APPARATUS FOR COMPARISON OF LENGTH OF GAGES

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ABSTRACT

Apparatus has been built for comparing spherical-ended gages of quartz having very small thermal expansion with standard flat-ended gages of steel which have a relatively large coefficient of expansion. The difference in length of two gages is measured by a micrometer screw which is driven by a very small reversible electric motor. Screw settings are made automatically by means of an electrical contact indicator which disengages an electromagnetic clutch at a definite measuring pressure. The gage-holding device is made so that the alignment between the measuring faces can be accomplished with the operator at a distance. Hence, the whole operation of length comparison can be made in an inclosed space where the temperature can be accurately controlled.

The gages are supported on steel balls which allow the easy endwise motion necessary when using light measuring pressures.

The sensitivity of the indicator is such that settings are repeated to within 0.1μ or 1 part in 1,000,000 on gages 10 cm long.

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I. INTRODUCTION

Apparatus for comparing a length gage having spherical ends with one having plane ends where the difference in the thermal expansion is large has been developed and several comparisons have been completed. The need for making the intercomparison of gages arose in connection with the measurement of the diameters of some single-layer solenoids which were used as absolute standards of self-inductance. The diameters of the solenoids have been measured at 30° C. by comparison with a gage or end standard using an electrically controlled micrometer caliper¹ which operates with a measuring pressure of about 150 g. In making the comparison between the solenoid and a gage it is essential to use a gage with spherical ends, since it is not feasible to align a gage with plane ends between the faces of the micrometer with sufficient accuracy. At this bureau, the lengths of

¹ Moon, Charles, J. Opt. Soc. Am. and Rev. Sci. Inst., vol. 11, p. 453, 1925.

gages with plane ends are determined at 20° C. by interferometer methods.² The present work was undertaken to determine the length at 30° C. of the gage with spherical ends in comparison with a plane-ended gage which had been measured at 20° C. in terms of the wave lengths of light.

The only gages with plain ends now available are made from steel having a coefficient of expansion ranging from 11 to 14 parts in 1,000,000 per °C. Long gages hardened on the ends only have a coefficient near the lower limit of the above range. For this work, gages with spherical ends were made both from steel and from fused quartz, the latter having a temperature coefficient of only 5 parts in 10,000,000 per °C. An intercomparison was first made at 20° C. between a calibrated steel gage with plane ends and a fused quartz gage with spherical ends. This gave the length of the quartz gage at 20° C. The length of the quartz gage at 30° C. was computed from the known temperature coefficient. The two gages were also compared at 30° C. so that the coefficient of expansion of the steel gages could be computed.

An electrically controlled micrometer caliper is especially suitable for the comparison of gages having a large difference of linear expansion, since it can be used to make measurements within a small closed space where the temperature can be accurately controlled. In this work there is the added advantage of having the end standards calibrated under the same conditions as that in which they were later used in measuring the diameter of the solenoids where the working pressure must necessarily be very light to prevent deformation of the copper winding. A suitable comparator for the calibration of gages has been made by mounting the micrometer ring and a gage holding device on a common base.

II. DESCRIPTION OF COMPARATOR

The general arrangement of the comparator is shown in Figure 1. A cast-iron bed supports the micrometer caliper and two gage holders. The ring of the micrometer caliper is mounted on three slender leveling screws which are rigidly fastened to the bed. The tops of these screws rest in a 3-point support of the point-slot-plane type. This support holds the micrometer in a fixed position with regard to the bed, but is sufficiently flexible so that any expansion of the bed will not deform the ring. The gage holders are mounted on a cross slide, the base of which is rigidly clamped to the bed. Since the bed serves only as a firm support for the gage holder and micrometer ring, it does not need to have precision ways. When in use the whole comparator is inclosed in a small insulated cabinet with thermostatic control of temperature.

III. GAGE HOLDERS

The gage holders are mounted on a carefully made cross slide. Each holder is capable of supporting either a rectangular gage or a cylindrical gage, as shown in Figure 2. In either case, the gages rest on steel balls which roll on grooved steel blocks and allow an easy endwise motion in a fixed line. The steel blocks are mounted on a

² Peters, C. C., and Boyd H. S., *Interference Methods for Standardizing and Testing Gage Blocks*, B. S. Sci. Papers, vol. 17, p. 677, 1922.

FIGURE 1.—Comparator with gages in position for measurement

flat bar which is attached to the top of the cross slide. One end of the bar is hinged to the cross slide by a thin steel spring while the other end can be moved horizontally or vertically by tangent screws with graduated heads. The ways of the cross slide are accurately straight so that once a gage is correctly aligned it can be moved from the measuring position and returned to it without change in alignment. The screw which moves the cross slide and also the tangent screws can be turned by keys which extend through the walls of the constant temperature cabinet.

IV. THE MICROMETER CALIPER

The electrically controlled micrometer caliper has many of the features of the one previously described.³ The mechanical design

FIGURE 2.—Gage holders

A, cross slide; B, steel spring hinges; C and D, tangent screws.

has been changed by a new device for automatically stopping the screw, and temperature compensation has been accomplished by the use of a nickel-steel ring. In order that these modifications may be easily understood, a brief description of the instrument will be given.

A precision micrometer head and a spring-controlled anvil which operates an electrical contact are mounted on a diameter of a ring of nickel steel. The micrometer is driven slowly through a train of gears by a motor which operates on about two watts at three volts. When a gage is so mounted between the screw and anvil that only a small force is required to move it in the direction of its axis, the advancing screw of the micrometer pushes the gage against the anvil until the force is sufficient to open the platinum-iridium contacts operated by the anvil. The opening of this contact releases a mag-

³ Moon, Charles, *J. Opt. Soc. Am. and Rev. Sci. Inst.*, vol. 11, p. 463, 1925.

netic clutch in the train of gears which drives the micrometer screw, thus stopping the motion of the screw. The position at which the micrometer stops is read directly from the micrometer scale. The micrometer can be turned back to make a new reading by means of a switch, which reverses the motor and reengages the clutch.

One of the new features of this micrometer is the magnetically operated clutch which is shown in Figure 3. Its action is due to the friction between a smooth steel disk and three pieces of cork inserted in another similar disk. When a current is flowing in the electromagnet, the two disks are pressed together and rotate at a speed of

FIGURE 3.—*Electromagnetic clutch*

six revolutions per minute or less. At this low speed the micrometer screw, which rotates at one-tenth the speed of the pinion, stops so quickly when the current is interrupted that the speed of the motor is of little importance. A change of the speed from 500 to 2,500 revolutions per minute does not affect the setting of the micrometer by as much as 0.1μ .

The nickel-steel ring has a coefficient of expansion of about 3 parts in 1,000,000 per $^{\circ}\text{C}$., whereas the steel of which the micrometer and anvil are constructed has a coefficient of expansion of about 12 parts in 1,000,000. The design is such that the length of nickel steel which affects the readings is about four times that of the steel. Hence with

a change of temperature there is very little change in the distance between the faces of the micrometer.

The micrometer has a large head graduated to read microns, divisions being about 1 mm apart; 0.1μ can be estimated and settings are automatically repeated to this order of magnitude. The anvil is pushed forward by a spring, thus pressing the contact operated by the anvil against the fixed contact. When the force on the face of the anvil exceeds the force exerted by the spring the contacts open. In the micrometer shown in Figure 1 the force required to open the contacts is 150 g.

V. RESULTS OF A SET OF MEASUREMENTS

In making a comparison of the length of two gages, three sets of three readings each were made on both gages. The interval between sets was a half hour. The mean values of the three sets agreed to 0.1μ , provided the temperature control was sufficiently accurate.

A summary of the results obtained in determining the length of a 28 cm quartz gage with spherical ends is given in Table 1. This gage has been compared with different combinations of gage blocks built up to have a length differing from that of the quartz gage by less than 0.3 mm. The comparator and gages were inclosed in a cabinet where the temperature was controlled to within a few hundredths of a degree centigrade. Since the micrometer caliper was compensated for temperature and since the coefficient of expansion of the steel gage is twenty times larger than that of the quartz, the temperature of the steel gage only needed to be carefully measured. This temperature was read from a mercury-in-glass thermometer held against the gage by a mass of soft wax pressed over the bulb. No measurements were made until the temperature of the gage and cabinet had been constant for two hours. The maximum difference in the lengths found for the quartz gage is only 0.4μ , while the average deviation from the mean is only 0.1μ , or less than 4 parts in 10,000,000. The difficulty of bringing two plane surfaces into intimate contact with very light pressure serves as a limit to the accuracy which can be obtained with the apparatus herein described. A few measurements similar to those given in Table 1 have been made, using a new quartz gage made from material obtained from a different source. The mean result of several measurements would indicate that the new quartz rod has a coefficient of expansion about 0.03×10^{-6} less than the rod used to obtain the results given in Table 1.

TABLE 1

Date of measurement	Temperature of cabinet	Nominal lengths of steel gages at 20° C.	Certified length of steel gages corrected to cabinet temperature	Measured length of quartz gage
	°C.	mm	mm	mm
May 27.....1931	20.02	275.0+1.9+1.7+1.6	280.2004	280.2654
May 28.....	19.90	275.0+3.0+1.9	279.9000	280.2658
June 6.....	19.75	275.0+1.9+1.8+1.6	280.2996	280.2657
June 8.....	20.10	275.0+1.9+1.8+1.6	280.3006	280.2656
August 8.....	20.24	275.0+1.6+1.7+1.9	280.2010	280.2655
August 9.....	20.00	275.0+1.6+1.7+1.9	280.2003	280.2656
August 16.....	19.98	275.0+2.5+1.9+1.6	1 281.0002	280.2663

¹ 2.5 mm gage block has never been standardized at the Bureau of Standards.

As comparisons of the steel and quartz gages were made at both 20° and 30° C., the temperature coefficient of expansion of the steel gage was computed on the assumption that the coefficient of expansion of fused quartz ⁴ is 0.4×10^{-6} per °C. The value of the coefficient, 11.0×10^{-6} per °C. for the steel gages, lies in the range of values found by other observers ⁵ for gage steels.

VI. SOURCES OF ERROR

Since many of the sources of error in length measurement are common to all measuring machines, the discussion here is limited to a few important causes and the corrective methods which were adopted.⁶

1. LACK OF ALIGNMENT OF THE MEASURING FACES

The measuring faces of the screw and anvil of the micrometer are not strictly planes, but convex spherical surfaces having a radius of 10 m. At 1 mm off the axis, this surface would curve away from a plane by approximately 0.05 μ . The faces are carefully made so that the center of the spherical surface of the anvil lies in the axis of the plunger, and the center of the spherical surface of the micrometer screw lies in the axis of the screw. The grooves in the micrometer ring, in which the screw and anvil are clamped, were first carefully lapped to bring the two axes nearly parallel. The lack of adjustment was determined by measurements on a spherical-ended gage placed at different points between the measuring surfaces. Adjustments in alignment were accomplished by changing the pressure on the clamps which hold the anvil and screw in position. By repeated trials an adjustment was reached so that a movement of the axis of the spherical-ended gage of about 1 mm in any direction perpendicular to its axis did not change the readings of the micrometer by more than 0.1 μ .

2. DEFECTIVE ALIGNMENT OF GAGES

The error due to defective alignment of gages depends on the type of gage which is being used. The spherical-ended gages could be aligned by sight with sufficient accuracy. The flat-ended gages were aligned by taking a series of micrometer readings for different settings of the horizontal and vertical tangent screws, then setting the tangent screws to a position which gave a minimum reading of the micrometer. By making the alignment in this manner, a measurement on realignment agreed with the original within 0.1 μ .

3. INFLUENCE OF FOREIGN BODIES BETWEEN THE MEASURING SURFACES AND THE ENDS OF THE GAGE

Before placing the gage in the comparator, both the ends of the gage and the measuring surfaces of the micrometer were carefully cleaned to remove any foreign bodies, such as dust, from the surfaces. With spherical-ended gages consistent readings were readily obtained after they were cleaned with ordinary care. With flat-ended gages, however, consistent readings at the pressure of 150 g could not be

⁴ Souder and Hildner, Measurements of Thermal Expansion of Fused Silica, B. S. Sci. Paper, vol. 21^a p. 1, 1926.

⁵ Souder and Hildner, Thermal Expansion of a Few Steels, B. S. Sci. Papers, vol. 17, p. 611, 1922.

⁶ A discussion of errors in length measurements is given by F. H. Rolt in Gages and Fine Measurements (MacMillan & Co. 1929), vol. 1, chs. 6, 16, and 17.

obtained even after the most careful cleaning when the measuring surfaces were brought directly against the surfaces of the gage. To obtain reproducible results with flat-ended gages, the measuring faces were set against the gage with the normal measuring pressure, then the cross slide was moved slightly back and forth two or three times. This action tended to remove or distribute foreign material, after which consistent readings could be obtained.

4. FRICTION IN TAILSTOCK

It is necessary that the plunger to which the anvil is attached work very freely in the tailstock since any friction causes a variation in the measuring pressure. While the total measuring pressure is only 150 g, this force is sufficient to distort the ring 1 μ ; so that a variation of 15 g would cause a difference in reading of 0.1 μ . These readings on the gages repeated so well that there was no reason to suspect a variation in measuring pressure.

VII. CONCLUSION

With the apparatus described, the length of a spherical-ended gage of quartz can be compared with a flat-ended gage of steel with an accuracy of about 1 part in 1,000,000 on 30 cm gages, using a very light measuring pressure of only 150 g. Since a large part of the error occurs in the readings on the steel gages, somewhat higher accuracy can be obtained in the comparison of two spherical-ended gages of the same material, or in the comparison of two similar flat-ended gages which would permit the use of spherical measuring faces.

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