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Parallel Testing Interferometer

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The conventional methods of testing the parallelism of opaque bodies, such as gage blocks, by interferometry require wringing of the body to an optical flat. This operation disturbs the temperature equilibrium, necessitating long periods between tests, especially for long blocks. It often injures the surfaces of both the optical flat and the test body. Also, if the body is a standard gage block, repeated wringings during use ultimately change the dimension. This paper describes an interferometer for measuring the parallelism of gage blocks and other bodies of any reasonable length without the necessity of the wringing operation. Two forms of this instrument are used—one for testing long blocks and another for testing short blocks. Either form can be constructed for testing blocks of any length, but two forms are found to be more practical.

1. Introduction

The conventional procedures for measuring the parallelism of gage blocks [1, 2] require the wringing of the blocks onto an optical flat. The wringing operation often injures the contacted surfaces and repeated wringings necessitate frequent refinishing of the optical flat that is used as a base. A method for measuring parallelism, without the wringing operation, has significant advantages because the danger of injury to the contacted surfaces is eliminated. Accordingly, two instruments that utilize this method are described: one is for testing very long blocks and similar bodies, whereas the other is designed for short blocks. Both instruments use low orders of interference and neither requires the use of a standard.

2. Optics of the Interferometer

A description of the optics for either form of this instrument covers a large portion of that for the other. For distinction we will designate them as "the long-block interferometer" and "the short-block interferometer". The double-image prism used in these instruments is adjusted during construction [3] so that a ray of light, shown in the plane of figure 1A, after division into two component rays, 1 and 2, at P_0 will, on reflection at P_1 and P_2, lie in planes that are parallel to the semireflecting plane of the prism but deviate equally toward or from opposite sides of the plane of figure 1A. The projection of the light rays on the dividing plane is shown in figure 1B, which is perpendicular to the plane of figure 1A. This deviation is effected by rotating one component of the prism relative to the other about an axis normal to the dividing plane of the prism. If this deviation is held constant, the width of the interference fringes in the direction normal to the plane of figure 1A is fixed. This component of fringe width is, therefore, frozen into the system [4] when the cement between the component prisms becomes hard by cooling after adjustments are complete. Furthermore, the tilting of any plane surface outside the prism that affects the two component beams between division and recombination, will produce equal effects in this direction and, consequently, will not affect the fringe width. However, the rotation of plane surfaces about an axis normal to the plane of figure 1A will produce equal effects on the two component beams but in opposite directions, thus producing a proportionate effect on the fringe width in the direction parallel to this plane.

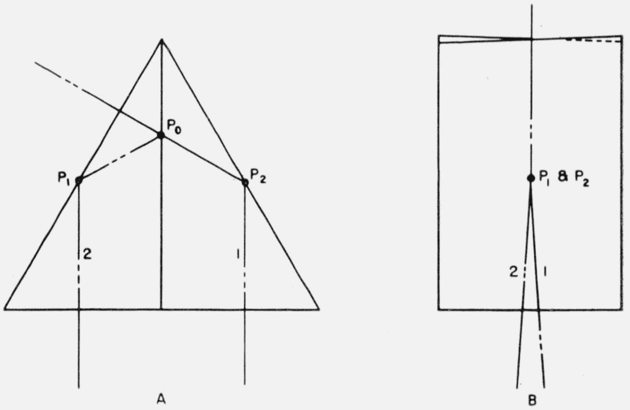

FIGURE 1. *Kösters double-image prism.*

A small angle is formed by the two 30° edges shown exaggerated in B.

Because of the above-described properties of this prism, adjustments of the instrument in which it is used affect the fringe width in one direction only. Consequently, when measuring the parallelism of gage blocks the test can be applied to parallelism in only one direction at a time. To test for parallelism in other directions the block must be rotated.

2.1. Long-Block Interferometer

Figure 2A is a horizontal section through the optical elements of this instrument. The light from a source at $S_1(S_2)$ is collimated by lens $L_1(L_2)$ and divided into two equal components by the beam-dividing plane $B_1(B_2)$. Each component suffers total internal reflection in the prism and emerges in planes

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[1] Gauges and fine measurements, by F. H. Rolt, **I**, p. 204 (Macmillan and Co., Ltd., London 1929).

[2] The science of precision measurement, by The DoAll Co., p. 143 (1953).

[3] Construction of a Kösters double-image prism, by J. B. Saunders, J. Research NBS **58**, 21 (1957) RP2729.

[4] NBS Tech. News Bul. **42**, 30 (1958).

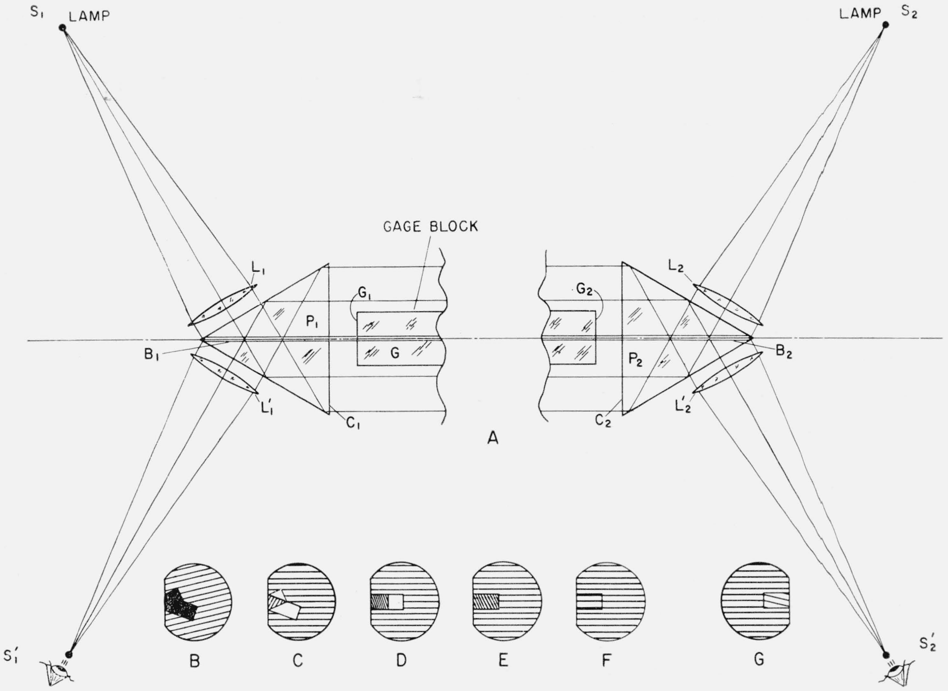

FIGURE 2. *Optics of interferometer for testing parallelism of long blocks.*

Figures B through G represent observed interference fringes.

parallel to $B_1(B_2)$, but at a small angle to the base surface $C_1(C_2)$. The latter condition is obtained by a slight rotation of $P_1(P_2)$ about an axis normal to the dividing plane $B_1(B_2)$. This serves to permit the elimination of light reflected from $C_1(C_2)$.

The two prisms, P_1 and P_2, are separated by a distance exceeding the length of the longest block to be tested. If desired, this distance may be made adjustable. The two dividing planes, B_1 and B_2, are adjusted to be coplanar and the two base faces, C_1 and C_2, are adjusted parallel to each other. A line joining the centers of P_1 and P_2 is adjusted to form a small angle with the normal to faces C_1 and C_2.

The light emerges from prism $P_1(P_2)$ as two separated components, one on each side of the dividing plane. It enters prism $P_2(P_1)$, again suffers total internal reflection, and each pair of component rays recombines in the plane of $B_2(B_1)$. One-half of each beam proceeds to the neighborhood of source $S_2(S_1)$ and the other half to $S_2'(S_1')$. An observer at $S_2'(S_1')$ sees a set of interference fringes that cover the entire aperture.

If a gage block, G, is inserted in the position shown with its end face, G_1, adjusted normal to the light beams, it will reflect equal and corresponding parts of the two component light beams from S_1 back through P_1 to S_1'. Accordingly, the observer at S_1' sees a background set of fringes, produced by light from S_2 and another set on the face of G_1, that is produced by light from S_1. Since G_1 is normal to the light beams these two sets of fringes will be parallel to each other and to the plane of figure 2A. If the other end, G_2, of the gage block is parallel to G_1, the fringes seen at S_2' will likewise be parallel to each other and to the plane of figure 2A. If, however, G_2 is not parallel to G_1, in the plane of figure 2A, it will not be normal to the light beams, and the sets of fringes seen at S_2' will not be parallel to each other. The angle between these two sets of fringes is a measure of the angle between G_1 and G_2 in the plane of figure 2A. The component of the angle between G_1 and G_2 that is perpendicular to the plane of figure 2A (or horizontally in figs. 2B to 2G) does not affect the fringes because it affects all pairs of component beams equally. If the component of the angle between the gage-block surfaces that is normal to the plane of figure 2A (or vertically in figs. 2B to 2G) is desired, the block must be rotated 90° and the operation repeated.

Since each prism is adjusted for complete compensation in the plane of figure 2A, white light can be used. A measure of the vertical width of the fringes (perpendicular to fig. 2A) for a known monochromatic light, with a micrometer eyepiece at S_2', gives a calibration of the micrometer scale in units (microns, millionths of an inch, etc.) of length for measuring the displacement of white-light fringes from a chosen reference point on the gage-block surface.

The procedure for adjusting a gage block is explained with the aid of inserts in figure 2. In general, when the block is placed on its supports, the light reflected from its end will not reach the observer because of excessive angular deviation from the eyepiece. The block will appear in silhouette, as indicated in figure 2B. When the surface G_1 is adjusted approximately normal to the light, fine fringes will usually be visible in the area covered by both images of it, as shown in figure 2C. The images of the two parts of G_1 are made to coincide by rotating G about the center line of figure 2A, causing the image to change from that of figure 2C to figure 2D. A lateral motion, without rotation, will then change the image from that shown in figure 2D to figure 2E. A further small rotation of G about an axis normal to figure 2A brings G_1 normal to the light and the fringes on G_1 will appear horizontal and parallel to the background fringes as shown in figure 2F. The observer then moves to position S_2' and observes the set of fringes shown in figure 2G. The angle between these two sets of fringes corresponds to the angle between surfaces G_1 and G_2.

A photograph of the long-block interferometer is shown in figure 3. The base of the instrument is designed for rigidity so as to avoid flexure. Rigidity is quite important. The two prisms are mounted on rigid tables at each end of the base. Three screws (D_1 and two others not shown) permit raising and lowering of prism P_2. They also permit rotation or tilting of this prism about any chosen horizontal axis. The prism housings are fastened to the table tops by means of large-headed screws, in oversize holes, that permit lateral adjustments of the prisms relative to each other. Two screws, D_2 and another concealed by the housing of prism P_2, permit small rotations of this prism about a vertical axis by applying lateral torques to the legs of the table. Similarly, screws D_3 and D_4 permit rotary adjustments of the other prism housing.

The adjustments described above permit the alinement of the two prisms. This adjustment is critical, rather difficult to attain, but when once obtained is very stable. The final adjustments are executed while observing interference fringes produced by lens L'_2, in one of the many images of the source S_2. This author uses a pinhole source of approximately 1-mm diam and a short-focus lens to observe its image at S_2'. There are two sets of fringes, superimposed upon each other, in the proper image to be used. When these two sets of fringes are horizontal and very broad, fringes can be seen with the two eyepieces when focused on the pinhole. These fringes, in white light, are horizontal with the zero order in the center of the field.

The supports on which the long blocks rest are located at the Airy points so as to reduce changes in the angle between G_1 and G_2 due to gravitational distortion.[5] These supports rest on an adjustable plate which, in turn, is supported at one end by two points and at the other by one point. This plate is adjustable at one end, laterally with screw D_5 and vertically with another screw D_6 which is concealed in figure 3.

2.2. Short-Block Interferometer

The optics of the short-block interferometer are shown in figure 4. The double-image prism, lenses light source, and viewing position in figure 4B are identical to that of either end of the long-block instrument described above. A reflecting prism, P_R in figure 4, replaces one of the prism assemblies of the long-block instrument. Also, the optical axis of the instrument is vertical instead of horizontal. Figure 5 is a photograph of the short-block interferometer. Figure 4A may be considered a section through the center of 4B, coincident with the dividing plane of prism P. The indicated rays, 1 and 2 in figure 4A, however, do not lie in this plane. Their positions relative to it are indicated in 4E, which is a vertical view through 4B. The two surfaces, G_1 and G_2, of the gage block (figs. 4A and 4D) appear as G and G′ in figure 4E. G'_2 in figure 4A is an image of G_2 as seen by light reflected from the right-angle prism, P_R.

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[5] F. H. Rolt, Gauges and fine measurements **II**, 340 (Macmillan and Co., 1929).

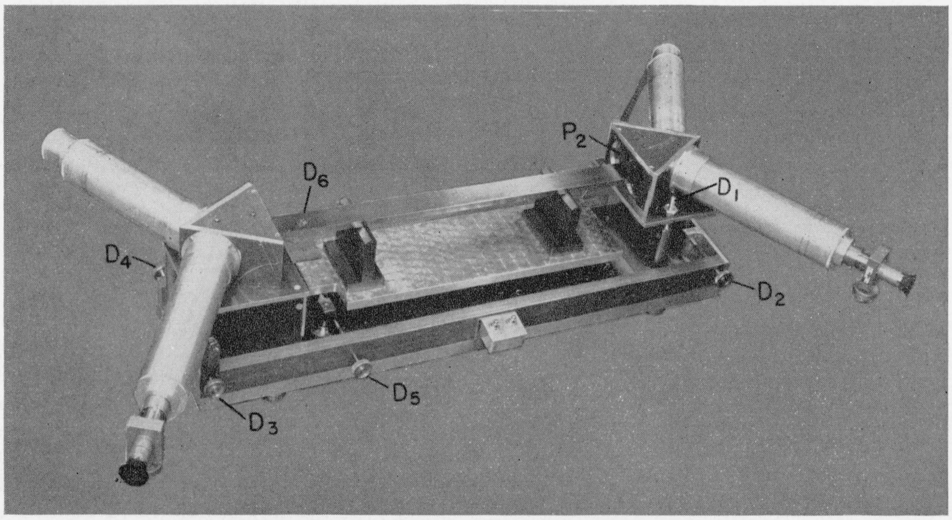

FIGURE 3. *Photograph of the long-block interferometer.*

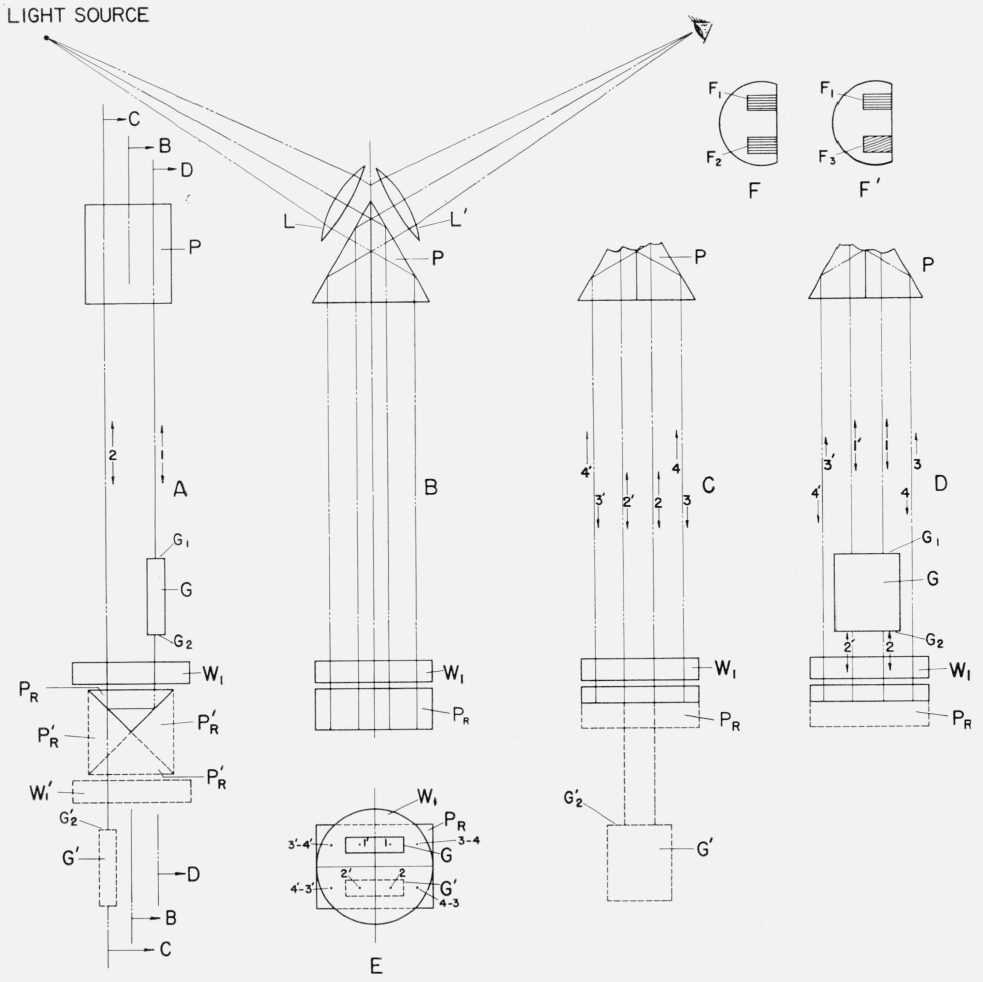

Figure 4. *Optics of the interferometer for testing parallelism of short blocks.*

Figures B, C, and D are sections through A. Figure E is a vertical view. Figures F and F′ represent interference fringes for a parallel and a nonparallel block, respectively.

A plane optical wedge, W$_1$, and its image, W$'_1$, (in figure 4A) are shown between G and its image G$'$. Figures 4B, 4C, and 4D are sections through 4A, along the lines indicated. The gage block is not located in the center as was the case in the instrument described above.

The two component rays of light, 1 and 1$'$ (figs. 4A and 4D), are caused to reflect normally from G$_1$ by adjusting G with a leveling screw. They return into P where they recombine to produce the interference fringes, F$_1$, shown in figure 4F. The two component rays, 2 and 2$'$ (figs. 4A and 4C) are transmitted downward through the optical wedge, W$_1$, suffer two internal reflections in P$_R$, and if P$_R$ is properly adjusted, return upward and parallel to their directions of incidence through W$_1$ to G$_2$.

The wedge, W$_1$, is adjusted initially by rotation so that its thickness is constant at all points in either of the planes B, C, and D. When in this neutral position it does not affect the interference fringes because of compensation in each pair of component beams that pass through it. The function of W$_1$ will be explained later.

In order to measure the angle between G$_1$ and G$_2$, the deviation of the light by P$_R$ toward or from the dividing plane of P must either be reduced to zero or its effect eliminated by measuring the observed angle for two orientations of G, which are 180° apart. The light that is not intercepted by G forms an interference pattern of uniform tint (or color) that fills the background about and between the two images of the gage block, shown in figure 4F or 4F$'$. Figures 4F and 4F$'$ represent the conditions observed when the ends of the block are parallel and nonparallel, respectively. A typical pair of component rays, which form this interference pattern, is indicated by 3 and 3$'$. They travel downward in figure 4C and upward in figure 4D. If the right-angle edge of P$_R$ is normal to the dividing plane of P, the pair of rays 3 and 3$'$ in figure 4C can be made to return in planes that are parallel to the dividing plane, by rotating P$_R$ about an axis parallel to the plane of 4A and normal to the incident light. This condition is attained when the background fringe is infinitely broad. The direction of the background fringes, when not infinitely broad,

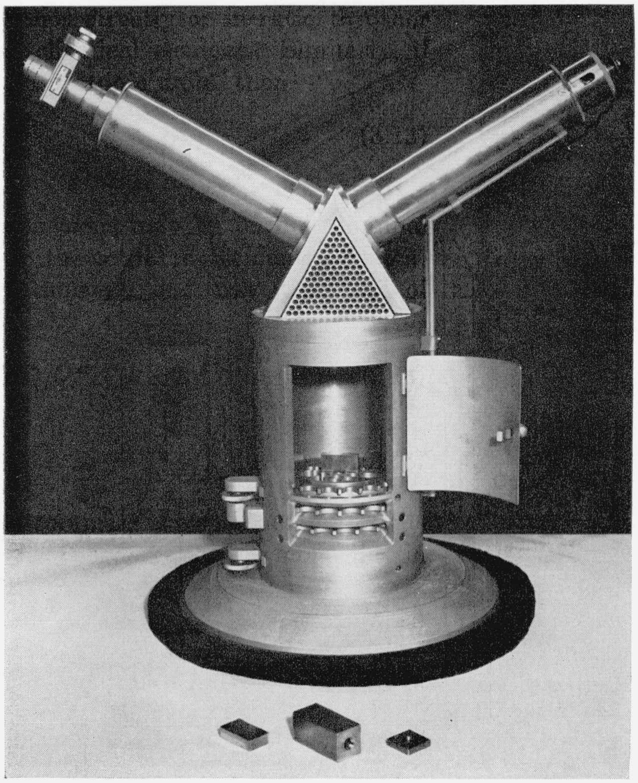

FIGURE 5. *Photograph of the short-block interferometer.*

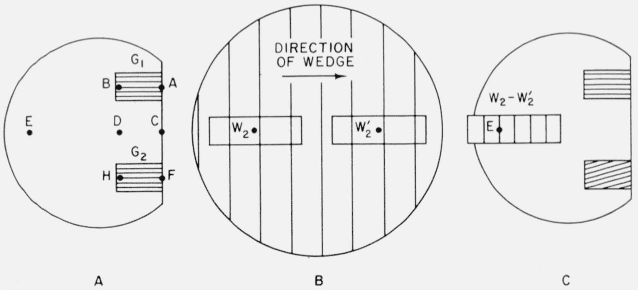

FIGURE 6. *Figures A and C represent the positions of reference points relative to the different sets of interference fringes.*

Figure B shows the wedge from which the two smaller wedges, W^2 and $W^{2\prime}$, were cut and the difference in optical thickness between them.

remain parallel to the dividing plane, because for each pair of component rays, such as 3 and 3′, there is a corresponding pair, 4 and 4′, that travel identical paths but in opposite directions. The optical path differences are, therefore, equal to each other and also equal to that for any other pair of component rays in the plane of 4C and 4D. The order of interference along the dividing plane corresponds to the optical path difference that was introduced into the double-image prism by the built-in wedges at the point that corresponds to the point of intersection of the right-angle edge of P_R and the dividing plane of P. This point is located in the center of figure 4E.

In general, due to the inherent error of judging when the background fringes are infinitely broad and to imperfections in the optical elements, a more precise method of evaluating the wedge between G_1 and G_2 is to measure the wedge for two positions that differ by 180°. If the background fringes are unaltered, the instrumental errors will be equal for the two positions and the value of the wedge unchanged except in sign. Consequently, the albebraic difference yields twice the value of the wedge.

There are three ways that one might evaluate the wedge between G_1 and G_2. The first is to rotate P_R until the order of interference at points C and E (fig. 6A) are equal; then rotate the gage block until the orders at A and B are equal; and finally, observe the difference in order of interference at points F and H. The second method is: After performing the above operations, instead of reading the order difference between F and H, reduce this order difference to zero by rotating W_1 and read the resultant change on a scale attached to W_1, figure 4E. This scale may be calibrated with monochromatic light and the units may be radians, degrees, or the corresponding variation in height of the block. A third method is to leave the wedge in its neutral position, adjust G so that the orders of interference of A and B are equal, and change the order at H to equal that at F by rotating P_R about an axis normal to the incident light and parallel to the plane of figure 4A. The order of interference between two points such as C and D (fig. 6A) after rotating P_R will be equal to one-half of that between F and H before this rotation was performed. By choosing a point, such as E in figure 6, such that CE equals K times CD, the order difference between C and E will be K times that between C and D.

When using this last method for testing gages that are almost parallel, the angle between G_1 and G_2 will be small and the background fringes will be too broad for reading fractions of fringes. To eliminate this difficulty, an optical wedge, illustrated in figure 6B, is constructed and from it two sections W_2 and W_2' are cut and placed on P_R as shown in figure 7. The wedges W_2 and W_2' are equal, but when placed in the position shown, the effect is to narrow the background fringes seen through them. The results are illustrated in figure 6C. The difference in thickness of W_2 and W_2' at a selected reference point E (fig. 6C) is determined by the choice of the corresponding positions on the plate from which they were cut. This difference in thickness is chosen so as to cause the zero order of interference to pass through the chosen point when the background fringes about W_2–W_2' are infinitely broad.

If the angles of wedges W_2 and W_2' are properly chosen, the width of the fringes seen through them will be most favorable for measuring the fractional parts of fringes. Also, the position of the zero-order fringe, relative to point E, may be calibrated to read directly the angle between the ends of the gage blocks.

The recommended procedure for measuring a block is: (1) Adjust the two sets of fringes seen on the ends of the block so that they are perpendicular to the dividing plane, as in figure 4F; (2) note the position

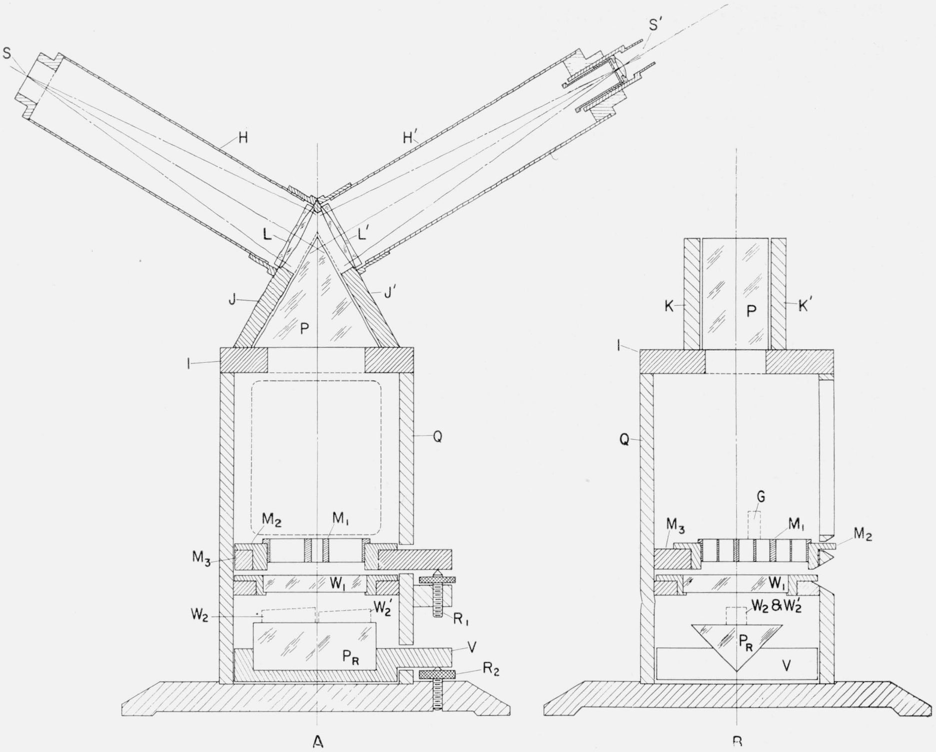

FIGURE 7. *Two vertical sections, at right angles to each other, through the short-block interferometer.*

of the zero-order fringe (or absolute order at E, fig. 6C); (3) rotate the block 180° about a vertical axis through its center; (4) readjust the fringes to restore the condition of (1) above; (5) again note the position of the zero-order fringe (or absolute order at E); (6) the difference in the two observed orders at E, or positions of the zero-order fringe, multiplied by the constant K, described above, is a measure of the angle between the ends of the block.

Figure 7 shows two vertical sections through the center of the short-block interferometer that are mutually perpendicular to and through the centers of each other. A pinhole, S, illuminated either with monochromatic or polychromatic light from outside the tube H, serves as source. The position of the pinhole is adjustable in the focal plane of the collimator lens, L, and the collimator tube is adjustable in length. The prism, P, rests on a thick plate, I, to which is fastened the lens-holding plates, J and J′. The plates, K and K′, which cover the ends of P, are not fastened to J or J′. Consequently, small stresses applied to tube H′ while adjusting the eye-piece or manipulating a micrometer in it, are not transmitted to P.

The material of the instrument, except for the collimator, the eye-piece tubes and optical elements, is made of steel. Steel was chosen because its expansivity approximates that of the glass elements more nearly than other usable materials.

The gage block, G, rests on a rotatable plate, M_1, that is perforated so as to transmit the required parts of the light beams used for making measurements. See also figure 8 for a vertical view of M_1 and its supporting parts. The plate, M_1, rotates in an annulus ring, M_2, which in turn is rotatable, from outside the instrument, in another annulus, M_3. The aperture in M_3 has its center displaced from the center of the instrument in a direction parallel to the dividing plane of P and by an amount equal to one-half the horizontal separation between the centers of the gage block, G_1, and its image, G′. The gage block rests on the center of M_1 (see fig. 6B). Accurate placement of the block is facilitated by stops.

The eccentric annulus, M_3, has an arm that projects through the wall, Q, of the instrument and is supported by this arm at one of its three supporting points by an adjusting screw, R_1. The other two supports for M_3 are steel balls, T_1 and T_2, (fig. 8B), which are held in conical holes by means of two screws, U_1 and U_2, respectively. The ends of these screws have eccentric conical depressions that permit a limited amount of rotation of M_3 about an axis normal to the dividing plane of P. The screw R_1 permits fine adjustment of M_2, and consequently the gage block, which it supports, about a horizontal axis parallel to the dividing plane of P. A similar pair of balls, screws, and the adjustable screw R_2, permits rotation of P_R about two axes parallel to those used for adjusting M_3.

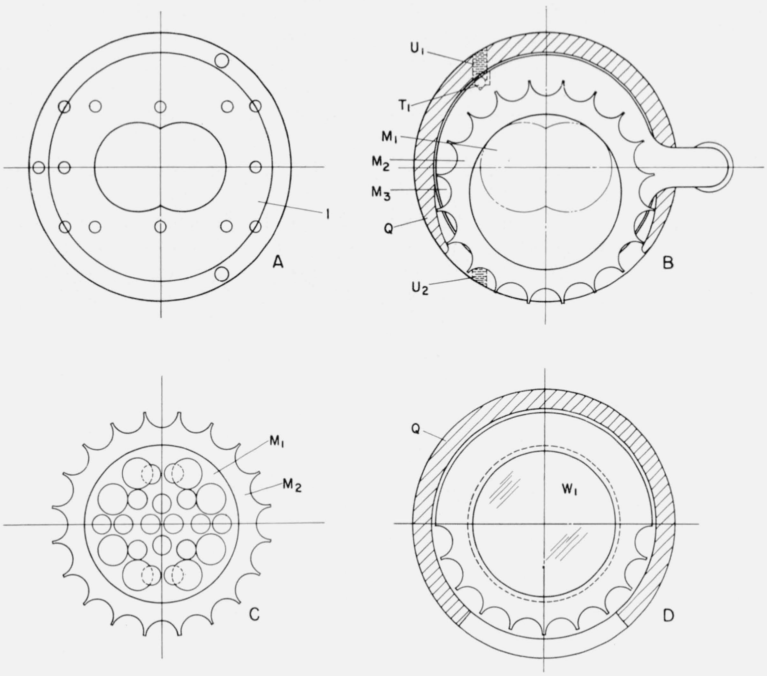

FIGURE 8. *Several views showing individual parts of the short-block interferometer.*

If the refracting edge of the optical wedge, W_1, is made perpendicular to the dividing plane of P (i. e., parallel to the plane of fig. 7B), each pair of component rays will traverse this plate at points of equal thickness. Consequently, W_1 in this orientation, does not affect the fringes of interference. It does, however, serve as a window, protecting the prism P_R from the accumulation of dust. Other functions of W_1 will be discussed later.

The prism, P, is centered over the aperture in plate I (figs. 7A and 8A) with its ends parallel to plates K and K′ (fig. 7B). Using the base surface of P as a plane mirror, the pinhole aperture S is located in the focal plane of lens L by varying the length of tube H and at a point in this plane where the light will form an image of the pinhole upon itself. This places the light beams, after division at the dividing plane, normal to the prism base and, consequently, parallel to each other.

A gage block, whose end faces are parallel to each other, is placed on the center of plate M_1 with its lower surface parallel to the top surface of M_1. When the surface of the block is adjusted parallel to the base of P by means of screws R_1, U_1, and U_2, the light from S is reflected normally from the top surface of the block and observed at the eyepiece as interference fringes.

The parts of the light beams that are not intercepted by the block and its support M_1, traverse the optical wedge W_1, and enter the right-angle prism P_R. After two internal reflections in P_R, the light returns along a path that is symmetrical to its incident path with respect to the 90° edge of P_R. The 90° edge of P_R is made normal to the dividing plane of P by means of screws in its support similar to U_1 and U_2 and the fine-adjusting screw R_2 (fig. 7A). This light forms the background fringes used in the test, but no interference is observed until this prism edge is nearly normal to the dividing plane. When it is not normal the two images of this edge, formed by the two component light beams, intersect in the extension of the beam dividing plane. The prism P_R is rotated until the two images coincide—perfection being attained when the background fringes have maximum contrast.

The above-mentioned contrast in the background fringes is not affected by screw, R_2, since it has no vertical rotational effect on the prism. Its effect is to change the width of the background fringes only. When the background fringes are made infinitely broad, the collimated beam of light returns toward P parallel to the incident beam—all rays having suffered a horizontal shift in P_R, as illustrated in figure 4A.

The holes in the gage-block support, M_1 (fig. 8C), are so spaced that when M_1 is rotated to one of the four positions for which the rectangular sides of the block are either parallel or perpendicular to the dividing plane, all light that goes through M_1 returns again through it. That is, the apertures in M_1 are symmetrical both with respect to the dividing plane and to the 90° edge of P_R. Parts of the beam (rays 3, 3′, 4, and 4′ in fig. 4) will pass downward through M_1 to P_R, shift horizontally in P_R, and pass upward through other apertures in M_1 to P. Other parts of the beam (rays 2 and 2′ in fig. 4) will pass downward through M_1, shift horizontally in P_R, pass upward through M_1 to the lower surface of the gage block, return through M_1 to P_R and again upward through M_1 to P. If the two end faces, G_1 and G_2, are parallel, the light will be incident on G_1 and G_2 at equal angles. When G_1 is adjusted normal to the light, G_2 will also be normal to it.

We have three sets of fringes, shown in figure 4F′, to consider: (1) The set F_1 is formed by light reflected from the top surface, G_1, of the gage block; (2) the background fringe between and about F_1 and F_3, formed by light reflected from P_R but not incident on the gage block; and (3) the set F_3 formed by light reflected from P_R to G_2 and back through P_R. The direction or orientation of F_1 determines the angle between G_1 and the incident wavefront; the width of the background fringes determine the direction between the incident and reflected beams to and from P_R; and the orientation of F_3 determines the angle between G_2 and the wavefront that is reflected from it.

The set of fringes, F_1, is adjusted by means of R_1 normal to the dividing plane of P, for which condition G_1 is normal to the incident light. The background fringe is made infinitely broad, for which condition the light beams returning from P_R are parallel to the incident beams. If the two surfaces of G are parallel, the set of fringes appearing on G_2 will be parallel to those on G_1 and indicated as the set F_2 in figure 4F. If G_1 and G_2 are not parallel, the fringes seen on them and indicated as F_1 and F_3 in figure 4F′ will not be parallel to each other. The angle between these two sets of fringes is a measure of the angle between the two ends of the gage block.

WASHINGTON, May 5, 1958.