.0

The mean or rest point here $= (6.6 + 17.0) \div 2 = 11.8$.

11. ESTIMATION OF TENTHS

In the application of the method the tenths divisions are obtained by estimation. This can be done after very little experience. In the estimation of tenths there may be, of course, a difference of a tenth between two different observers. This, however, is of no importance if the sensibility of the scale is sufficient for the purposes of the test.

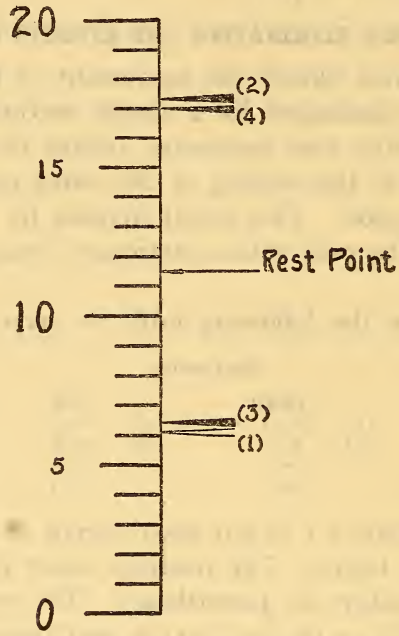

FIG. 2.—*Illustration of method for determining rest point from readings of the end positions of the pointer.*

Successive readings are indicated by (1), (2), (3), and (4). The rest point at 11.5 is determined from the average of readings (2) and (4) added to (3) and divided by 2. Reading (1) serves as a check on reading (3), but is not otherwise used in the computation.

12. UNNECESSARY TO DIVIDE BY TWO

In the preceding paragraph it has been mentioned that the rest point of the beam can be determined by adding the extreme readings, one in one direction and the other in the other, and dividing by 2. This would give the actual reading on the graduated scale that would be obtained if the beam were at rest. In practice, however, it is unnecessary to divide by 2, and in the form given later the nominal value of the rest point is taken as the sum of the 2 extreme readings. This saves time and introduces no errors.

The computations must be made consistent with the plan, of course, but this is easily done and without confusion. For instance, in place of the *sr* there is used one-half the *sr*. This is the change in weight on the platform that would change the sums of the extreme readings 1 division. The effect of not dividing by 2 is precisely the same as would be obtained if a graduated scale just twice as fine were used and the readings obtained on it were divided by 2.

13. MOUNTING OF POINTER ON THE TRIG-LOOP STAND

It is possible to place the pointer on the beam and the scale on the trig loop. In practice experience has shown that it is found to be of advantage to attach the pointer to the trig-loop stand and mount the graduated scale on the beam. This has the advantage that the level at which the readings are made does not vary, and it is not necessary to move the eye up and down to follow the pointer, and the illumination remains unchanged. In this case, however, care should be taken that the scale is placed and read so that the low readings correspond to the low position of the beam and high values for the high positions of the beam.

14. METHOD OF APPLYING THE WEIGHTS

In the test of a scale a known test load is applied on the platform and standard counterpoise weights are applied on the beam; the error in the scale is given by the lack of correspondence between the weights on the platform and the counterpoise weights on the beam. It has been found advantageous to use an even number of pounds, or some simple division of a pound, on the counterpoise and then make the necessary changes required to obtain the balance by changing weights on the platform. This method has many advantages, in that the use of weights of very small denomination on the counterpoise is avoided.

For convenience in carrying out the test and avoiding the use of small weights on the counterpoise it is the practice to balance the scale at zero load with a number of standard weights on the platform, varying from 1 to 50 pounds, according to circumstances. These should be greater than any error that is likely to develop in the scale. This scheme is of particular value in the case of scales which are fast.

For illustration, take a scale which is fast 1 pound per 1000 pounds, and let it be balanced so that the position of equilibrium of the beam is in the center of its play at zero load. If the nominal

multiplication is 1000:1 and a 10 000-pound weight is placed on the platform and a 10-pound weight is placed on the counterpoise of the beam, the scale will not balance, but the beam will be high. In order to obtain a balance, it will be necessary to remove 10 pounds from the platform or to add 0.01 pound to the counterpoise. It is desirable to avoid the use of small weights on the counterpoise; but in this case they would be needed, as it would not be possible to remove any of the solid 10000-pound weight placed on the platform. However, if the scale had been balanced with 20 pounds on the platform at zero load, then, when the 10000-pound weight was placed on the platform and the 10-pound weight was placed on the counterpoise, it would be possible and convenient to balance the scale by removing 10 pounds of the 20 pounds of weights which were placed on the platform at zero load. In this case it would not be necessary to use or to provide small weights for the counterpoise. Thus, where the scale is balanced at zero load with a few weights on the platform, weights of large denomination can be applied to the platform and the weights corresponding to the nominal amount required to balance can be placed on the counterpoise, and the balance can be determined by suitable changes in the small weights on the platform.

15. DESCRIPTION OF RECORD FORM AND COMPUTATION SHEET

With the preceding discussion in mind, the application of the method in connection with a record form and computation sheet used by the Bureau of Standards can be followed with understanding. Referring to Form 243 E, Fig. 3, the columns have been numbered in order.

Column No. 1 is for recording time. The time is not entered, as a rule, with each observation, but should be noted every few observations, particularly when the next step to be taken is different in character from what has just been carried out. The time record is of importance in some tests in correcting for a shift of the zero balance or other changes which appear to progress in a more or less uniform manner with time. This record is also, in practice, found to give information as to what time will be required to shift weights and conduct certain features of the test, so that it is possible to predict when the work will be completed and to make other deductions of practical interest in guiding the details of the work.

In column 2 are recorded the observation numbers. It should be noted that a number is assigned each time a change is made

or whenever the observations are interrupted. These numbers are of great value in referring to and identifying any of the data taken.

Column 3 is for the record of the counterpoise weights applied at the end of the beam. The values and identification of the

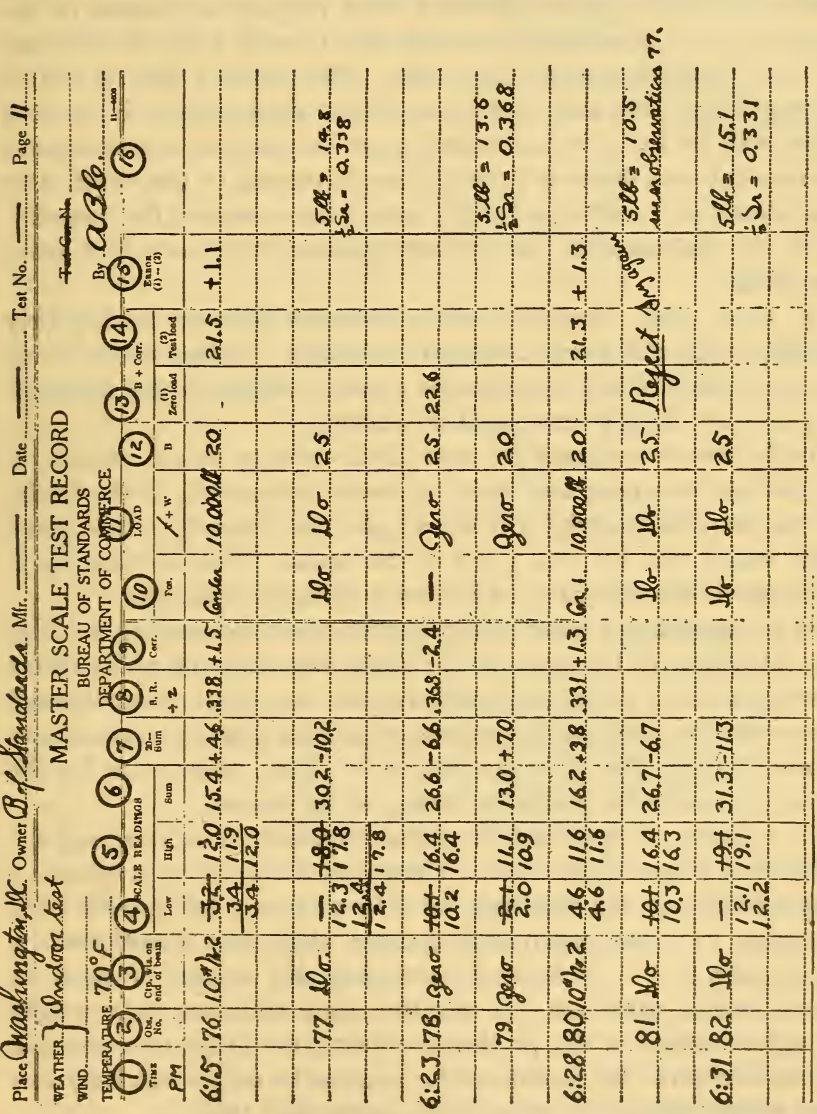

FIG. 3.—*Example of record form and computation sheet showing the method of entering the observations and determining the errors in the multiplication of the scale*

weights can be entered here by using suitable abbreviations. Also, under usual conditions more than one line can be employed for this, as two lines or more are generally required for recording the readings of the pointer.

Columns 4 and 5 are for recording the readings of the pointer. When the first reading is a high one a dash should be made opposite in column 4 to indicate this fact. Otherwise, confusion exists; low readings which occurred after certain high readings appear to have come before them, and errors are introduced. In accordance with the requirement for a proper elimination of the damping, one observation on one side is used with the average of two observations on the other. Note that a line is drawn through the value not used or a circle is placed about it, so that there will be no misunderstanding on the part of the computer as to what was done or intended on returning to the work after the immediate recollection of the details have escaped the memory. This also indicates to the person checking the work just what was done.

In most cases, especially with observers who are particularly familiar with the work, it is not necessary to place the average values of the readings in columns 4 and 5, because these averages can be very readily computed mentally.

In column 6 is placed the sum of the average or representative values for the upper and lower extreme movements of the beam. If this were divided by 2 it would give the reading on the ruled scale which was the rest point of the beam. This division by 2, however, is unnecessary, as has been already explained.

If the graduated scale is adjusted so that the reading 10 is at the mid-point of the play of the beam and is at the point where the beam is in a horizontal position, then the value 20 in column 6 represents the mid-point or reference balance position of the beam. It may be thought of as the sum of 10 taken twice, once for the upper and once for the lower swing of the beam.

In column 7 is recorded the value obtained by subtracting the value in column 6 from 20.0. Therefore, if the value in column 6 is less than 20.0 the resulting value in column 7 will have a positive sign (+), and when it is greater than 20.0 it will have a minus sign (−). It is important that this matter of signs be given careful attention. A positive sign indicates that weight should be added to the platform to bring the beam to a position of equilibrium in the middle of the loop, and a minus sign indicates that weight should be removed to accomplish this.

It is strongly recommended that for saving time and eventual economy of effort the pointer and scale be adjusted so that the double value of the horizontal position of the beam be caused to read 20, or, if not 20, then 10, 30, or 40. A double reading of 20

can be used for all except unusual cases. When the double reading of the beam in its horizontal position is taken as other than 20, then that other value should be used in place of 20 in obtaining the values in column 7.

In column 8 the value of one-half the *sr* is recorded. This value is determined from entries usually made in column 16. The one-half *sr* is the pounds per division of column 7.

Experience indicates that for most purposes the *sr* should be determined for each particular load each time that load is applied and should be used for that particular load. The chief advantage of this is that it serves as a check on the accuracy of the readings taken on the beam. Also, after values of the *sr* are obtained for 2 or 3 loads a fair idea can be had of what is likely to be found for other loads, and this permits errors in readings or defective conditions to be recognized and corrected.

If, therefore, any mistake occurs in the readings determining the position of equilibrium, it will disclose itself in its effect on the value of the *sr* obtained. This is illustrated by observation 81 on the Form 243 E, where the *sr* did not agree with that of observation 77 and it was rejected. Agreement was reached on repeating. The difficulty was probably from reading the scale 5 divisions too low at one point.

In the test the same loads may be used time and time again, and many values for the *sr* for the load may be obtained. There is some argument for using one average value of the *sr* for all computations for this load. However, when this is done the data of the test are always held up, and no final figures are established before the test has come to an end. In most cases the practical value of using an average *sr* is not sufficient to justify the delays and corresponding difficulties thus introduced.

In column 9 is recorded the correction. It is the product of the value in column 7 and the corresponding value in column 8. It should carry the same algebraic sign as the value in column 7. It is the value, in pounds, which is required to be added to or removed from the load on the platform to bring the position of equilibrium of the beam to the center of its play in the loop.

In column 10 is recorded the position of the test load on the platform, together with information of interest in this connection.

In column 11 is placed the value of the test load applied. It will be observed that this is headed by "T+W." This is on account of the fact that this form was arranged primarily for use in connection with the test of master scales by the equipment of

the Bureau of Standards, and "T+W" stands for "truck and weights." In this column is recorded the test load or portion of the test load which nominally is required to balance the counterpoise weights on the beam. It does not include the smaller weights mentioned next and used on the platform to facilitate the conduct of the test.

Column 12, marked "B," is for the small weights which are applied on the scale platform as a matter of convenience in establishing the balance and determining the *sr*, as has been previously referred to. The letter "B" in the railroad track scale testing work signifies "Brass weights," as brass weights are generally used for this purpose. This column 12 represents the quantity of weights on the platform in addition to those which correspond to the counterpoise weights applied at the end of the beam.

Column 13 is used for data for zero load, and also, where the built-up test loads are used, for the balance taken for the lower load of the step before the standard test weight load is applied or after it has been removed. The values entered here represent the additional weight which would be required on the platform to bring the position of equilibrium of the beam to the middle of the loop. The entries are obtained from the values in column 12 plus those in column 9, all with due regard for sign. This is more fully explained in the illustration in the use of the form given later on.

Column 14 is similar to column 13, except that the data entered here represent results obtained when the test weights are applied to the platform.

In column 15 are recorded the differences in the values of columns 13 and 14, as indicated at the top. The values in this column represent the error in the scale—a plus (+) sign indicates that the scale is fast and a minus (−) sign indicates that it is slow. A scale is said to be fast when the scale indicates a change in load greater than the actual change made in the load on the platform, and it is said to be slow when the scale indicates a change in load less than actually takes place on the platform.

In column 16 are entered the values used in computing the value of one-half *sr* of column 8. The change in weight employed in determining the *sr* is entered here, together with the resulting change in double divisions produced in the rest point.

16. ROUNDING OFF OF DECIMAL PLACES

If the data are being recorded and computed to the tenth of a division, there will be times when a number results expressed to half a tenth, or 0.05. This occurs for the average of a sum in

which the last figure is odd. In this case the value is rounded off to the nearest tenth, and the value selected should be that one where the last figure is even. This is illustrated on the computation sheet in observation Nos. 76 and 77. This rule is one which is often used in scientific computations and has the advantage of being a fixed rule that can be applied without loss of time otherwise required for the computer to make up his mind what he will do, and work can be checked by different individuals who will make decisions alike. Moreover, in checking work it clearly fixes in many cases whether or not a minor mistake has been made in the computations.

17. DISCUSSION OF PARTICULAR EXAMPLE SHOWN ON THE FORM

Considering, now, the particular data shown in the illustration of the use of the record form in observation 76, a 10 000-pound test load was centered on the scale platform and a 10-pound weight was applied on the end of the beam to counterpoise. The nominal multiplication ratio of the scale was 1000:1. With 20 pounds of small brass weights on the platform in addition to the lot of 10 000-pound weights, the rest point or position of equilibrium of the beam was 4.6 divisions below the mid-position, as shown in column 7. (In this the double divisions are used, of course, thereby avoiding the need for dividing by 2.) On adding 5 pounds to the platform observation 77 was taken, and it was found that the rest point was 10.2 divisions above the mid-position of the beam, as shown in column 7. On comparing the rest point of observation 76 with that of observation 77 it appears that the change of 5 pounds on the platform changes the rest point of the beam 14.8 half divisions. This is shown in column 16. The one-half *sr* or pounds per half division is therefore $5 \div 14.8 = 0.338$. This is entered in column 8 opposite that value in column 6 which is nearest to the value 20.0, in this case observation 76. On multiplying the value of column 7 with that of column 8 it is found that a change of $+1.5$ pounds is required on the platform to bring the beam to a position of equilibrium in its mid-position. The plus sign indicates that weight should be added to the platform. Combining the value $+1.5$ in column 9 with the value of 20 pounds in column 12, there is obtained the value of 21.5, which is placed in column 14. Therefore, the beam will have a rest point in its horizontal position in the middle of its play in the loop, for the conditions of observation 76, if a load of 21.5 pounds is placed on the platform in addition to the test load of 10 000 pounds.

In observations 78 and 79 it is determined in a similar manner for zero test load that the small weights required on the platform to bring the beam to a position of equilibrium in the middle of its play are equal to 22.6 pounds. This is shown in column 13. From this result and that of column 14, observation 76, it appears that the error in the scale for a 10 000-pound load placed on the center of the platform is +1.1 pound, or the scale is 1.1 pound fast, as shown in column 15.

In observation 80 the test load of 10 000 pounds is reapplied, this time on corner 1. In observation 81, 5 pounds were added to determine the *sr*. However, it was found that the 5 pounds produced a change in the rest point of 10.5 half divisions, when in observation 77 with the same load 5 pounds produced a chaned in the rest point of 14.8 half divisions. The results, therefore, do not check. It appears that a mistake was probably made in observations 80 or 81. On repeating and obtaining observation 82 under the same conditions as 81, a different value resulted, and it was found that the *sr* of observations 80 and 82 now check with that of observations 76 and 77. Observation 81 was therefore rejected. There appears to be a difference of about 5 divisions between observations 81 and 82. This may have come from reading the pointer 5 divisions in error on one side.

This illustrates the value of taking the *sr* each time, as an error was detected and corrected. It can be understood, also, that if an average value of the *sr* were to be used, it would be necessary to wait until all of the observations had been made before entering new values in column 8, and this would hold up and prevent the entries in columns 9, 14, and 15.

From observation 80 and 82 the error for a 10 000-pound load placed on corner 1 is found to be 1.3 pounds. This happens to be in close agreement with the results obtained for the center position of the test load.

18. SUMMARY

In conclusion it may be remarked that the method of test outlined herein gives a systematic and scientific procedure for making tests of unusual accuracy on compound lever scales. This method has been developed in the testing of railroad master scales, hopper scales, and other scales, and is found to be satisfactory. In the interest of uniform and efficient methods it is recommended and outlined here for those who may desire to adopt the procedure.

WASHINGTON, March 10, 1921.