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Air Flow Rate as a Test For Gage Block Wringing

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Gage blocks can be joined by "wringing" to produce a vacuum-tight joint. Hoke gage blocks have square gaging surfaces with a central hole connecting them. The quality of the joints between blocks can be tested by measuring the vacuum leak rates through the joints into the central hole. When two Hoke blocks are in contact at one edge but tilted at an angle ϕ, the vacuum leak rate into a chamber of 22 cm^3 produces a rate of pressure increase which can be represented by the following polynomial:

$$dp/dt = 0.42 \quad \phi^2 + 0.022 \quad \phi^3 \ \mu\text{m Hg/min},$$

where ϕ is in μrad. Hoke blocks in suitable condition to be joined by wringing can also be joined by alining them and evacuating the joint through the center hole.

Key words: End length standards; gage blocks; joining; wringing; wring test.

1. Introduction

The lapped surfaces of gage blocks are ordinarily joined by greasing them very lightly and then pressing them together with a twisting and sliding motion known as "wringing." A similar joint can be made with fused silica surfaces (without grease) by techniques known as "optical contacting." The closeness of two surfaces joined by wringing is more reproducible than that produced by any other means of positioning except optical contacting. For this reason, joints made by wringing are used extensively for assembling end length standards and for other precise assemblies.

When components with lapped surfaces are constrained, however, wringing may not be a practical means for joining them. Typically, components being joined by wringing are free to aline themselves, and the drag of their relative motion is a fairly reliable indication of the quality of the joint. For constrained components, the possible motions for wringing may be insufficient for good joining, and the sensing of the drag may well be misleading. This arrangement exists with the NBS precision manometer, where the height of the mercury column is determined by a column of Hoke gage blocks, joined between the cell boss and its pedestal [1][1]. Because it was difficult to perform wringing, it became important to develop other means to produce the joints and to sense their reliability.[2]

2. Experimental Method

A tightly wrung joint between continuous, optically flat metal surfaces is "vacuum tight." It was decided, therefore, to investigate the rate of air flow from the ambient atmosphere into an evacuated small volume through the center hole of a Hoke block, as a function of the dihedral angle between it and a fused silica optical flat.[3]

Hoke gage blocks are end length standards of square cross-section, 2.41 cm on a side with an axial hole 0.67 cm in diameter running between the gaging faces. As used for the manometer, the holes of the gage blocks served for vacuum lines and were connected to lines incorporated in the pedestals of the manometer base. The remainder of the measuring system included a group of valves and a thermocouple gage (see fig. 1), with a total volume of 22 cm^3, which was small enough to allow good responses for the tests.

To determine the angle of tilt, we observed the number of fringes of the cadmium green line (508.582 nm) produced by a Fizeau interferometer that was formed by a fused silica optical flat wrung to one edge

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[1] Figures in brackets indicate the literature reference at the end of this paper.
[2] Based on earlier measurements, a brief discussion of the techniques to be presented in this paper has appeared in the manometer paper.
[3] Clearly such a test will be useless if the surface is either heavily greased or discontinuous.

TABLE 1.

(1) Fringes	(2) Meas. time (seconds)	(3) Pressure increase (μm Hg)	(4) dp/dt (μm Hg/min)	(5) Cal. by eq (2)	(6) Dev.	(7) Order of meas.
1.00	46.2 46.5	50	64.9 64.5	56.5 56.5	8.4 8.0	17
1.05	45.5 46.3 46.3	50	65.9 64.8 64.8	64.1 64.1 64.1	1.8 0.7 0.7	15
1.08	46.4	50	64.7	68.9	−4.2	4
1.2	36.8	50	81.5	90.6	−9.1	5
1.2	30.1 30.7	50	99.7 97.7	90.6 90.6	9.1 7.1	10
1.3	21.6 21.3	50	138.9 140.8	111.5 111.5	27.4 29.3	9
1.75	20.2 20.0	100	297.0 300.0	242.4 242.4	54.6 57.6	14
1.9	18.4 18.6	100	326.1 322.6	301.0 301.0	25.1 21.6	3
2.0	18.9 18.8	100	317.5 319.1	344.7 344.7	−27.2 −25.6	16
2.05	17.6 17.9	100	340.9 335.2	368.0 368.0	−27.1 −32.8	13
2.2	12.8 12.7	100	468.8 472.4	443.8 443.8	25.0 28.6	8
2.5	18.6 19.2	200	645 625	624 624	21 1	12
2.5	17.2 17.6	200	698 682	624 624	74 58	2
2.6	15.4 15.3	200	779 784	694 694	85 90	7
3.05	28.3 29.5	400	848 814	1067 1067	−219 −253	11
3.05	30.5 24.7		787 972	1067 1067	−280 −95	11
3.1	23.0 23.0	400	1043 1043	1115 1115	−73 −73	1
3.3	15.4 15.9 15.9	400	1558 1509 1509	1321 1321 1321	237 188 188	6
0	3600	1.5	0.024	0	0	18

of the Hoke block. The illumination was provided by the optical system of a Saunders interferograph [2], whereby the green line was separated by a constant deviation prism and projected normal to the face of the Hoke block. The time for the pressure to increase by a selected amount from air flow into the evacuated system was measured for angles producing 1 to 3 fringes, and for a tightly wrung joint (see table 1).

Once a technique of measurement to test for wringing was established, it was also desired, if possible, to find an alternative technique for making the joints. Very lightly greased, dirt-free surfaces that were aligned and vacuum pumped, showed very low leak rates, and proved to be tightly joined as sensed subsequently by resistance to motion. As is true for wringing, the blocks could not be joined by evacuation

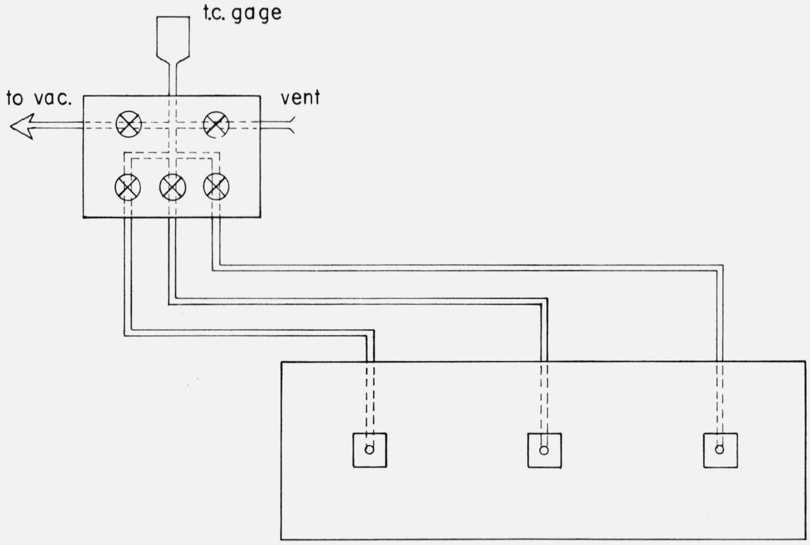

FIGURE 1. *Schematic drawing of vacuum system for leak rate test.*

when their surfaces were completely grease-free nor could a permanent joint be made with a film of volatile material.

3. Discussion

The data can be adequately represented by the polynomial expression $dp/dt = af^2 + bf^3$ μm Hg/min, where f is the fringe number. The constants determined by the method of least squares are

$$a = 32.22$$

$$b = 27.01 \qquad (1)$$

Because the phase change at the surface of the metal differs from that at the surface of the fused silica, the actual distance between the silica flat and the gage block surface may be less than would be inferred from the fringe count. The difference is estimated to be equivalent to 0.1 fringe or less, and depends upon the metal and the condition of its surface, as well as the wavelength. If the fringe number is uniformly reduced by 0.1, the constants of the polynomial become

$$a = 46.49$$

$$b = 25.78 \qquad (2)$$

The deviation, obs.–calc., is shown in table 1 for the second set of constants, and the percent deviation relative to the calculated value is shown versus fringe number in figure 2. Either equation suffices to represent the rate of pressure increase with about the same precision and the same estimate of the standard deviation of the mean.

As a test for wringing, we are interested in the leak rate for angles between gage blocks for $f \sim 0.1$. More important than whether $a = 32$ or 46 is what exponent of the fringe number should dominate the interpolation between 0 and 1 fringe. The flow of gas at large angles and high pressures takes place as Poiseuille flow, while at small angles and low pressures, the flow is of the "free molecule" type. It is to be expected that the gas flow in this experiment occurs over a large pressure range involving a combination of types of flow. The form of the polynomial which was used is consistent with classical theory [3, 4, 5, 6], and the constants are of such values as to be reasonable for the transition pressure range in which the concept of "slip distance" is employed. As theory demands, the experiment confirms that for small angles of tilt ($\phi < 5$ μrad) the interpolation follows an essentially quadratic function.

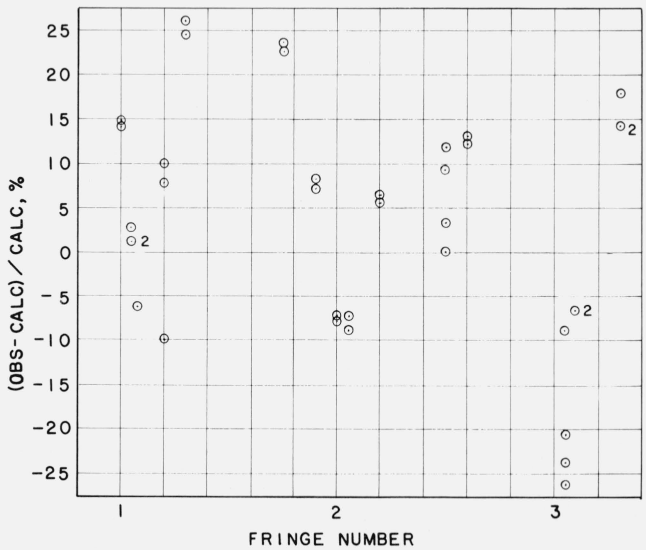

FIGURE 2. *Percent deviation versus fringe number.*

The controlling error is the reading of the fringes.

508-076 O - 73 - 8

Interference occurs for vertical separations of integral half-wavelengths, so that a fringe corresponds to a distance of 254.1 nm, which in our system is equivalent to an increase in the angle of 10.54 μrad. Expressed as a function of angle, eq (1) is

$$dp/dt = 0.2900\ \phi^2 + 0.02307\ \phi^3\ \mu\text{m Hg/min},$$

where ϕ is in μrad. Similarly, eq (2) expressed in μrad is

$$dp/dt = 0.4185\ \phi^2 + 0.02202\ \phi^3\ \mu\text{m Hg/min},$$

or with only significant figures retained,

$$dp/dt = 0.42\ \phi^2 + 0.022\ \phi^3\ \mu\text{m Hg/min}.$$

Thus we see that a vacuum leak rate of 0.3 to 0.4 μm Hg/min can be expected for an angle of 1 μrad and that the rate will vary as the square of the angle if the angle is < 5 μrad.

The values given for the relation between the angle of tilt and the vacuum leak rate were incorrect as quoted in the manometer paper [1]. They were derived using "white light fringes," which we now conclude was an idea (as we used it) without acceptable definition.

For angles around 10 μrad (1 fringe), degassing contributes a significant amount of the pressure rise unless the system has been evacuated at least 15 minutes. For smaller angles, the effect is relatively larger, so that no final evaluation of a good joint can be made until the system has been evacuated for a number of hours. After cleanup, we have observed vacuum leak rates as low as 3 to 5 μm Hg/hr for as many as 10 joints in the system, and thus were able to confirm by a single measurement that several gage blocks had been properly joined.

Even though a tilt of 1 μrad does not represent a good joint, it produces an error within an acceptable range of uncertainty for most purposes. The component of length along the gage block axis is not significantly affected, and the displacement, at the center, of 12 nm is about the same amount of uncertainty, or less, than typical uncertainties of flatness, calibration, phase shift, wringing film variation and lack of parallelism of the faces.

4. Conclusions

A vacuum leak rate method of estimating the extent of alinement of Hoke gage blocks has been demonstrated. The practical limits of error for the method are no greater than several others to be expected in the careful use of gage blocks. The same process of evacuation can be used to produce a joint between the gaging surfaces, when their alinement and surface conditions will permit joining.

5. References

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