Methods for Standardizing and Testing Precision Gage Blocks

This paper by C. G. Peters and H. S. Boyd [1] summarizes the efforts at NBS in the early 1920s to improve the calibration of precision gage blocks. Since their invention at the turn of the twentieth century, gage blocks have been the major source of length standardization for industry, and their calibration is one of the most important high precision calibrations made in dimensional metrology. In most measurements of such enduring importance, it might be expected that the measurement would become much more accurate and sophisticated over 80 years of development. Because of the extreme simplicity of gage blocks, this has only been partly true. The most accurate measurements of gage blocks have not changed dramatically in accuracy in the last 70 years, because one of the major sources of uncertainty is the geometry of the gaging face of the block. The very best gage blocks have always had the gaging surfaces flat to 20 nm or better, but these blocks were very rare at the turn of the last century. This level of geometry simply was not necessary to obtain the measurement accuracy needed by industry of the time. What has changed is the much more widespread necessity of such accuracy. Measurements that previously could be made only with the equipment and expertise of a national metrology laboratory are routinely expected in private industrial laboratories.

By the end of the nineteenth century, the idea of interchangeable parts begun by Eli Whitney had been accepted by industrial nations as the model for industrial manufacturing. One of the drawbacks to this new system was that, in order to control the size of parts, numerous gages were needed to check the parts and set the calibrations of measuring instruments. The number of gages needed for complex products, and the effort needed to make and maintain the gages, was a significant expense. The major step toward simplifying this situation was made by C. E. Johannson, a Swedish machinist.

Johannson's idea, first formulated in 1896 [2], was that a small set of gages that could be combined to form composite gages could reduce the number of gages needed in the shop. For example, if four gages of sizes 1 mm, 2 mm, 4 mm, and 8 mm could be combined in any combination, all of the millimeter sizes from 1 mm to 15 mm could be made from only these four gages. Johannson found that if two opposite faces of a piece of steel were lapped very flat and parallel, two blocks would stick together when they were slid together with a very small amount of grease between them. The width of this "wringing" layer is about 25 nm, which was so small relative to the tolerances needed at the time that the block lengths could be added together with no correction for interface thickness. Eventually, the wringing layer was defined as part of the length of the block, allowing the use of an unlimited number of wrings without correction for the size of the wringing layer.

In the United States, Henry Ford enthusiastically adopted the idea, and the use of gage blocks was eventually adopted as the primary transfer standard for length in industry. By the beginning of World War I, the gage block was already so important to industry that the Federal Government had to take steps to ensure the availability of blocks. At the outbreak of the war, the only supply of gage blocks was from Europe, and this supply was interrupted.

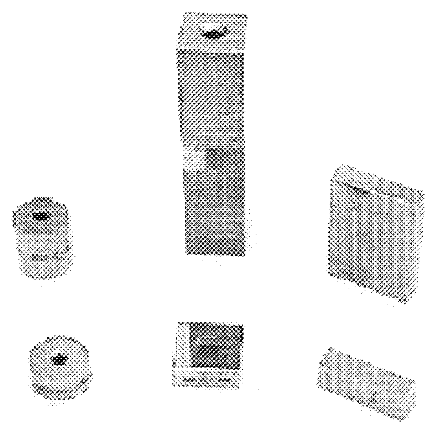

Fig. 1. Gage Blocks. The blocks on the left were manufactured at the Bureau of Standards during World War I. In the center are the descendants of the Bureau of Standards blocks, square "Hoke" style blocks. The rectangular style is the international standard, used all over the world.

In 1917 inventor William Hoke came to NBS proposing a method to manufacture gage blocks equivalent to those of Johannson [3]. Funds were obtained from the Ordnance Department for the project, and 50 sets of 81 blocks each were made at NBS. There were problems, of course. The major problem was the difficulty of making a flat surface. Nearly any error in the system tends to produce block faces shaped like a dome. The solution was to make a hole in the center of the block, preventing the dome in the center. While nearly all gage blocks today are rectangular or square cross-section, the holes in the center of square blocks are the direct descendants of the NBS blocks, and are called "Hoke blocks."

Besides making gage blocks, NBS was also, obviously, engaged in measuring gage blocks. While the standard of length, the International Prototype Meter, was a line scale, the precedent of comparing length to the wavelength of light was well established. Albert Michelson, the great American scientist well known for his speed of light measurements, had been asked by the International Committee of Weights and Measures to measure the meter in terms of light waves in the early 1890s. By 1893 Michelson had compared the International Prototype Meter to the wavelength of the red emission line of cadmium. The average value of 1,553,164.5 wavelengths at 15 °C and standard atmospheric pressure is remarkably close to the current value.

By 1920 work was underway at the International Bureau of Weights and Measures (BIPM) and in some of the national measurement institutes to build interferometers to measure end standards. The work of Peters and Boyd [1], published in the *NBS Journal of Research,* is a very complete report on the NBS effort.

The paper begins with a basic discussion of interference and the accuracy of the optical method of measurement of length, flatness, and parallelism. The uncertainty estimates, for blocks of good geometry, are about the same as currently realized. The interference section leads to a discussion of measuring flatness using a master optical flat and an interferometric viewer: the Pulfrich Viewer. This same instrument is still used at NIST to calibrate master optical flats. The discussion of the interpretation of interference fringes is still an accurate and practical teaching tool.

That section is followed by a section discussing one of the more subtle problems with gage blocks, the effects of wringing blocks together into a stack. Their eventual advice is the same we give out today: make up a stack of three or more blocks that equal the nominal height of another block, e.g., compare a stack of 2 mm, 3 mm, and 5 mm to the 10 mm block. They show examples of the growth of two stacks, and even throw in a warning not to rub the block on the user's wrist to make the wringing film more substantial. This horrid practice, subjecting steel gage blocks to salt water, is still used and occasionally showed up in textbooks into the 1960s.

The calibration of gage blocks is covered in the next few sections. The details include the thermal expansion of gage blocks and their temporal stability, with examples of each of these effects. Finally, there are three sections on comparing gage blocks, the development of standard gages, and the use of gage blocks to measure other types of gages.

The section on comparing gages of the same nominal length describes how two blocks can be compared by wringing them next to each other on the same reference plate. The fringe patterns are discussed, and the use of a third block to break the ambiguity between concave and convex curved blocks is discussed. The next section explains how to generate a set of gages by subdivision. By comparing two 50 mm blocks to a 100 mm block, and then comparing the two 50 mm blocks to each other, an accurate calibration of the 50 mm blocks is made. Using wrings of two or more blocks, the entire set of gage blocks can be generated. Included is a short discussion of how two end blocks with small lines on them can be wrung to the ends of a gage block, making the stack into a line scale. The distance between the lines is measured with the two auxiliary blocks wrung together, and then again with the unknown gage wrung between them. The difference is the length of the unknown gage. This method is still occasionally used because of the high accuracy of instruments designed to measure line standards, such as meter bars.

Finally, there is a section showing how interferometric methods can be used to compare gage blocks to gage balls and cylinders.

Overall, the paper is surprisingly modern in its treatment of interferometry as a length measurement tool. Moreover, the use of examples and line drawings to explain the material makes the paper a useful introduction to the subject for beginning metrologists.

Chauncy G. Peters was born in Emerald, Wisconsin, in 1897. After obtaining a physics degree at Ripon College, he did graduate work at the University of Wisconsin. From Wisconsin, in 1913, he was brought to NBS by Samuel W. Stratton, the first Director. Stratton had worked with Albert Michelson at the University of Chicago and had a personal interest in optics. He also had long expressed concern over the foreign monopoly of high quality optical glass, and the Optics Division of NBS became one of his major interests. Peters had a long and active career as Staff Chief for Interferometry from 1919 until his retirement in 1949 [3].

After his interferometry studies of the 1920s Peters began studies of the optical and mechanical properties of glasses, eventually working with Frederick Knoop on diamond indenters for microhardness testing. One style indenter invented by Peters was later commercialized as the "Tukon Hardness Tester." During World War II his primary work was to investigate making holes in diamonds by electric discharge methods and to devise methods of using these diamonds as wire dies. His career then came full circle, returning to interferometric length testing in a paper *Interference Methods for Producing and Calibrating End Standards,* with W. B. Emerson in 1950 [4].

H. S. Boyd is, unfortunately, a more obscure figure. He was the co-author with Peters on a number of interferometry publications, but was an NBS employee for only a few years. Checking the phone books in the NBS Historical Archives for the years 1910 to 1930 shows entries for Boyd from 1919 to 1922; thus it appears that he was a scientist or technician in the Interferometry Section, but left NBS in 1922.

Prepared by Ted Doiron.

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