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The History of Gauge Blocks





Mitutoyo

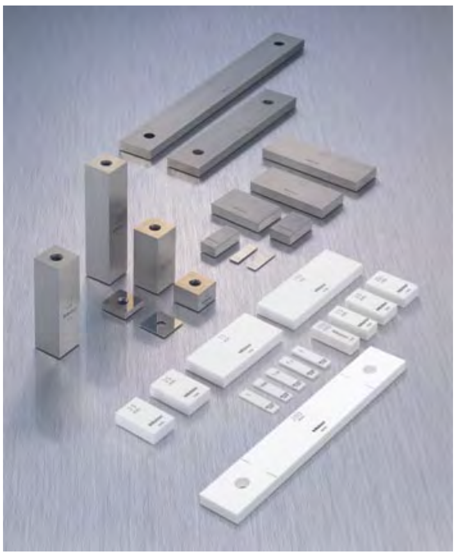
Contents

Preface

Although length is defined by the velocity of light and a variety of length measuring systems are available based on the wavelength of a highly stable laser beam, it is gauge blocks that are used as the practical standard of length for the calibration or dimensional reference of measuring tools and instruments because of their ease of use, dimensional stability and relatively low cost. Since the use of gauge blocks helps an organization to demonstrate traceability to national length standards, gauge blocks are in widespread use in corporations, universities and laboratories throughout the world.

Gauge blocks are equally as useful for the regular inspection and calibration of the small tools such as micrometers, calipers and dial indicators used in manufacturing industry and research institutes as they are for calibrating large measuring instruments such as coordinate measuring machines.

A gauge block is rectangular with two opposing sides (called the measuring faces) finished precisely flat and parallel by grinding and lapping so that the actual distance between these two faces is exceedingly close to the nominal size marked on the block. One of the major features of gauge blocks is that a precise length can be obtained by combining several gauge blocks of the appropriate sizes by *wringing* them together, so that they form one cohesive stack. The wringing phenomenon involves a wringing layer for every block in a stack and this fact has had a practical effect on the definition of block size, which is now defined as the length between the top measuring face of a block that is wrung to a platen of the same material (reference plane) and the surface of that platen, thus including the thickness of one wringing layer. This has the advantage that no wringing film allowance is needed when calculating the precise size of a stack of blocks.



Gauge blocks

Requirements for gauge blocks are high dimensional and form accuracy, the ability to wring to other blocks, low secular variation (high dimensional stability over time), excellent abrasion resistance, a thermal expansion coefficient close to that of common workpiece materials, superior resistance to rust and corrosion, and so on.

Gauge blocks in the size range 0.5mm to 1m are manufactured in four grades of accuracy to ISO (JIS) Standards and five grades to ASME Standards. The tightest limits of size used for blocks that are calibrated mechanically are ±0.3μm for 100mm blocks and ±2μm for 1m blocks in ISO (JIS) Standards. The highest grade blocks are calibrated by interferometer with an uncertainty of measurement of approximately 0.2μm, with respect to 1m. This value corresponds to the thickness of a strand of hair with respect to a full circuit of a 400m running track.

There are two kinds of length standard: *line standards* and *end standards*. A steel rule, a precisely-graduated standard scale and the international standard meter (obsolete since the definition of the meter became based on the speed of light) are all line standards that are read optically. On the other hand, measuring-face-based standards, such as gauge blocks and length bars, are end standards that are used with contact methods of comparison. The prototype meter (Meter de Archives, constructed in 1799) was an end standard with 25.3mm x 4mm rectangular end faces, similar to a long gauge block.

The following chapters describe the birth and history of gauge blocks, the history of domestic gauge block production in Japan and the history of Mitutoyo gauge blocks.

Chapter I The Birth of Gauge Blocks

The beginning

The concept of a set of gauge blocks that can be used to assemble a gauge to accurately represent almost any practical length from a small number of pieces was invented by Carl Edvard Johansson (Figure 1), a Swedish machinist, in 1896 and therefore has more than a century of history.

Figure 2 illustrates a demonstration of gauge block wringing force performed by Johansson in 1917 at a mechanical engineering conference in Stockholm. A total of 200lb (more than 90kg) of weights were suspended from the lower gauge block. The wringing force was equivalent to that generated by a differential pressure of 33 atmospheres on the wrung surface area.

It is a curious fact that the wringing force often increases with the time blocks are left wrung together[2]. For this reason it is unwise to leave gauge blocks in the wrung state for any length of time in case they become inseparable without risking damage to the measuring faces.

This chapter traces the history of gauge block development based on the article *The Master of Measurement – Carl E. Johansson* serialized in Mitutoyo's in-house magazine Approach. This history was translated into Japanese by Nobuo Suga (the former vice-president of Mitutoyo America Corporation) from the book *The Master of Measurement*[3]

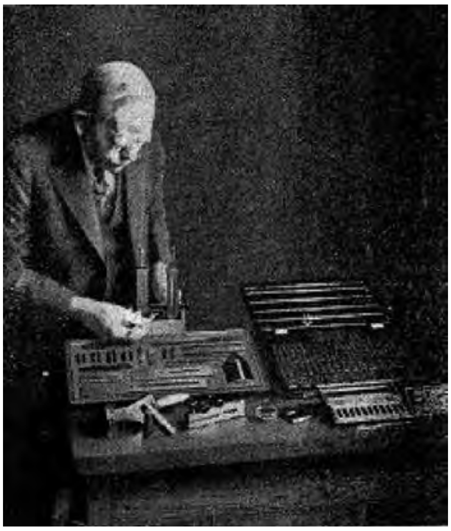


Figure 1 Johansson and his gauge blocks

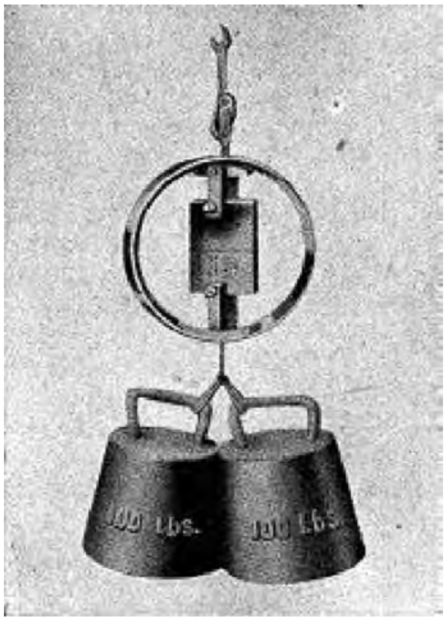


Figure 2 Demonstration by Johansson at the conference (wringing force equivalent to 33 atmospheres)

based on Johansson's diary under license from Johansson Corporation.

Johansson worked for a rifle manufacturer (Carl Gustaf Stad's Rifle Factory) in his home town of Eskilstuna as an armoury inspector involved with Remington rifle manufacturing (Figure 3). According to Johansson's records, variously shaped gauges and a large number of limit gauges used on the shop floor were collectively referred to as gauge blocks.

The top-end reference at the factory in those days was the micrometer made by Brown & Sharpe Corporation, with which the shop-floor gauges were measured and calibrated. Nowadays, micrometers are calibrated with gauge blocks. The ranking order between gauge block and micrometer seems to have reversed around 1906 when the accuracy of gauge blocks reached the submicron range.

The limit gauges used for inspecting rifle parts were manufactured specifically for each part, and required remanufacturing every time a model was renewed or any part modified. When Johansson visited the Mauser Corporation in Germany, famous for the Mauser carbine, he was disappointed to discover that the factory used several thousand limit gauges. Therefore Johansson thought about

Figure 3 Johansson at the rifle factory (leftmost in the front row)

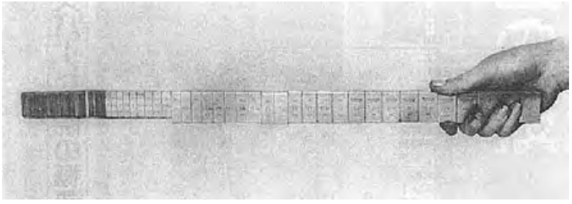


Figure 4 Example of wrung gauge blocks

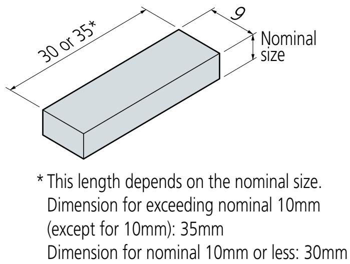


Figure 5 Johansson type (rectangular type) gauge block

combining a minimum number of gauges based on the idea of 'how to test more dimensions with fewer gauges'.

After taking great pains, Johansson came up with a combination of 102 blocks that provided about 20-thousand different dimensions from 1mm to 201mm in increments of 0.01mm.

He named this his 'combination gauge block set', which comprised 49 gauge blocks of 1.01mm to 1.49mm in increments of 0.01mm; 49 blocks of 0.5mm to 24.5mm in increments of 0.5mm; and 4 blocks of 25, 50, 75 and 100mm.

This idea of obtaining many sizes with a minimum number of blocks was also adopted in the United States at that time.

Johansson subsequently found an introductory article about a product called *Size Blocks* in the American Machinist magazine. This product was a set of 16 gauge blocks consisting of sizes from 1/16 inch to 1 inch in increments of 1/16 inch, i.e. a combination of 1/16, 1/8 (=2/16), 3/16, 1/4 (=4/16), 5/16, 3/8 (=6/16), · · · · 7/8 (14/16), 15/16, and 1 inch. Upon seeing this article, Johansson hastened to obtain a patent for his gauge blocks.

Although the patent on his gauge blocks was filed in 1898, the idea was not easily understood by the government. Consequently, Johansson appealed the patent to the Swedish royal family and finally got it established in 1908. However, the patent claim was how to use a number of blocks of different thicknesses by *stacking end-to-end* to make up a given length, without use of the term *wringing*, so the patent was thus granted on the basis of the idea of a combination of dimensions.

The phenomenon of wringing had already been reported by J. Tyndall (1820-1893) working in the U.K. He pointed out that "well-ground steel plates are wrung together and the force is above atmospheric pressure", and that wringing also occurs in a vacuum (Figure 4). A wringing experiment was demonstrated to the public in 1875 at the Royal Society in London.

The first time Johansson experienced wringing was in 1900 when he found that two lapped gauges that were tightly stuck together would not separate when they were accidentally dropped.

From the fact that the patent application for gauge blocks was filed in 1898, two years before his first experience of wringing, and that nothing about wringing was claimed in the patent, it can be seen that the idea of 'making up a given dimension by wringing gauge blocks together' as a major feature was derived from the acquisition of a high wringing force due to a process improvement in lapping quality.

Much research has been conducted into the wringing force phenomenon. As a result it is believed to be primarily due to intermolecular attraction between the material at the surface of the blocks themselves and with any liquid (often oil) in the wringing film. Surface tension of the oil and differential

Figure 6 Johansson's house

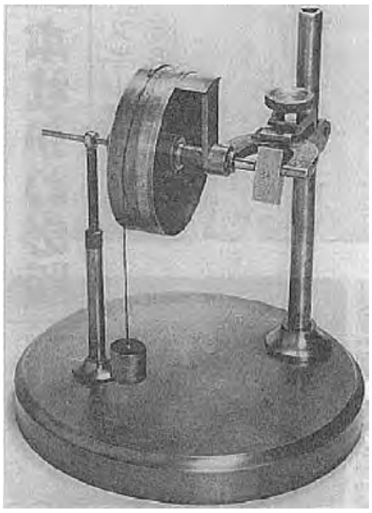


Figure 7 Gauge block measuring tool using a modified micrometer

air pressure between the exposed surfaces and the wrung surfaces are thought to be secondary causes. It is also known that the force varies depending on the flatness, surface roughness and type of liquid used on the wrung faces. It has been established that, if wringing is properly performed, the thickness of the wringing film is around 0.01μm (10nm) or less.

Johansson's gauge blocks had a 9x28mm rectangular cross-section (9x30/35mm at present). This is because the steel sheet used at the rifle factory to make gauges was 10mm in thickness. This rectangular gauge block is known as the Johansson type or rectangular type (Figure 5).

At first, Johansson's gauge blocks had many problems in spite of some successes in trial production. It took 2 years (till 1900) for production to get on track and for the quality to reach a level the government required. There was no fixed sales price at that time and a gauge block set was sold for 500 to 700 krona. Sometimes it took a year for a set to be delivered to the customer. After joining the rifle factory, Johansson acutely felt the need for industrial knowledge, so he attended industrial school at night over a period of years and eventually graduated. At the same time he was promoted to the position of apprentice armoury inspector, but his yearly pay was only 600 krona. It would be safe to say that the yearly salary of a subsection chief or section chief was similar to the price of a gauge block set in those days.

It is said that the gauge block manufacturing process finished at the factory after the surface grinding stage and then transferred to Johansson's house (Figure 6) for heat treatment, lapping and inspection, amid great secrecy. A converted sewing machine was used for lapping and a dedicated tool was used for inspection, in which the thimble diameter of a Brown & Sharpe micrometer was increased to 150mm to provide a resolution of one micrometre (1μm) per division and a deadweight arranged to ensure a constant measuring force (Figure 7).

Sweden, being rich in iron ore, is famous for producing high-quality steel (Swedish Steel) and in fact has been known as the Iron Country from the time of the Vikings. Johansson carefully selected carbon steel used in gauge blocks in collaboration from C. E. Tahlin, the director of the Wikmanshytte Co. steelmaking plant, and also obtained a great deal of help from him regarding the technology of heat treatment.

Johansson manufactured gauge blocks so that they assumed their nominal size at a measurement temperature of 20°C (the mean of a factory temperature range of 15 to 25°C), although international practice at the time specified 0°C as the standard measurement temperature. The standard temperature in industrial length measurement was not specified to be 20°C by CIPM (Comite International des Poids et Measures) until

1931, and then afterwards by the International Organization for Standardization (ISO). The root of the current standard temperature for length measurement can thus be traced to Johansson's time. Johansson maintained this temperature at the factory in winter using heating [4].

The accuracy of gauge blocks manufactured in those early days is a matter of great interest. Johansson himself gave "the order of 1μm (0.001mm)" as the answer to this question.

In 1903 Johansson made a cylindrical reference gauge that was just 100mm at 20°C, according to his measurements. He then asked the International Bureau of Weights and Measures in Paris to measure the gauge to determine the temperature at which it measured exactly 100mm, which turned out to be 20.63°C. In other words, this reference gauge was found to have an error of approximately 0.7μm at 20°C [5].

The International Bureau of Weights and Measures (BIPM) keeps the International Standard Mètre platinum-iridium alloy bar, made in 1889, in safe custody at the originally defined environmental conditions under which the length was defined, including at a temperature of 0°C. It is said that the accuracy of Johansson's gauge blocks at that time in 1908 was within the range of ±1μm when assembled to a dimension within 100mm with each block wrung tightly.

After that, Johansson made 100mm, 50mm and 25mm gauge blocks and again asked the BIPM for an accuracy assessment. In 1912, he received the result, which was that their accuracy was within 0.1μm. From that point onwards Johansson knew he possessed gauge blocks traceable at an extremely high level to the BIPM.

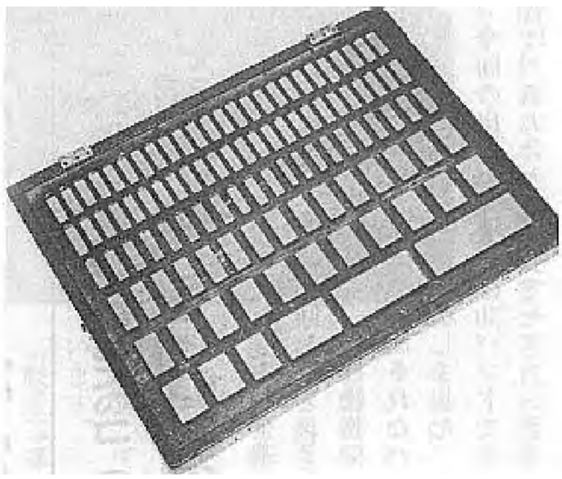


Figure 8 103-piece gauge block set made by Johansson (1899, Johansson Corporation's possession)

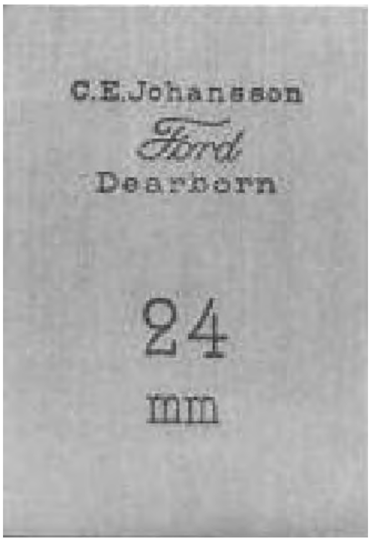


Figure 9 Johansson gauge made in the U.S.

From 1909 the BIPM conducted scientific research on gauge blocks, which were then being introduced worldwide, and reported favourably on their self-checking capability and high reliability.

Johansson revised the initial 102-piece set by adding a 1.005mm block (Figure 8) to create a 103-piece set. In 1909 he created a 112-piece set by adding 9 blocks with sizes of 1.001mm to 1.009mm in increments of 1μm. This enabled around 200-thousand dimensions to be available in increments of 1μm.

Johansson was independent from the rifle manufacturer in 1911 and established C.E. Johansson Corporation. After that the demand for arms greatly increased due to the outbreak of World War I. Johansson's gauge blocks were used by more than 450 companies in the world and supplied to both friend and foe alike.

At that time the U.K. and U.S. differed slightly in the definition of the inch, as well as the standard temperature at which it was measured.

The U.K. worked to a length standard known as the *Imperial Standard Yard* (36 inches) and defined the reference temperature as 62 degrees Fahrenheit (16.67°C). One inch in the U.K. was precisely 25.399977mm, based on comparison with the international standard meter. On the other hand, the U.S. defined one inch as 25.4000508mm at 68 degrees Fahrenheit (20°C) (congressionally determined in 1866), which amounted to a difference of less than 3 parts per million.

Johansson actually manufactured inch gauge blocks assuming 1 inch was exactly equivalent to 25.4mm at a temperature of 20°C. In later years when the inch definition between the U.S. and U.K. was unified to agree with this definition, Johansson's gauge blocks had penetrated widely in the weapons industry, which then could not help but conform to Johansson's definition. As a result, Johansson might be seen as the originator of the current definition of the inch.

Johansson's gauge blocks were also used at the National Bureau of Standards (NBS) and were declared to be *strategic goods*. A million pieces (11,000 sets) of his gauge blocks had been manufactured by 1929. At this time Johansson went over to America and started production of U.S.-made gauge blocks (Figure 9) in collaboration with Henry Ford (1863-1947) of the Ford Motor Company.

The National Physical Laboratory (NPL) in the U.K. succeeded in trial manufacture of gauge blocks in about 1918, after which the Pitter Gage Precision Tool Company started production and sales. Hommel Corporation and other companies also sold gauge blocks.

In the U.S., in 1917, a National Bureau of Standards (NBS) employee, W. E. Hoke, invented a round (later, square) gauge block with a hole in the middle (Figure 10, right). This design of gauge block enables assembling a stack of blocks with a threaded rod and screws and is referred to as a *Hoke Gauge* or square gauge block (SGB) (Figure 10, left). Gauge blocks of this type are used even now in the U.S. (Figure 11 and 12). In Japan, Mitutoyo Corporation started production and sales of this type of gauge block in 1982.

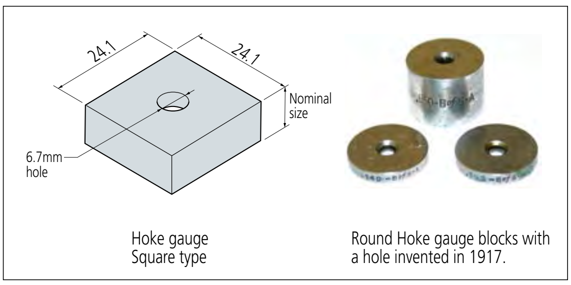


Figure 10

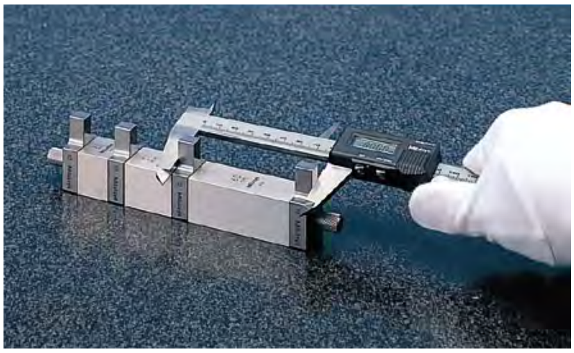


Figure 11 Using square gauge blocks to calibrate an electronic caliper

Figure 12 Using square gauge blocks in a height comparison measurement

Chapter II Manufacture of Gauge Blocks in Japan

Gauge blocks were manufactured and sold for the first time in Japan by Taisuke Tsugami (1893-1974)[6, 7]. He started research on the domestic production of gauge blocks in 1923 and established Tsugami Seisakusho Co., Ltd. in 1928 (renamed later, Toyo Seiki Co., Ltd. and currently, Mitsui Seiki Kogyo Co., Ltd.). The company received an industrial incentive payment of 10-thousand yen from the Industrial and Commercial Department and set up an advanced facility with equipment from the top manufacturers, such as a constant temperature and humidity room, Zeiss interferometer and SIP jig borer.

His company succeeded in trial manufacture in 1931 and started production and sales of gauge blocks under the Mitsui Seiki Kogyo brand label in 1934.

Taisuke Tsugami had confidence in the quality of his company's gauge blocks and regretted that clients did not believe in their quality merely because they were domestic products. At that time the military and naval factories had Johansson gauge blocks that were regarded as the best in the world. Taisuke Tsugami borrowed those gauge blocks to check the dimensional stability and made a presentation of the report to the U.K. technical magazine *Engineering*. Meanwhile, Johansson presented the research result on Tsugami's gauge blocks to the *Precision Measurement Association Magazine*. The debate continued for 3 years.

After that, Tsugami conducted full-scale production of gauge blocks in 1937 at Tsugami Seisakusho Co., Ltd. (presently TSUGAMI Corporation, taking over Toyo Seiki Co., Ltd.) established at Nagaoka in Niigata Prefecture, in addition to Mitsui Seiki Kogyo Co., Ltd.

Following Tsugami's pioneering lead in Japan, Saburo Kuroda[8] the founder of Kuroda Gauge Manufacturing Company (presently Kuroda Precision Industries), who was independent from SONOIKE MFG. (presently AMADA), succeeded in the development of gauge blocks in 1934 and started full production in 1935.

The military and naval forces were enthusiastic about engaging in domestic production of gauge blocks, probably starting production sometime around 1934. Fifty or more workers might have worked for Kokura Military Arms Factory as gauge block personnel. Meanwhile, Kure Naval Arsenal promoted the development of gauge block technology. In 1935 Toyo Kogyo Co., Ltd. introduced the technology from the arsenal and started production and sales of gauge blocks.

Nachi-Fujikoshi Corp. started gauge block production in 1937, and a year later so did the SEKI KOUHAN FACTORY (presently SEKI KOUHAN, LIMITED). Then, in 1955, Mitutoyo Manufacture Co., Ltd. (presently Mitutoyo Corporation) started sales of gauge blocks and in 1965, Showa Seiko Co., Ltd. in Hiroshima started full-scale marketing[9].

Chapter III Production of Gauge Blocks by Mitutoyo

Figure 13 Yehan Numata, the founder of Mitutoyo

Figure 15 Model of Kamata Factory (built by Taro Morioka of Kogeisha).

Mitutoyo started producing gauge blocks along with domestic production of micrometers [10]. Yehan Numata (1897-1994, Figure 13), the founder of Mitutoyo Manufacture Co., Ltd (presently Mitutoyo Corporation), who was a statistics officer of the Cabinet Resource Department at that time, got the idea of business promotion for the purpose of gaining funds for Buddhism missionary work. In 1934 he established a research laboratory at Musashi Shinden in Tokyo and launched domestic production of micrometers, which were then imported goods, with several persons employed.

However, the business did not yield the quality of results he desired, so he resigned from his government post to focus on his business and constructed a factory at Kamata in Tokyo, naming it Mitutoyo Manufacture (Figure 15). Repeating trial manufacture and evaluation many times, in December of the same year he finally succeeded in manufacturing good quality micrometers and from the next year, 1937, sales commenced (Figure 14).

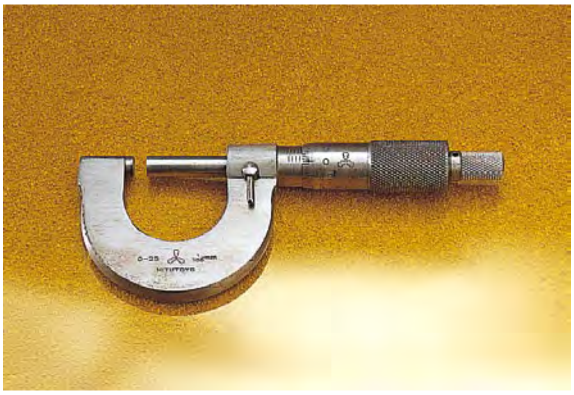


Figure 14 Mitutoyo's first micrometer (1937)

Trial manufacture of gauge blocks at the Kamata Factory

Micrometers were inspected at the time using Johansson gauge blocks. Research on gauge blocks was started at the Kamata Factory with a view to self-manufacture and trial manufacturing of them in 1941 proved successful.

Producing gauge blocks for in-house use at the Mizonokuchi Plant

In 1940, the Mizonokuchi Plant (Figure 16) at Kawasaki in the Kanagawa Prefecture went on-line for mass production of micrometers and the output rose to 1,000 pieces per month.

Mitutoyo started production of gauge blocks at the Mizonokuchi Plant, where from 1942 gauge blocks were mass produced for in-house use to inspect micrometers.

At that time, Mitutoyo used the Zeiss Ultra Optimeter and Horizontal Optimeter for inspection of gauge blocks and, in the next year, succeeded in trial manufacture of its own electrostatic capacitance electronic micrometer.

Figure 16 Mizonokuchi Plant

Producing gauge blocks for sale at the Utsunomiya Plant

In 1944 the Utsunomiya Plant (Figure 17) started operation, after which the production of gauge blocks was transferred there. In 1945 the Kamata Factory was lost due to war damage and the Mizonokuchi Plant was also closed temporarily.

Since the domestic market collapsed after World War II, the production of measuring instruments could not be kept going because of a sharp downturn in demand. Mitutoyo only continued operation with the Utsunomiya Plant that, during this period, produced daily commodities such as electric heaters, hair clippers and kitchen knives to support the livelihood of employees. The Utsunomiya Plant then manufactured wooden pipes for spinning, automated weighing machines and automated weighing and sorting machines for caramel candies, sticks of chewing gum, Ajinomoto condiments and golf balls, etc., while plant management planned an early recovery.

Figure 17 Utsunomiya Plant

The Mizonokuchi Plant continued minimal production of micrometers to preserve the associated production technologies. Additionally, the Hiroshima Research Laboratory, founded at Shiwa in Hiroshima Prefecture, the founder's birthplace, commenced production of micrometers in 1947 by demobbed employees, along with existing personnel.

In 1949, in accordance with the founder's original intention, Mitutoyo restarted production of micrometers at the Mizonokuchi Plant and also started production of calipers and height gages at the Utsunomiya Plant.

The first time Mitutoyo made sales of gauge blocks was in 1955 when the Utsunomiya Plant produced the 8-piece gauge block set for micrometer inspection (Figure 18).

A measuring instrument of the highest accuracy is essential to the production of gauge blocks. Some very high-accuracy measuring instruments were developed by Mitutoyo in tandem with gauge blocks production.

To illustrate examples of these measuring instruments, in 1957 the Utsunomiya Plant manufactured the gauge block inclination adjusting device on the built-in gauge block measuring instrument in a constant temperature tank supplied to the Central Inspection Institute of Weights and Measures and, in 1953 and 1960, the interferometric length measuring system on the interferometric standard barometer developed by the Central Inspection Institute of Weights and Measures. In 1964, the second upgraded version of this barometer was adopted as the standard laboratory barometer in Japan.

Figure 18 Gauge block set for micrometer inspection

Figure 19 Riken-system Interferometer

In 1958, a Riken-system interferometer (using the comparative method of measurement) (Figure 19) was produced experimentally and high-accuracy dial indicators with a resolution of 1 µm were put into production. The Utsunomiya Plant developed a high-accuracy digital micro indicator using a differential transformer in 1961, and the Research Department at Mitutoyo headquarters developed the high-accuracy Okoshi-system surface roughness tester AA-1 with an enhanced magnification of 24,000X in 1962. Meanwhile, the Research Department at Mitutoyo headquarters developed the Ultra Comparator with a resolution of 0.01 µm (Figure 20) by using the principle of a strain gauge in 1962. This comparator received an award as one of the Nikkan Kogyo Shinbun Ten Big New Products in the next year.

In 1957 the Mizonokuchi Plant commenced production of height check micrometers (height standards, later renamed

Figure 20 Ultra Comparator

Height Masters) (Figure 21) by using stacked gauge blocks. Although the Height Master (and associated *Check Master*) design has been changed a few times, they have been used regularly by customers for more than half a century and represent a truly enduring product (Figure 22, 23 and 24).

Figure 21 Original Height Master (height check micrometer)

Figure 22 Current Height Master (analog type)

Figure 23 Current Height Master (digital type)

Figure 24 Current Check Master

Construction of Numata Research Laboratory and full-scale production of gauge blocks

In 1940 the Numata Research Laboratory (Figure 25), later the factory dedicated to gauge blocks, was constructed for R&D in measuring instruments in the Shonan area of Chigasaki in Kanagawa Prefecture (nearest station: Tsujido on the Tokaido line). However, since it was difficult to import laboratory machines from German companies during World War II, the establishment was used as a recreation facility for employees. Eventually, in 1961, the laboratory reverted to a factory producing micrometers, micrometer heads, inside micrometers, etc.

Toshihide Numata, director (presently a Mitutoyo senior adviser, 1932-), who is the eldest son of the founder, and Hiroshi Sasaki, plant manager (former Mitutoyo vice-president) managed its operations.

According to statistical information from the Ministry of International Trade and Industry concerning the domestic gauge block sales situation at that time, the total amount of gauge block sales in four companies: Tsugami, Kuroda Precision Industries, Toyo Kogyo and Nachi-Fujikoshi in 1962 was 140 million yen a year, and that in five companies, including Showa Seiko in 1965, it was 250 million yen a year. The total sales in 1967 was 290 million yen.

Among those companies, Tsugami's gauge blocks commanded nearly an 80% share of major users and those from Kuroda Precision Industries made up 40% of the total domestic sales. Regardless of sales of gauge blocks for micrometer inspection since 1955, Mitutoyo did not secure a strong market position because of a limited choice of blocks and less sales volume than other companies at that time.

Figure 25 Numata Research Laboratory at the time of starting operations (1961)

Figure 26 New factory of Numata Research Laboratory (1966)

In 1967, Mitutoyo-brand gauge blocks were introduced to the market on a full-scale basis. The Numata Research Laboratory was rebuilt to become a dedicated gauge block facility and a new two-storey plant was completed in 1966, constructed from well-insulated concrete block and equipped with a constant-temperature room.

In the same year, the production of gauge blocks was transferred from the Utsunomiya Plant to this plant where machining and heat-treatment equipment was relocated, or newly acquired, and a dedicated heat treatment room was constructed. A lapping machine developed at the Mizonokuchi Plant was also introduced.

As a background to the entry into full-scale marketing of Mitutoyo gauge blocks, MTI Corporation (founded in 1963 as a local sales subsidiary in the U.S.) had made a request for an early launch of them onto the market. Mitutoyo made a production plan from the start with a view to the world market by manufacturing products premised on compliance with American Standards and domestic standards (as well as German Standards).

Figure 27 Gauge block lapping (1966)

The factory first started production of discrete gauge blocks and then 81-piece block sets (inch sizes). The production output reached 1,000 pieces a month in the first year and 10,000 pieces a month the year after.

Lapping of gauge blocks (Figure 27) requires a lot of skill. Although this had been a hand process for many years, mass production was implemented from the start by introducing a lapping machine. This was because machine lapping made it possible to manufacture high quality gauge blocks with a high degree of flatness and parallelism and little variation in size at low cost, without resort to skilled workers. Other domestic manufacturers were also promoting a shift to machine lapping at that time.

Inspection facilities, including in-house digital micro indicators, interferometric flatness measuring instruments and the Koester Interferometer (Figure 28), were relocated and Zeiss Optimeters (Projektions Optimeter) were introduced. Mitutoyo transferred young employees to the Utsunomiya Plant for training in lapping and machining and to the Metrology Research Laboratory, an Agency of Industrial Science Technology in the Ministry of International Trade and Industry for the acquisition of interferometric measurement technology. Additionally, three veteran employees were transferred from the Utsunomiya Plant to the latter.

The factory also produced the special gauge blocks for Height Masters in addition to standard gauge blocks. In the same year, Mitutoyo commenced sales of the Digital Height Master (counter separation type), which was our first digital product. Since 1968, Mitutoyo has participated in Gauge Block Round-robin Measurement Comparisons (comparison of measurement accuracy started in 1955 among manufacturers, laboratories and major users that have interferometers) under the auspices of the Research Laboratory of Metrology, intending to maintain traceability and improve measurement technology.

Figure 28 Koester interferometer (Interference Comparator made by Carl Zeiss Jena Corporation in former East Germany)

Figure 29 Inspecting gauge blocks (1966)

History of product development and technical development

This chapter traces the history of Mitutoyo's gauge block product and technology development.

1970

Enhanced the range of gauge block sets offered and achieved full-scale entry into the market (103-, 76-, 56-, 47-, 32-, 18- and 9-piece metric sets, and a 10-piece set for calibrating micrometers). In this year the serial number marking method was improved from that of engraving with a pantograph to that of imprinting by means of photographic film in order to attain clearer letters in advance of other manufacturers (Figure 30).

1972

Started production of 2mm-base gauge block sets. This set was designed to ease the wringing operation by changing the base dimension from 1mm to 2mm. This is because thicker gauge blocks are flatter and therefore wring more readily. Monthly production of 30,000 pieces was achieved.

1973

Started production of tungsten carbide gauge blocks.
Developed Mitutoyo's first automatic gauge block calibration tester (Figure 31). This development made it possible to perform measurement of ultra-high precision gauge blocks efficiently without requiring special skills.
This epoch-making tester was provided with differential transformer-type high precision sensors and a cam-type positioning unit in addition to automatic calculation, grade judgment and error judgment functions using a computer, which later boosted its sales to several major outside users. Monthly production of 40,000 pieces was achieved.

Figure 30 103-piece gauge block set (manufactured by Mitutoyo)

1974

Developed an 8-piece set of long gauge blocks (Figure 32) and a 10-piece set of all-tungsten carbide gauge blocks for calibrating micrometers.

Figure 31 Calibrating gauge blocks with the original automatic calibration tester

Figure 32 Long gauge blocks

1975

Started production of long gauge blocks ranging from a nominal size of 600mm to 1000mm. Succeeded in developing the world's first ultra-thin gauge blocks of nominal size 0.1mm (Figure 33).

Figure 33 Ultra-thin gauge block set

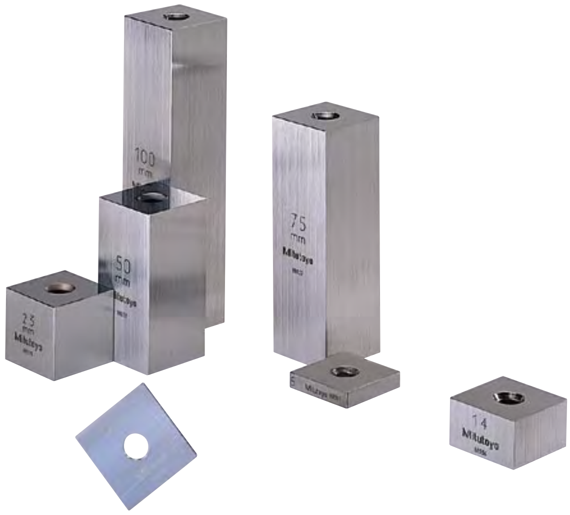


Figure 34 Square gauge blocks

1981

The 20th anniversary of the start of production at the Numata Research Laboratory. A total production of 5 million pieces had been achieved.

1982

Started production of square gauge blocks In response to demand from the U.S. (SGB, Hoke-type) (Figure 34).
Founded the Measurement Technology Research Laboratory on the Mizonokuchi site and started the wavelength calibration business for lasers available for absolute measurement of gauge blocks. The laser wavelength calibration system was developed in the following year, at which time Mitutoyo's standard supply system was complete.

1984

The Automatic Interferometer for Long Gauge Blocks (Figure 35), developed by the Measurement Technology Research Laboratory, was introduced into the Numata Research Laboratory where the measurement of long gauge blocks up to a nominal size of 1000mm had been made possible. In this interferometer the technology employed by Mitutoyo for manufacturing the holder part when the trial production of the 1m-interferometer was carried out at the Central Inspection Institute of Weights and Measures, Agency of Industrial Science and Technology (later the Research Laboratory of Metrology) in 1957 was utilized. In Japan, this interferometer is used only by Mitutoyo and the National Institute of Advanced Industrial Science and Technology (AIST, the former Research Laboratory of Metrology), which is one of the public research agencies.

Figure 35 Interferometer for measuring long gauge blocks

Up until then the scale of production of gauge blocks had also expanded and, therefore, the space available at the Numata Research Laboratory had become insufficient for reinforcing/ augmenting the production facilities. Moreover, since there was a strong welcome initiative at that time from Miyazaki Prefecture a plan to found a factory there emerged, and Mitutoyo decided to transfer the manufacturing base for gauge blocks to Miyazaki Prefecture by the end of the year.
Practical use of fine ceramics as industrial materials progressed in the 1980s on account of their obvious advantages, including greater hardness and wear resistance and their corrosion-free nature as compared to steel, which suggested the possibility of applying them to gauge block manufacture. In the same period, also at the Numata Research Laboratory, the development of ceramic gauge blocks was started. After performing several trial production runs and evaluating gauge blocks using various kinds of ceramic materials, they reached the conclusion that zirconia was the most promising. In 1985 a trial was made by manufacturing wear gauge blocks (nominal 1mm and 2mm sizes) from zirconia ceramic, and they were introduced at a private exhibition. As to commercialization, there still remained the need to reduce material cost and solve some outstanding technical issues (Figure 36).

Figure 36 Mitutoyo steel gauge blocks (back) and ceramic gauge blocks (front)

Progress at the Miyazaki Plant

Figure 37 Miyazaki Mitoyo Precision Co., Ltd. (presently Mitutoyo Miyazaki Plant Co., Ltd.)

In October 1985 the production of gauge blocks moved from the Numata Research Laboratory to Miyazaki (Miyazaki Prefecture Tano-Cho Tsukijihara Industrial Complex) located in the south of the country.
The Miyazaki Plant (Figure 37) was Mitutoyo's 12th factory in Japan and is a state-of-the-art facility dedicated to gauge block production. It has a large precision measurement room located 5.5m underground to ensure the most stable environmental conditions.
At this time the production of Height Masters (including Check Masters), which had always been produced in the Utsunomiya Operations, was also transferred to the Miyazaki Plant. Next year the production of long square gauge blocks (SGB) started.
The Miyazaki Plant was founded as the Miyazaki Mitutoyo Precision Co., Ltd., as one of the Mitutoyo affiliates and, five years later, its name was changed to Miyazaki Mitutoyo Co., Ltd., and then changed again to Mitutoyo Hiroshima Operations Co., Ltd., in 1993. Later it became the Hiroshima Operations Miyazaki Manufacturing Department and lastly, since April 2009, has become the Miyazaki Plant.
Below is a brief review of the characteristics which a steel gauge block should possess and the method of manufacture.
First of all, steel gauge blocks are required to be subject to minimum variation in their size due to wear from normal use, i.e. wringing, etc. To achieve this, gauge blocks must have a Vickers Hardness (HV) of 800 or more. Therefore high-carbon steel, which is easily hardened through quenching (rapid cooling after heating), must be used as the base material (Figure 38). For commercial production a special carbon tool

Figure 38 Heat treatment line

steel alloy is used. If such material is rapidly cooled (quenched) in water or oil after heating, in a similar way as quenching a Japanese sword, its crystal structure is transformed into a very hard form. After hardening various kinds of stabilizing processes, including tempering and annealing, are applied. The dimensional stability requirement (the amount of secular change permitted) for a gauge block is very high, and is defined by one International Standard (ISO3650) to be 0.045μm or less per 100mm per year, and 0.27μm or less per 1m per year in the case of Grade K or 0 (zero) gauge blocks. Therefore, every gauge block manufacturer makes strenuous efforts to suppress possible secular change by devising special heat treatment methods for relieving residual process stresses in their steel gauge blocks that otherwise would reduce performance.

In 1988 Mitutoyo started full-scale production and sales of the world's first zirconia ceramic gauge block called *CERA block* (rectangular type) (Figure 39).

This snow-white gauge block has remarkable characteristics including extreme resistance to wear, requires no special handling (non-corroding) and has very low secular change,

Figure 39 CERA block

Figure 40 Heat processing/forming line for ceramics

properties that have traditionally been the weakest points of steel gauge blocks. In addition, the thermal expansion coefficient is close to that of steel gauge blocks, so CERA blocks can be used as direct replacements for steel blocks without the need for temperature corrections when working with steel workpieces.

This is in contrast with tungsten carbide gauge blocks, conventionally marketed as a block with high wear and abrasion resistance, that have a thermal expansion coefficient only half that of steel blocks and a modulus of elasticity very different, so they cannot be used easily with steel components, requiring careful thought and precautions when using them to avoid the risk of dimensional errors arising.

The wear and abrasion resistance of CERA blocks is at least 10 times better than steel blocks, and secular change is even less than the uncertainty resulting from interferometer measurement, so is practically zero.

Furthermore, to allay any user concerns about the perceived fragility of ceramics, the material used for CERA blocks has been made very chip-resistant by implementing an integrated production system from raw material to finished product (Figure 40) that includes investment in advanced heat processing plants and factories dedicated to ceramics, which has also achieved high quality assurance and a competitive cost for this product.

In advance of these actions, Mitutoyo employed university graduates in ceramics and dispatched trainees to the Japanese Fine Ceramics Center in Nagoya in order for them to master the heat processing/forming techniques that were needed.

As a result of these efforts there have been almost no complaints regarding chipping or cracking of CERA blocks from users since the introduction of this exceptional product to the market. Thereafter, even though gauge blocks featuring zirconia began to be marketed by other vendors both from within Japan and overseas, still the *CERA block* is viewed throughout the world as the epitome of a ceramic gauge block, demonstrating the many eminent features of its type such as long life, freedom from corrosion and extreme resistant to wear.

History of product development and technical development (continued)

1990

Started the production of long CERA blocks up to a nominal size of 500mm (Figure 41).

Figure 41 Long CERA blocks

1991

Started the production of square CERA blocks.

1992

Achieved the total cumulative production of five million pieces at the Miyazaki Plant.

1993

The Automatic Gauge Block Interferometer (GBI) (Figure 42) developed at the Kawasaki Research and Development Center (MKC) was introduced. This interferometer is provided with a function to automatically read interference fringes, thus contributing to the improvement of both accuracy and efficiency in interferometric measurement. Up until then, Mitutoyo had used interferometers manufactured by Zeiss for many years.

Figure 42 Automatic Gauge Block Interferometer (GBI)

1994

Aimed to improve accuracy in comparison measurements by introducing the Calculation Type Automatic Gauge Block Interferometer (Figure 43) with Bidirectional Touch Signal Probe, which was developed at the Kawasaki Research and Development Center (MKC). Acquired the certification of the first JCSS (Japanese Calibration Service System)-authorized calibration laboratory in gauge block calibration based on the Measurement Law, and the Tsukuba Research Laboratory acquired the accreditation of JCSS-authorized calibration laboratory in laser wavelength calibration. Miyazaki Plant acquired the accreditation of ISO9002 (quality system of the International Standardization Organization), which was the first within Mitutoyo's domestic organization.

Figure 43 Calculation Type Automatic Gauge Block Interferometer

1995

Acquired accreditation as a calibrating organization that conforms to ISO/IEC 17025 (general requirements regarding the capability of a test station and calibrating organization which is defined by the International Standardization Organization) from RvA NKO (the Netherlands Calibration Association / Netherlands Accreditation Organization). Since the JCSS Calibration Certificate issued by Mitutoyo for a gauge block is under the endorsement of MRA (Mutual Recognition Agreement) accreditation based on APLAC (Asia-Pacific Laboratory Accreditation Cooperation) and ILAC (International Laboratory Accreditation Cooperation), it is also valid in each country (Western and Asian Nations) affiliated to these organizations. Against this background, Mitutoyo planned to introduce the second version of the Automatic Gauge Block Interferometer (GBI) that used two laser wavelengths.

1998

Started production of the world's first low-expansion glass gauge block, developed as a reference standard in support of the trend toward temperature-compensated precision coordinate measuring machines (CMMs) (Figure 44). Because successful operation of this type of CMM depends on knowing the effect of temperature differences between a workpiece and the CMM scales, a smaller gauge block with a much smaller coefficient of thermal expansion is required in order to minimize uncertainty in the calibration that establishes this relationship. In this year, falling as it did on the 10th anniversary of the initial sales of the CERA block, Shunji Sudo (vice plant manager and quality control section chief of Miyazaki Plant), made a research presentation on the *phase compensation of a CERA block* at a meeting of the International Society for Optical Engineering, SPIE) held in Europe. The speech concerned the report addressing reliability of the interferometric measurements of CERA blocks which had already been widely disseminated.

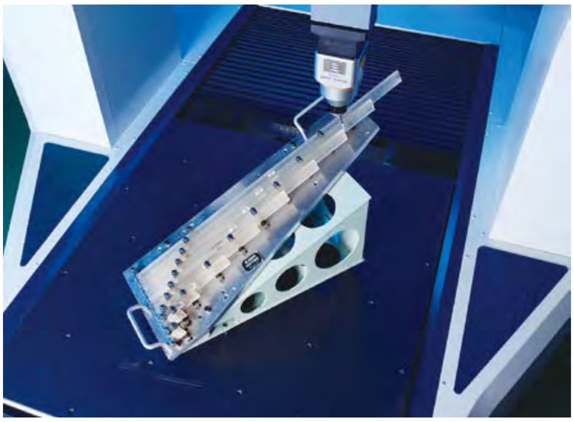


Figure 44 Calibration of a high-precision coordinate measuring machine with low-expansion glass gauge blocks

2000

Started to sell the 122-piece set which contained the largest number of gauge blocks ever marketed.

2002

Launched the technology development to process one-piece gauge blocks made to a special dimension (customer-specified dimension). Shortened the delivery period for special dimension gauge blocks, and thus gained many customers.

2003

Announced the introduction of mixed sets of steel blocks and CERA blocks. These sets offered increased resistance to wear by using CERA blocks for those blocks that are most frequently used in normal use. This development was to meet customer demand for a lower priced, but still long lasting, gauge block set.

2004

Achieved the world's highest performance level in the interferometer measurement capability of gauge blocks among JCSS authorized calibration laboratories (Uncertainty of Measurement = 0.03 micrometre/100mm).

2005

Developed the Mitutoyo-original non-contact type interferometer which can measure the thermal expansion coefficient of gauge blocks to high accuracy.

2006

Started selling the world's first gauge blocks (Steel/CERA blocks) (Figure 45) designed for applications requiring blocks calibrated not only for size but also for coefficient of thermal expansion.

Figure 45 Gauge block with a calibrated coefficient of thermal expansion

2009

Developed the world's first ceramic gauge block with a negligible thermal expansion coefficient. This *Zero CERA* block (Figure 46) has been used by universities and research organizations, in addition to major company customers, for research regarding the calibration of coordinate measuring machines and other high-precision applications.

Figure 46 Zero CERA block

Figure 47 Micrometer-check gauge block holder (developed in 2002)

Figure 48 122-piece gauge block set (developed in 1999)

Afterword

The year 2012 marks 70 years since Mitutoyo first started production of gauge blocks. Since the time when the Numata Research Laboratory entered the market on a full-scale production basis, the production of Mitutoyo gauge blocks now exceeds a total of 23 million pieces in 45 years, and they continue to be used all over the world. Advanced processing techniques have been cultivated by Mitutoyo over the years with its research and development advancing measurement technology and creating new products, such as new types of gauge block, as well as leading-edge measurement equipment for gauge block evaluation. With a reputation for innovation and reliability endorsed by history, and an extensive sales/service network stretching throughout the world, Mitutoyo continues to support manufacturing industries wherever they may be found.

Written by Tetsuo Kosuda, the Miyazaki Plant Manager.

Figure 49 Mitutoyo Miyazaki Plant, Co., Ltd.