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ABSTRACT — This paper describes a project in which students worked in close cooperation with both the physics department of Macalester College and the gage block laboratory of the Continental Machine Company, manufacturers of precision gage blocks. Brief descriptions, including drawings, are given of both the interferometer and the constant temperature laboratory in which all measurements were taken. This constant temperature laboratory is set with precision at those two temperatures between which the average coefficient of linear expansion of a gage block is to be determined. Many such readings were taken and computations of the coefficient of expansion were made. Comparison of values obtained here for Stainless Steel and ordinary Carbon Steel showed a remarkably close correlation; e.g., the average value obtained in this experiment for Stainless Steel is 5.79 to compare with 5.75 given by the National Bureau of Standards; for Carbon Steel the average value is 6.50 compared with the Bureau's 6.55. All values are in microinches per inch per degree Fahrenheit.

A liaison between a liberal arts college and an industry has been shown to be beneficial to both in certain instances. This is particularly true when the relation is close enough to justify a place on the campus for specific projects associated with an industrial enterprise. The science of precision measurements, commonly referred to as metrology, affords a challenging problem of this nature since it necessitates a knowledge of scientific terms and procedures, and an understanding of how to put them to work in a practical way. For many reasons, connection between education and industry is both desirable and educationally justifiable. For example, industry is frequently equipped with scientific instrumentation far beyond the purchasing capabilities of most small colleges. This is true of both quantity and quality of materials available for scientific purposes. Again, students associated with a project may develop a strong interest in the science of metrology and upon graduation desire further association with the field. A connection between a college and an industry tends to make each aware of some of the problems of the other and a mutual understanding may be brought about which otherwise might be missing. In the ideal college-industry relation there are no rigid bonds exerted by either over the other. Each should have a genuine interest in making its facilities available. In particular, the college should not expect financial return from the industry except in the form of financial aid or scholarships for student research assistants and for the maintenance of the laboratory.

Purpose

The project to be described in this paper has to do with the accurate determination of the dimensions of gage blocks at different temperatures, and in the use of these data in the computation of the coefficient of linear expansion of the material of the block over certain temperature ranges. Much valuable work on this subject has been done at the National Bureau of Standards and is well described in their book, *Metrology of Gage Blocks* (U.S. Department of Commerce, 1957). The instrument used was furnished by the Wilkie Brothers Foundation of the DoAll Company,[1] Des Plaines, Illinois, and is one of the finest of its kind. It is a gage block interferometer made by the Carl Zeiss Company of Germany. This instrument is capable of measuring a dimension to one-millionth of an inch and is readily adaptable to the determination of the coefficient of linear expansion in different temperature ranges between 50° and 100° F.

Methodology

The principle of operation of the interferometer is presented in Fig. 1. From cadmium lamp Q, the light goes by way of a condenser L to entry slit EP, passes through compensator K, is deflected by mirror S_5, and proceeds by way of a collimator objective O_1 and prism P to dividing plate T. Here the ray is split. One portion passes over mirror S_4 to the gage-block surfaces where the light is reflected and returns by S_4 to dividing plate T. The other portion passes through compensator plate K, is deflected by mirror S_1 to mirror S_v. After being reflected, the ray returns to the dividing plate by the same path. In either case, a part of the two rays penetrates the measuring plates M_1 or M_2. From T on, the two rays together go by way of deflecting mirror S_6, objective O_2 and mirror S_7 through inverting prism U to exit slit AP, and interference phenomena are observed in the eyepiece.

Preliminary trials on dimensions of various gage blocks soon made it evident that although the interferometer is provided with an air-tight housing, slight temperature differences produce noticeable irregularities in the readings. In fact, the instrument is so sensitive that the body temperature of the operator has a marked effect on readings. Since this type of instrument is highly desirable, from the point of view of gage block measurements, and since it is not practicable to employ the tech-

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[1] The Gage Block Laboratory is located at Continental Machines, Inc., Savage, Minnesota, a member of The DoAll Corporate Family.

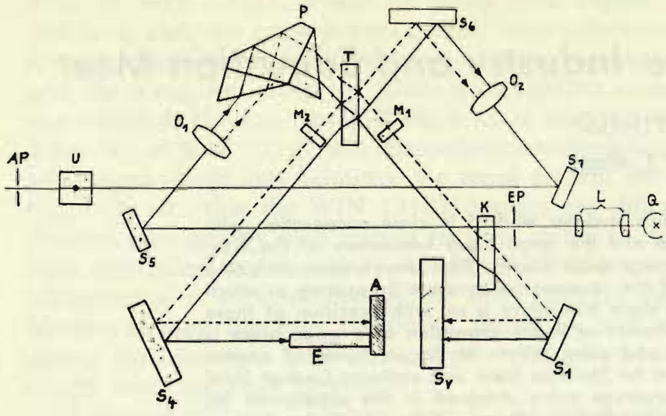

FIGURE 1.

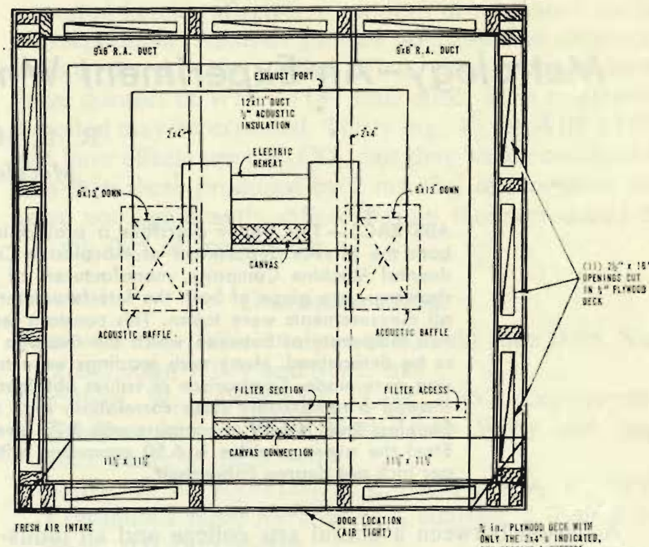

FIGURE 3. PLAN VIEW

nique of oil immersion here, it was decided to construct a small variable temperature enclosure large enough for two operators together with the necessary controls and instrumentation. Because radiant heat due to the body temperatures of the operators is such an important factor here, some means to counteract its effects were necessary. Although motion of the air in the laboratory would not affect the radiant energy directly, it was, nevertheless, felt that constant but gentle circulation of the air could produce a sufficiently stabilizing effect on the temperature of the interferometer and surroundings to enable the taking of readings for which the temperature variation would be less than ½ of 1° F. Accordingly, the laboratory was designed with hollow walls and perforated ceiling through which temperature-controlled air was gently circulated. Figs. 2 and 3 show the various details associated with the temperature enclosure, including the circulatory features through ducts at the bottom of the hollow wall sections. Brief specifications for air temperature control are given in Fig. 4.

To obtain the length of a given gage block, it is wrung on to a steel base plate, as shown in Fig. 1. Scale values for red, green and blue wavelengths are read and the mean and theoretical values are found. The difference is converted into microinches. In the present paper, the value used to correct the gage-block dimension is taken in every case to be the greatest deviation from the red line value.

To get the coefficient of linear expansion, the gage-block laboratory is set at a certain temperature for 24 hours. Then a reading is taken. The laboratory is then set at another temperature for 24 hours and the second reading is taken. The coefficient of expansion between these temperatures is then found by the following equation:

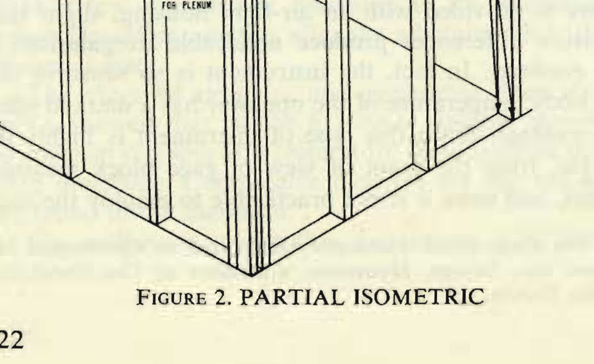

FIGURE 2. PARTIAL ISOMETRIC

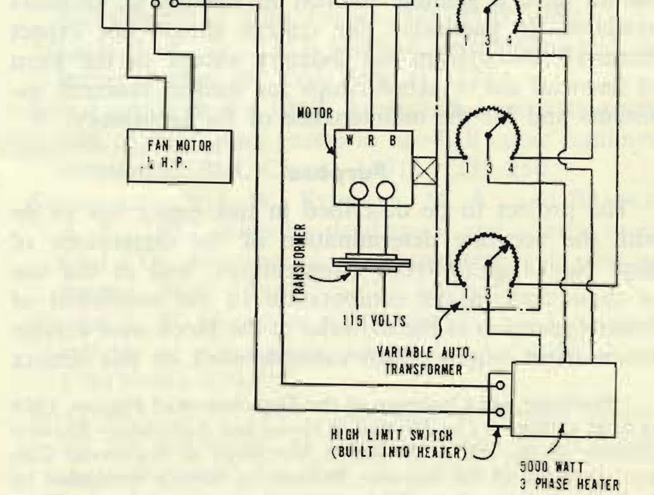

FIGURE 4. CONTROL DIAGRAM

$$a = \frac{L_t - L_o}{L_o(t_2 - t_1)}$$

where a = coefficient of linear expansion

L_t = length of block at higher temperature t_2

L_o = length of block at lower temperature t_1

t_2 and t_1 = temperature values in degrees Fahenheit

To obtain a more accurate reading, various corrections should be made. This is because the wavelength of light depends upon atmospheric pressure, humidity and temperature. Therefore, barometer, psychrometer and thermometer readings must be a part of the data for accurate gage-block determinations. The equation used for the corrected determination is [2]

$$k = 0.36\ (760 - p) - 0.05\ (e - 10) - 0.93\ (t - 20)$$

where k = total correction factor for pressure, humidity and temperature

p = corrected barometric pressure

e = corrected vapor pressure

t = temperature

Results

Using the corrections indicated above, the coefficients of linear expansion of many gage blocks made of different materials have been computed. Below are actual values from tests made by college students in the Wilkie Metrology Laboratory. They were not specially prepared for this paper, but represent samplings from much accumulated data. Results like these can easily be produced with a minimum expenditure of time and effort. Some typical values for stainless steel and carbon steel are given.

Conclusions

The convenience of this method seems fairly obvious. With the instruments and operator all in the same temperature enclosure, experimentation is convenient and quickly accomplished. Some question may exist as to the accuracy obtainable, particularly with reference to effects of the operator's body temperature. On the interferometer and gage block under test, it is our opinion that constant, gentle circulation of air whose temperature is accurately controlled reduces the error to a negligible minimum. Instruments in our constant temperature laboratory never show a variation in temperature of more than ½ of 1° F.

[2] Taken from Zeiss book of instructions for the interferometer.

VALUES FOR COEFFICIENT OF LINEAR EXPANSION IN MICROINCHES PER INCH PER DEGREE FAHRENHEIT

Stainless Steel	Carbon Steel
5.60	6.22
5.44	6.42
5.48	6.07
6.04	6.14
5.93	6.48
5.88	6.38
5.56	6.65
5.60	6.43
5.63	6.60
5.93	6.33
5.89	6.60
5.88	6.64
5.88	6.67
5.88	6.57
5.87	6.64
5.86	6.66
5.88	6.61
5.87	6.67
5.86	6.68
Average value — 5.79	6.50

(The National Bureau of Standards values for the coefficient of expansion of the above materials are: Stainless Steel—5.75, Carbon Steel—6.55)

References

U. S. Department of Commerce, 1957. Metrology of Gage Blocks. National Bureau of Standards, Circular 581.