

E12029(2)

History of Precision Measuring Instruments The Origin and Evolution of Calipers



Mitutoyo

Contents

| | |
|--|----|
| 1. About the Nogisu..... | 1 |
| 2. About the Caliper..... | 2 |
| 3. Origin of the Name Nogisu and Vernier Graduations..... | 4 |
| 4. Oldest Sliding Caliper: Nogisu..... | 8 |
| 5. Scabbard Type Sliding Caliper till the Middle of 19th Century..... | 9 |
| 6. World's Oldest Vernier Caliper (Nogisu) in Existence..... | 11 |
| 7. Theory That the Vernier Caliper (Nogisu) Was Born in the U.S..... | 12 |
| 8. Calipers before Around 1945 (the End of WWII) in the West..... | 13 |
| 8.1. Slide-Catching Scale without Vernier Graduations: Simplified Calipers..... | 14 |
| 8.2. Sliding Calipers with Diagonal Scale..... | 18 |
| 8.3. Sliding Caliper with a Vernier Scale: Vernier Caliper..... | 19 |
| 9. Depth and Height Gages..... | 26 |
| 10. The Beginning of the Sliding Caliper in Japan..... | 28 |
| 11. Industrial Production Startup and Proliferation of Vernier Calipers in Japan..... | 36 |
| 12. Trends in Vernier Calipers after the End of WWII and the Establishment of JIS..... | 39 |
| 13. Development of Height Gages in Japan..... | 45 |
| 14. Development and Advancement of Digital Calipers..... | 47 |
| 15. Summary/Acknowledgments..... | 53 |
| References..... | 55 |

1. About the Nogisu

Nogisu is the term commonly used in Japan for "a handheld dimensional measuring tool using a sliding caliper arrangement". The tool comprises a straight beam with an engraved scale and a pair of jaws (calipers) which can determine the size of an object by sliding the moving jaw along the beam to trap the object against the fixed jaw and then reading the scale. To provide finer resolution there is an auxiliary scale, known as a vernier scale, that is used to interpolate between the coarser graduations on the beam scale.

Any engineering factory worthy of the name uses a nogisu - even a factory on the scale of one employee and one lathe. Also, many people who do maintenance work on their car have one.

Scale technology originated in the West in ancient Egypt around 5000 B.C. and later in China around 1500 B.C. However, the history of industrial measuring devices is unclear, especially regarding the vernier type caliper. It is presumed that the sliding jaw vernier caliper derives from the evolution of ancient scales combined with the convenience of using projections (jaws) to touch, and so define, the precise part of an object that is to be measured. The details will be covered in a further section but, in Japanese usage, a caliper used to be classed as a scale device until 1945 after which it became a separate measuring tool.



Note *1: This brochure is compiled by partially adding to the document of Origin and Transition of Calipers in Precision Engineering Fundamental Course "History of Precision Measurement" 3rd Lecture (Website version posted on December 26, 2012).

Note *2: The terms used in this original document conform to academic jargon or JIS terminology.

First of all, it is necessary to define what we mean by a caliper. This is because the writer has come across a specification draft of ISO/DIS (International Organisation for Standardisation / Draft of International Standard) 13385-2.2. The title of this draft is Geometric Product Specification (GPS) - Dimensional Measuring Equipment- Part 2: calliper depth gage - Design and metrological requirements.

This draft was embarrassingly approved in 2011. The problem is that it uses the term caliper depth gage. However, this specification clearly concerns depth gages alone and so the word caliper is erroneous in this context. It is believed that the specialists who were in charge of compiling ISO/TC213 did not realize the significance of the term caliper so it was decided to address this point in this document.

Moreover, to support this fact, the revision process for ISO 3611:1978 specification for the Micrometer was carried out around the same time and the title was revised from Micrometer calipers for external measurement to Micrometers for external measurement (2). The removal of the term calipers proves the above point.

A calliper is a measuring device which measures a diameter or thickness of an object by gripping it between

two parallel jaws, or point contacts). Therefore, a caliper depth gage does not exist. It is believed that the reason why the term caliper was used is because a depth gage also has a slider, but this carries a reference base instead of a jaw.

About 10 years ago, a specification plan for a calliper height gage was submitted in Denmark. At that time, this writer attended the meeting as a member of the committee and gave reasons to request a revision of this plan, which swiftly gained approval by many of those present on the committee. Another reason why this plan was submitted incorrectly was that the BSI (British Standard Institute) committee member had not attended that meeting for several years. The abovementioned caliper depth gage was established as an ISO specification however, with an opinion submitted by the writer in December 2012, it was reported that this specification is to be revised in five years time.

There are many types of measuring tools that use a pair of jaws, i.e. calipers, that have evolved over time. The main types found today are shown in Figure 1, listed under their English names.

The calipers in Figure 1(a) and 1(b) are external and internal calipers. These calipers were mostly used in

Japan until early in the Showa era and even during the Second World War in some industries. They cannot make direct measurements themselves but rely on an auxiliary measuring instrument (such as a steel rule) to determine the distance between the jaws after the caliper has been set, and held by friction in the joint, to the wanted dimension by lightly gripping the corresponding workpiece surfaces simultaneously with the jaws. In fact they were often used together in a comparative mode to aid in machining matching components to a required degree of fit, typically a bearing and shaft, which made actual measurement unnecessary. These calipers require considerable skill as successful use depends heavily on the consistency of the user's feel.

After this time vernier (sliding) calipers, as shown in Figure 1(c), began to be used in place of external/internal calipers. This more advanced caliper enabled a workpiece dimension to be measured directly with efficiency and good accuracy. In recent times vernier calipers have become widely available and external/internal calipers are now practically obsolete, although the principle is still used. Due to the widespread use of vernier calipers, a measuring tool with the sliding section carrying a vernier scale has become synonymous with the term caliper. This

misunderstanding of the original definition of a tool that grips an object between two jaws, or points, resulted in the misnaming of the abovementioned ISO Standards.

A type of caliper that uses the mechanical magnification of the inclined plane (a screw thread) to provide improved resolution, down to the micrometer level, is the micrometer shown in Figure 1(d). However, a micrometer is not considered a caliper in the same sense as are types 1(a), 1(b) and 1(c) even though its formal name is micrometer caliper, which is commonly abbreviated to micrometer.

A sliding type of caliper that uses a gear system to increase resolution is shown in Figure 1(e) and is known as a dial caliper. Non-sliding calipers such as the dial thickness gage, shown in Figure 1(f), and internal and external dial calipers shown in Figures 1(g) and 1(h) are also available and also fall into the dial caliper group. Recently, the digital calipers and digital thickness gages shown in Figures 1(i) and 1(j) have become widely used instead of the dial thickness gage and these also belong to the caliper group.

Now the time has come to recognize how greatly the various types of caliper described above have played an important role in the history of mechanical and production engineering.

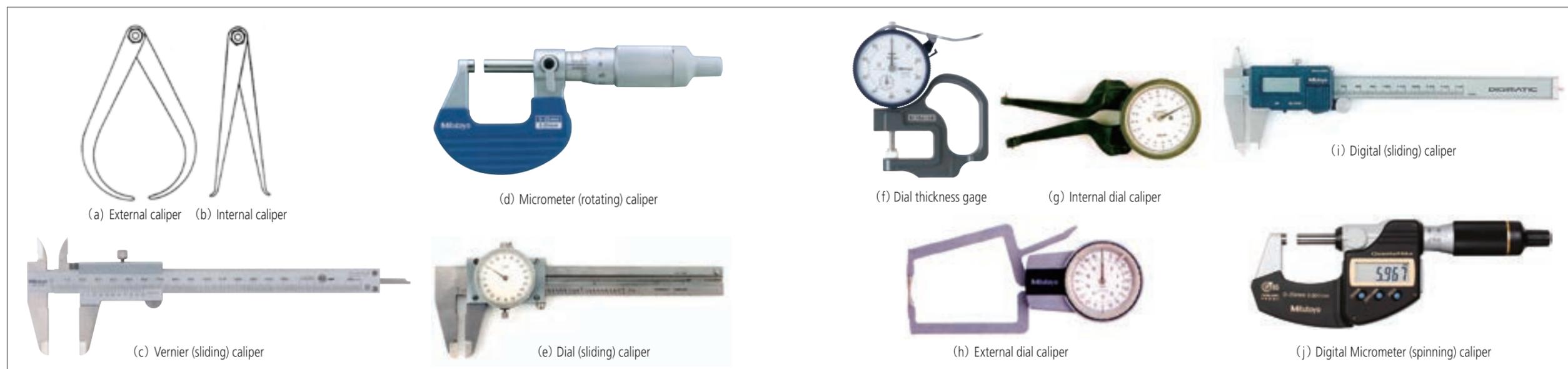


Figure 1 Various Types of Caliper *3

Figure 1 Various Types of Calipers *3

Note *3: Calliper is the British English spelling and Caliper is the American spelling. ISO Standards use British spellings. The terms in parentheses indicate the method of contact of the movable jaw. The Vernier caliper does not provide magnification while micrometer and dial calipers provide higher measurement resolution through mechanical magnification.

The word *nogisu* somehow sounds non-Japanese. However, it is actually a Japanese word and it would not be understood in other countries. In English the term is vernier caliper, In French, *ped a coulisse* and in German *Schiebehre* or *Messschieber*. In Spanish the term is *calibres pie de rey*.

The Japanese word *nogisu* is believed to be a corruption of *Nonius* (meaning an auxiliary scale which divides a main scale into smaller increments) from the German language. This is believed likely because there are many words in Japanese that are derived from German. Alternatively, it could be a corruption of a Dutch word. However, in terms of mechanical usage, in Japanese there are more words derived from English than from other languages. As will be mentioned later, machining technology was introduced to Japan in two places; the Nagasaki steelworks and the Yokosuka steelworks, which were built by the Edo government as modern shipyards. A Dutch engineer came to Nagasaki and a French engineer to Yokosuka. For this reason a large number of terms were bastardized from Dutch and French to Japanese through the Meiji, Taisho and Showa periods (before WWII). Some examples are given below.

The Japanese word *Touskan* means surface gage in English and *Parallelreisser* in German, both of which are completely different in pronunciation to the Japanese word. However, in French the word is *Troussequin*, which bears a strong resemblance to *Touskan*, so it may well be that *Touskan* is a corruption of the French word. Prior to WWII, a lathe was called a *Daraiban* and a planer a *Shikaruban*. Similarly, both words are corruptions of the Dutch words *Draaibank* and *Schafbank*. *Swarf* is called *Daraiko* and a machine tool is *Banko*, which are also derived compound words.

Nonius is a Dutch term for the vernier scale and *nogisu* in Dutch is *Schuifmaten*. The German word for *nogisu* has been mentioned before but the word *Schieblehre* is a compound of the word *Schieb* meaning sliding and *Lehre* meaning gage or scale. Moreover, the word *Messschieber* is a compound of the word *Mess*, meaning to measure,

and *Schieber*, meaning slide, which is therefore translated as a sliding measuring device. In this connection, the French word *Pied*, meaning scale, and *Coulisse*, meaning slide, is therefore translated as a sliding scale. Consequently, the origin of the word *nogisu* would have to be from *Nonius* whether from German or Dutch. At Nagasaki steelworks, if *nogisu* were used back then, it is conceivable that they were hearing the word *Nonius* which became *Nonisu*, which was eventually corrupted into *nogisu*.

The word *nonius* derives from a Portuguese named Pedro Nunes who wrote under the Latin name of *Petrus Nonius Salaciensis* (1502-1578; *Salaciensis* simply indicates that he came from *Salacia*). In 1542 Nunes invented the scale shown in Figure 2. This invention improved the accuracy of the *astrolabe*, which was an elaborate inclinometer (an angle measuring instrument) used by astronomers, astrologers and navigators for locating and predicting the positions of the heavenly bodies, among other things. His scale comprised equally divided concentric quadrant arcs with each arc having one less division than the one outside it. The first had 90 divisions, the next 89, the next 88, then 87, and so on. When an angle was measured, the circle and the division on which the index arm fell were noted. A look-up table then provided the corresponding angle.

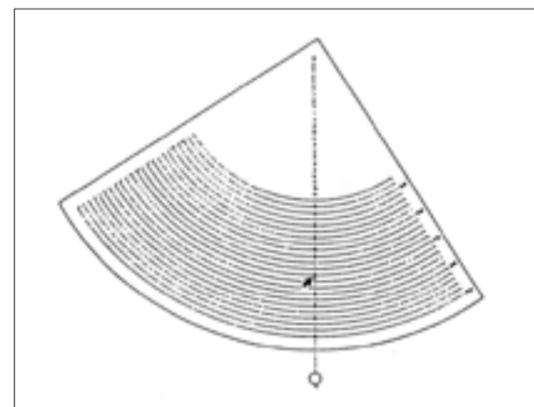


Figure 2 Nunez Scale

In Germany, the term *Nonius* became synonymous with *vernier* despite the fact that it was the Frenchman Pierre Vernier who invented the scale named after him. All German dictionaries give *Nonius* as the definition of a vernier scale, presumably because Nunes' quadrant division method was seen as similar in principle to Vernier's scheme and that, for historical reasons, Germany did not want to use a French name.

It has widely been alleged that the vernier graduation scheme was invented by Frenchman Pierre Vernier (1580~1637). He was famous as a mathematician, but he was employed as a local government official. In his book *New Quadrant Configuration, Application and Property* issued at Brussels in 1631, he described vernier graduations, thereby becoming known as the inventor of the vernier scale. This was further embellished elsewhere, resulting in a story that he also invented the vernier caliper.³⁾⁴⁾ However, the caliper itself with his invented vernier graduations has not been found up to the present time. Some doubt remains as to whether he actually made a vernier caliper. Since French people are strongly patriotic, his vernier caliper would certainly be displayed in the *Conservatoire National des Arts et Metiers* in Paris which has a collection of old instruments, if he had made one, but no caliper of his has ever been stored or displayed there. I also have no idea why old Vernier calipers from those days are not stored or displayed.

In France they call a micrometer a *Palmer*, derived from the name of its French inventor, J. L. Palmer. Although Vernier, who is reportedly the inventor of the vernier caliper, was French, it is not understood why they do not call a vernier caliper a *Vernier* but use the term *Pied à Coulisse* instead. The thing that Vernier invented was probably not a vernier caliper but only the graduation scheme, about which he wrote in his book. Since sliding calipers were already in use, I think he merely made a sliding caliper incorporating his vernier graduation scheme. Even though French people are strongly patriotic they did not use the term vernier caliper for some reason. The places where old industrial instruments are displayed are the Science Museum at

South Kensington in London, the Munich Science and Technology Museum, Germany, and the *Conservatoire National des Arts et Metiers* in Paris mentioned above. Despite displays of old micrometers in all these museums, I wonder why no old Vernier calipers are displayed. Some people say the birthplace of the vernier caliper was the U.S. and this may be difficult to dismiss, according to the description in Chapter 7.

There are several ways of constructing a vernier scale, and five of the examples described in the Japanese Industrial Standard (JIS) Vernier Caliper are as shown in Figure 3(6). They all use the same principle with the aim of increasing the resolution of a scale without using mechanical magnification, which is that one vernier scale division is slightly shorter than one or more main scale divisions (limited to two in practice) and this difference in length determines the resolution provided. As the vernier scale is moved relative to the main scale each of the vernier graduations is successively aligned with one of the main scale graduations, and the number of the aligned vernier graduation times the resolution equals the increment of size to be added to the main scale graduation indicated by the zero graduation (the origin) of the vernier scale. The vernier graduations are numbered to indicate increments of 0.1 or 0.2 mm for ease of reading the 1st decimal place, so that only a small number of subdivisions need to be counted to read the 2nd decimal place. There is no confusion in identifying the aligned graduation pair because there is, in general, only one vernier graduation that aligns with a main scale graduation at any one time, the exception being when the zero graduation is aligned at which time the last graduation (marked as 10) is also aligned, but it is understood that when this occurs the vernier increment of size is zero.

Main scales universally adopt 1 mm divisions (for metric types) and vernier scales are 19 mm (c) or 39 mm long (d), equally divided into 20 divisions to give a resolution of 0.05 mm, or a scale 49 mm long is equally divided into 50 divisions to give a resolution of 0.02 mm. In the past some vernier scales used schemes (a) or (b) in which scales 19

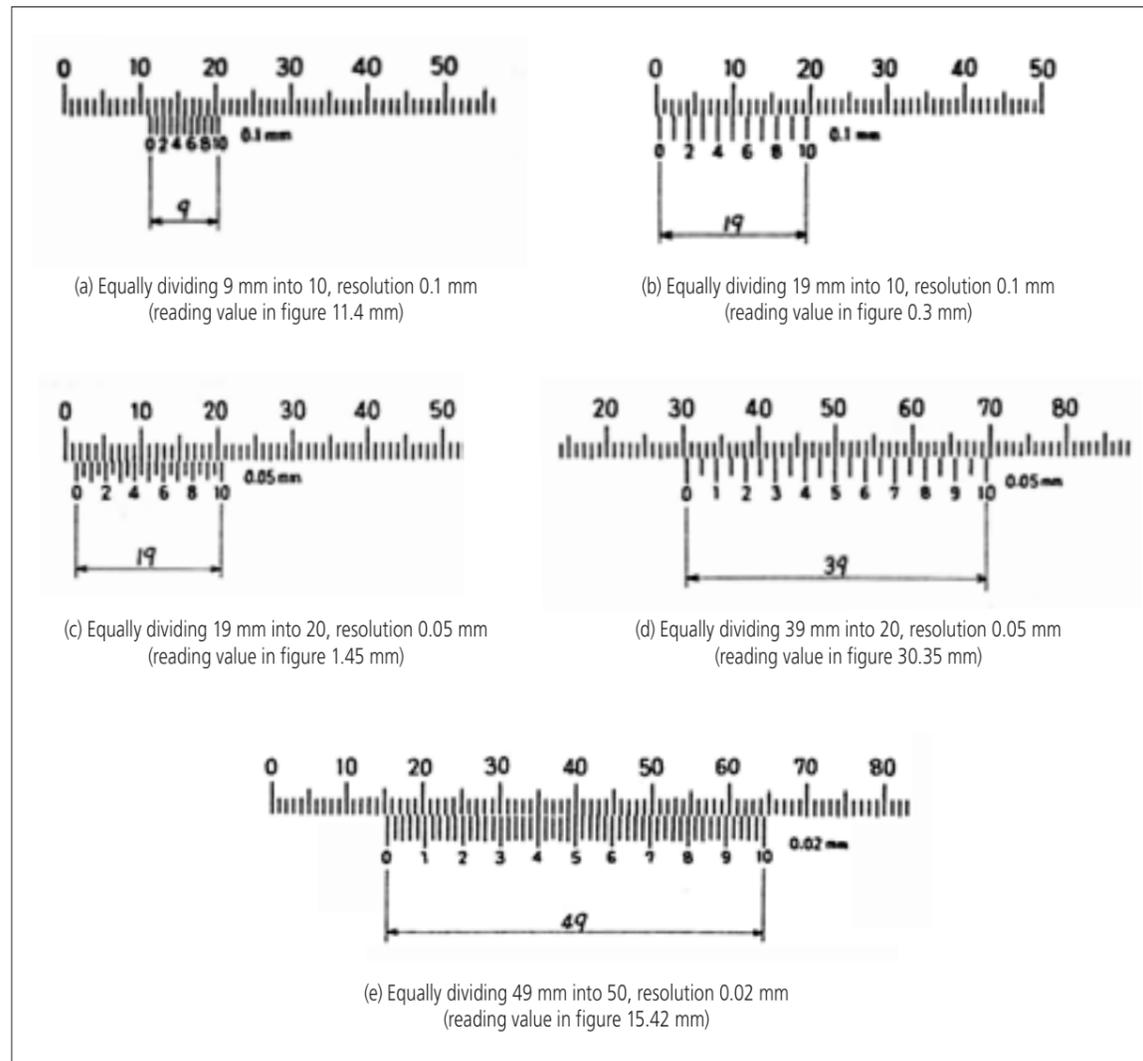


Figure 3 Examples of Vernier Graduations and Their Readings

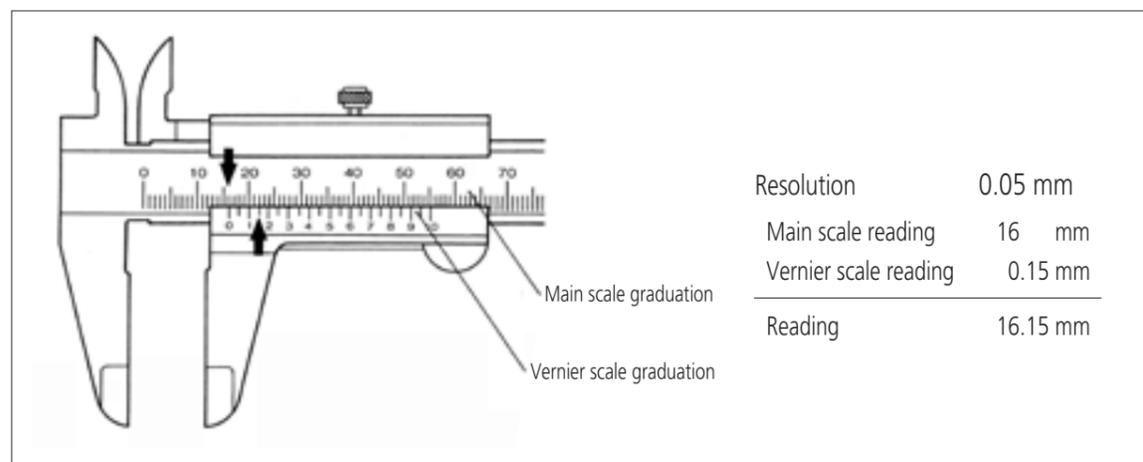


Figure 4 Reading measurements for Vernier scale graduation

mm and 39 mm long are equally divided into 10 divisions to give a resolution of 0.1 mm, but these schemes are seldom used today because of their inferior resolution. In theory (see below) there is no lower limit to the resolution of a vernier scale but the visual acuity of humans sets the limit at 0.02 mm, and this is often only possible because the adjacent almost-aligned graduations each side of the aligned pair can be compared to enable correct identification. Sometimes low-power optical magnification is also needed, depending on an individual's eyesight. The principle of the vernier scale is simply as stated above but for completeness the mathematical principle is given below.

For a vernier scale with division length V , number of vernier divisions n , working with a main scale division length of S , these parameters are related as follows:

$$(\alpha n - 1)S = nV \dots\dots\dots (1)$$

where α is an integer value (limited to 1 or 2 in practice) whose only effect is to make the vernier scale easier to read by spacing out the vernier graduations if > 1 . There is a small disadvantage to setting $\alpha > 1$ because this means that a longer main scale is needed to provide a certain full-range reading due to the longer vernier scale.

The resolution C provided by a vernier scale is the difference in length between one vernier division and one or more main divisions, so that:

$$C = S\alpha - V \dots\dots\dots (2)$$

Expressions (1) and (2) can be combined to show that:

$$C = S/n \dots\dots\dots (3)$$

So that resolution is only dependent on the main scale division length and the number of vernier divisions. In principle any value could be used for n but it only makes sense to use a value that gives a sensible increment based on 10, 20 or 50. Values for n are almost always 20 or 50 to provide 0.05 or 0.02 mm resolution respectively, with the latter representing the limit of usefulness.

The vernier graduation numbering for a normal vernier caliper runs in the same direction as the main scale numbering because the vernier divisions are shorter than

the main scale divisions. This is called a forward vernier. However, another case is possible where the vernier divisions are longer than the main scale divisions and the factor becomes $(\alpha n + 1)$ in expression (1). In this case the vernier graduations run in reverse, thus being called a reverse vernier. A reverse vernier is seldom used due to the non-intuitive reverse reading direction

Nogisu in Japanese corresponds to Vernier Caliper in English, which means a caliper with a vernier scale. A digital readout Nogisu, of course without vernier graduations, may sometime be referred to merely as a Caliper. Communication using Japanese only may not cause a misunderstanding of terms. Today when exchanges of goods with foreign countries occur frequently, the use of the term Caliper may not be proper in some cases because the term means a category that includes vernier caliper, micrometer, etc., as shown in Figure 1. It needs to be recognized that the term Caliper signifies a measuring tool to determine dimensions of depth, diameter, etc. by pinching an object between two points. Owing to the development of the latest measuring instruments, the term Digital Caliper indicates not only a digital caliper but also a digital microscope.

A sliding caliper with vernier graduations is known as a Nogisu in Japan, which should be considered to be the term for a sliding caliper itself independent of the pronunciation and form even if it was derived from Nonius, meaning a vernier scale in German or Dutch. Now, the pronunciation of this word has no direct relation with any foreign language. Consequently, we can say the term Digital Nogisu is more appropriate than Digital Caliper. In this document a sliding caliper is referred to as a Nogisu regardless of whether it has vernier graduations or not. Nowadays, both micrometer and Nogisu (sliding caliper) are digital measuring tools that can read in units of micrometers. Therefore, a digital sliding caliper and a digital micrometer (shown in Figure 1) that can read in units of micrometers should be named a digital micrometer sliding callier and a digital micrometer spinning caliper, respectively.

4. Oldest Sliding Caliper: Nogisu

The oldest scale of this type could be said to be that used in the ancient Chinese Yin era and made of mammoth bone, tusk, horn and stone. This was the Bronze Age, around 1400 BC, and it was not until around 500 BC iron that was introduced to the construction. As time passed, bone became bronze and bronze became bamboo, wood, iron and glass.

It is possible to measure a circular object with a line scale but it is a difficult and error prone operation. However, such an object can be easily be measured by fixing jaws to the line scale and then placing the object between the jaws.

Nogisu type of scale can be seen in the Chinese national treasure museum in Beijing in the bronze age section, and is shown in Figure 5. It has a bronze main scale with an attached jaw, a sliding scale carrying another jaw and is called Tama Shyaku which Wang Mang, who started the Xin dynasty in 8 AD, ordered to be made the year after establishing his dynasty. It is embellished with a beautiful fish tail shape on the right hand side. Immediately after his enthronement, Wang Mang put Chinese measuring units in order when he created this scale, which was used mainly to measure marble and jewellery. This is all recorded in writings from the end of the Xin era and was followed by successive ruling families in China.⁷⁾

This is the world's oldest sliding caliper in existence, i.e. a Nogisu without vernier graduations. I would not be surprised if a sliding caliper like this had been made in the period of Han or Qin even before the Wang Mou era. From the fact that the master gage used for the design of the scale standard already existed in the Han Period¹⁰⁾⁻¹²⁾, it can be seen that science was advanced in those days.¹³⁾ For 1500 years or more after that there has been little information about any sliding caliper, Nogisu. I imagine, however, that a Nogisu structured in a type of L-shape sliding scale as in Figure 5 had continued for quite a few years.

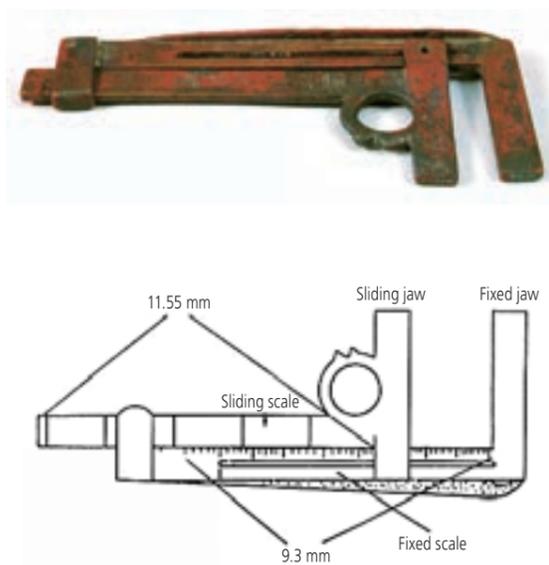


Figure 5 Brass Sliding Caliper Developed by Wang Mou in Xin (China), A.D. 9

5. Scabbard Type Sliding Caliper till the Middle of 19th Century

At the beginning of the Industrial Revolution era in Britain a sliding caliper was introduced in which the graduated main scale with a jaw slid inside a sheath that carried the other jaw. A workpiece was pinched between the jaws and the measurement value read from the edge of the sheath opening. Figure 6 is a diagram of the operating principle. Hereinafter, this caliper is referred to as a simplified Nogisu.

At the Industrial Technology Museum in Paris, an 1887 Pieds a Coulisse is displayed that has a sliding element scale. It is shown in Figure 7, where one jaw is movable and the main scale carrying the other jaw emerges from a sheath. An object is gripped between the jaws and the reading is taken from the edge of the sheath. The sheath also has a scale engraved on it and the reading from this is added to that of the main scale to obtain the measurement value, so that this instrument can measure up to twice its closed length. This sliding caliper can also be used as a height gage by setting the caliper upright with one of the jaws aligned with a reference surface. Figure 8 is a simplified nogisu of an older version of Figure 7. It was made in France and is presently displayed in the Mitutoyo museum in Tokyo. Like the one in Figure 7, the main scale emerges from a sheath for measurement and has a millimeter scale on the front and a pouce scale (which was the unit used before the meter in France) on the back. The main scale of this simplified nogisu has a width of 12 mm, a thickness of 2 mm and a measuring range of 150 mm. The jaws are triangular in section with iron measuring surfaces of 5 x 50 mm. The sheath is brass with a width of 15 mm, thickness of 5mm and length of 180mm. The main scale includes a pouce scale of 1/12 which has two scales: 1 ligne and 1/24 scale (6 point). The sheath has a 1 mm graduated scale on the front and a 1 ligne scale engraved on the reverse. Similarly to the Figure 7 type, it has a 300 mm range when the main scale is fully extended, and it can also measure height. One pouce

is equivalent to 27.07mm, just a little more than an inch. After 1840, France banned the use of units other than the meter so it is assumed that this nogisu was made at about this time.

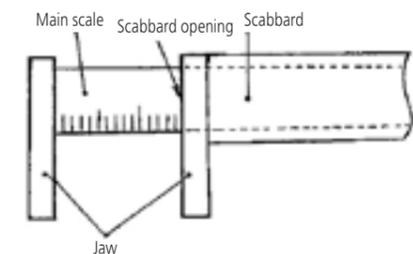


Figure 6 Conceptual Diagram of Scabbard Type Sliding Caliper, Simplified Nogisu



Figure 7 Scabbard Type Sliding Caliper, Simplified Nogisu (Made in France), 1887



Figure 8 Scabbard Type Sliding Caliper, Simplified Nogisu (in Units of inch and pouce) (Made in France), about 1840



Figure 9 Scabbard Type Sliding Caliper, Simplified Nogisu (in Units of inch and mm) (Made in France), about 1870

A simplified Nogisu (of the same type had also been made with almost the same range of inch and mm unit graduations engraved on the front and rear faces of the main scale. Figure 9 shows the simplified Nogisu with a measuring range of 5 inches and 120 mm, which was made in France and used in the U.S. The main scale to be inserted in the scabbard has 1-mm graduations and 1/10, 1/12 and 1/16-inch graduations. This Nogisu seems to have been well used as the engraved mm graduations on the sheath have almost worn off, leaving only little indentations. Various lengths of jaws were available for a simplified Nogisu in those days.

As for a measuring tool to measure a workpiece by pinching it between jaws, Gascoigne in the UK made the world's first screw-operated micrometer caliper, as in Figure 10, in about 1639¹⁶⁾⁻¹⁹⁾.

The simplified Nogisus shown in Figures 7~9 have no vernier graduations at all. They are just sliding calipers as the name implies. As described above, Vernier introduced vernier graduations in his book in 1631, but he may not actually have made a vernier scale.



Figure 10 Gascoign's Screw-operated Microscope Caliper (UK), 1639

6. World's Oldest Vernier Caliper (Nogisu) in Existence

Figure 11 shows a vernier caliper (Nogisu) which was reportedly made and used at the Army Artillery Royal Factory in France in about 1840 (Tenpo 11) in the same year as the simplified Nogisu in Figure 8 was made. This Nogisu is stored at the Weights and Measures Museum (curator: Kenzo Kobayashi) near the Hobo station on the Sangi Line, located at Nakano-cho, Yokkaichi City, Mie Prefecture. This Nogisu is 650 mm in total length. The main scale has a width of 25.4 mm, a thickness of 7.13 mm and a measuring range of 530 mm, and provides mm-unit graduations on the front face and pouce-unit graduations on the rear face. The front vernier scale in Figure 11 (a) allows reading down to 0.1 mm by equally dividing nine 1-mm divisions into ten. The rear vernier scale in Figure 11 (b) allows reading down to 1 point by equally dividing 11 graduations of 1 ligne (which is produced by equally dividing 1 pouce into 12) into 12. France had prohibited the use of units such as pouce instead of metric units since 1840 by a law established on July 4th, 1837. Therefore, millimeter graduations were engraved on the front face in contrast to previously-existing pouce graduations on the rear face while the metric unit was made more legible. For this reason, this Nogisu is believed to have been made between establishment of the law in 1837 and its enforcement in 1840.

To check the measuring accuracy of this Nogisu, Professor Isao Ootsuna and others in Tokyo University compared its performance with that of the latest Mitutoyo Nogisu in 2009²⁰⁾. They measured the lengths of 4 kinds of workpiece over the range 79.00 to 400.00 mm²¹⁾, with the result as shown in Figure 12. The longitudinal axis in the figure expresses the value given by subtracting the Mitutoyo Nogisu measurement from the French Nogisu measurement. The measurement results using the metric scale are indicated with ● points and those using the pouce scale are indicated with × points.

His paper was intended to determine pouce values for the lengths of individual workpieces and then the mean of pouce values for each workpiece measurement. However, this figure changes pouce values to the equivalent metric values according to the relation 1 pouce = 27.07 mm. From the result that the measurements obtained from

those two Nogisus agree, on average within a difference of 0.05 %, it can be said that this French Nogisu is very accurate. I do not understand why this Nogisu made at the French Army Factory is not displayed in the Conservatoire National des Arts et Metiers in Paris even though this Nogisu exists in Japan, but since my visit to the museum was some time ago the articles on display may have been updated in the meantime.



(a) mm-unit graduated surface



(b) Vernier scale section with pouce-unit graduations

Figure 11 Nogisu Made and Used at the Royal French Army's Artillery Factory (in about 1840)

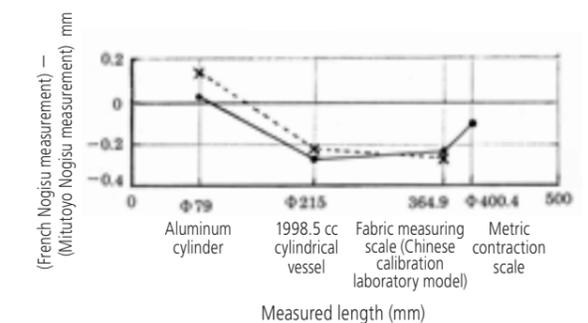


Figure 12 Accuracy of a Nogisu made in France (● points are readings of the metric scale on the front face and × points are those of the pouce scale. The pouce scale readings were converted to millimetres using the relation 1 pouce = 27.07 mm.)

7. Theory That the Vernier Caliper (Nogisu) Was Born in the U.S.

An authority on U.S. machine tool history, J. W. Roe, who might not have known of the existence of the above-mentioned French Army's vernier caliper, said in his book "English/American Machine Tool Manufacturers" that a vernier caliper was first manufactured by the U.S. Brown & Sharpe Mfg. Co., also describing its origin as follows. J. R. Brown, a leading mechanical engineer and the founder of Brown & Sharpe Mfg. Co., invented and manufactured an automated linear graduating machine (with correction device) for scales in 1850. Using this graduating machine he made the first vernier caliper with a resolution of 1/1000 inch (0.025 mm) in 1851 (Kaei 4). He was very proud that every mechanical engineer could now obtain a precision measuring tool capable of reading in such a small unit, shouting with delight that it was really epoch-making. Consequently, the Brown & Sharpe Mfg. Co.'s catalog stated (for a while) that Jos. R. Brown had invented the vernier caliper.²²⁾

The appearance of the vernier caliper made by Brown is as shown in Figure 13. The graduated vernier scale is connected with the slider which moves along a dovetail groove in a similar way as does the blade in the scabbard-type sliding caliper. The 1/32-inch main scale graduations are engraved on the 'scabbard' to give a range of 6 inches. Although the details are uncertain from Figure 13, this caliper would have had a resolution of the order of 1/1000 inch if the vernier scale was graduated with 32 divisions the same length as 31 on the main scale ($1/32 \times 1/32 = 1/1024$ inch). However, this resolution is based on fraction two, not ten, so is not practical for precision engineering. Thereafter the vernier calipers of Brown & Sharpe Mfg. Co. mostly used vernier graduations in which 1 inch on the main scale was evenly divided into 40 and then a vernier scale of 25 divisions gave a resolution of the more convenient 1/1000 inch.²²⁾



Figure 13 Brown & Sharpe-made Vernier Caliper (U.S.) in 1851

In 1848, three years before the appearance of this caliper, a patent for a micrometer was first applied for in France. At that time micrometers were not valued products in Europe, therefore Brown's vernier caliper might be rightly viewed as an epoch-making measuring tool. Since the accurate graduation of a scale over a long range is far from an easy skill, the development of a linear graduating machine is a technology to be highly valued.

However, these excellent vernier calipers were not popular among engineers at first and only four pieces were manufactured in the first year. It seems they only became saleable three years after introduction. In other words, the graduating machine was invented in order to make accurate scales, the new vernier caliper was launched using this machine, and then this type of caliper gradually became widespread. In later years it seems to have become an accepted tool as shown by a Brown & Sharpe advertisement in the premiere issue of the American Machinist magazine, launched in November 1877, shown in Figure 14. The advertisement included the eye-catching subtitle FINE MACHINERY, SEWING MACHINES, and lists the various tools and gages on offer, among which Vernier Calipers can clearly be seen.

If Brown & Sharpe Mfg. Co. had first started manufacturing calipers with vernier graduations as above, a similar belief that the principle was born in Europe and manufacturing and proliferation were achieved in the U.S. might have appeared in the same manner as for micrometers. Such a theory would have been more credible in those times when communications were relatively poor and under circumstances where no sliding caliper with vernier graduations seemed to have appeared in Europe. This report of U.S. caliper development was widespread and people seemed to have believed it.⁸⁾ However, as mentioned above, the French-made caliper with vernier graduations in metric and pouce units (manufactured in about 1840) is stored at the Weights and Measures Museum. All in all, it can definitely be said that vernier calipers were manufactured in Vernier's country, France, ahead of the first U.S.-made version.

8. Calipers before Around 1945 (the End of WWII) in the West

Two types of caliper were in widespread use from around 1840 to around 1950, or till immediately after WWII, and it is considered that either type was selectively used depending on the application. One is a simplified caliper classified as a scabbard type sliding caliper, where only the main scale graduations inscribed on the caliper beam are read, and the other is classified as the original type of caliper or sliding caliper with vernier graduations. It seems that each type was used so as to meet the needs of the application, but the vernier type became dominant over a long period.

As described previously, in Chapter 5, the former sliding caliper type (or simplified caliper) was used as a kind of rule since long ago. The later sliding caliper with vernier graduations, or vernier caliper, was the measuring tool whose origin is thought to be in France (or other European countries) around 1840 or before.

Due to the advantage of these calipers that they use jaws to grip a workpiece and read the dimensions more accurately with their vernier graduations, they have been widely applied in the mechanical industries.

It is found from examining the calipers exhibited in the Mitutoyo Museum that the simplified caliper and the vernier caliper, which is to say a sliding caliper with vernier graduations, appear in parallel up to around 1950²³⁾.

Judging from this exhibition it can be seen that French calipers provided with vernier graduations have appeared since the early days, proving the development of calipers as already described in Chapter 6.

The both types of calipers are described in the catalogs²⁴⁾⁻²⁸⁾ (from 1924 to 1985 or later) of Brown & Sharpe Mfg. Co., which manufactured calipers provided with vernier graduations early, around 1851, and in the catalogs^{29) 30)} of the L. S. Starrett Company of 1927 and 1930, taking considerable advertising space.

Moreover, even in the L. S. Starrett catalogs of 1979³¹⁾ the simplified calipers, which are of the pocket type sliding calipers, are described, with 3 pages besides for calipers with vernier graduations. It can be said that both are considered to have been used according to the appropriate purpose.

Furthermore, similar treatment is observed in the catalog of the Adolf Phifer company³²⁾, a tool dealer in Mannheim, Germany, which was issued earlier (1905) and the 1958-edition catalog of the Lufkin Rule Co. in the United States and Canada after WWII. In the catalog of the Stanley Rule & Level Co. there is a description of rules³⁴⁾ that also provided the caliper function. This document describes these instruments seen in the abovementioned literature as typical examples.



Figure 14 Brown & Sharpe Mfg. Co.'s Advertisement in the first issue of the American Machinist, Vol.1 No.1 (1877)

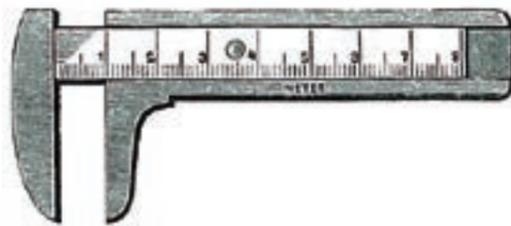


Figure 15 Adolf Phifer Trading Company's (Germany) Simplified Calipers (Maximum Scale Value 80 mm) 1905

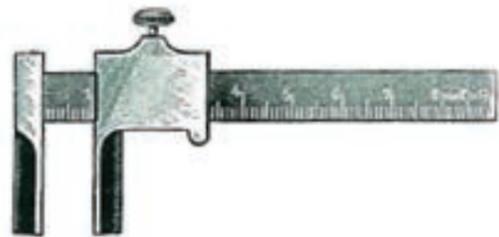


Figure 16 Adolf Phifer Trading Company's Simplified Calipers (Measuring Range 65 mm) 1905



Figure 17 Brown & Sharpe Mfg. Co. (United States)-made Simplified Calipers (Maximum Scale Value 4 in, Scale Interval 1/32, and 1/64 in) 1924

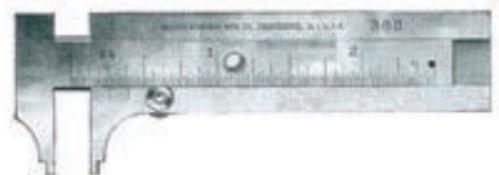


Figure 18 Brown & Sharpe Mfg. Co. (United States)-made Simplified Calipers (Maximum Scale Value 3 in, Scale Interval 1/32 in) 1924

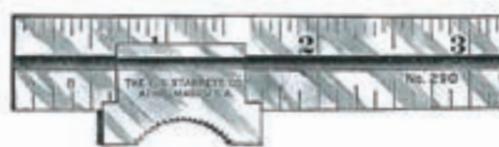


Figure 19 The L. S. Starrett Company (United States)-made Rule with Thumb Slider (Maximum Scale Value 6 in, Scale Interval 1/8, 1/16 in) 1927

8.1. Slider on Scale without Vernier Graduations: Simplified Calipers

Simplified calipers evolved from the form of Figure 6 by removing the front of the scabbard with the scale running in a dovetail groove formed in the scabbard so that the scale surface and scabbard surface are almost flush. This improved accuracy by eliminating parallax error when taking a reading. Figure 15 shows this form of simplified caliper with millimeter graduations used in Germany in around 1905³². The maximum scale value is 80 mm, and the dimension measured is read from where the jaw on the scabbard abuts the scale. In the same period simplified calipers, as shown in Figure 16, with a slider on the scale instead of the scale encased in a scabbard were used. This simplified caliper reads measurement at the edge of the slider end face and has a maximum scale value of 90 mm and a measuring range of 65 mm.

Simplified calipers of a similar type also appeared in the United States. Figure 17 shows a Brown & Sharpe Mfg. Co. simplified caliper on which a feed knob is attached in order to make the main scale (corresponding to a sword in a scabbard) easily fed²⁴. Measurements are read using the projected portion of an arrow-like notch provided in the scabbard as an index. Graduations are also made on the scabbard at 1/32, 1/64 inch intervals, making this caliper useful as a 4-inch rule.

The Figure 17 model is shown in Brown & Sharp's 1924 catalog. Since this company was founded in 1833 to undertake tool manufacture, it is quite natural that they dealt with calipers, as mentioned above, in 1851. From this background, it is reasonable to judge that this type of simplified caliper had been manufactured and marketed at least before 1851. Calipers, as shown in Figure 17, on which main scale graduations are visible were also manufactured and marketed by the L. S. Starrett Company in the same period^{29) 30)}, a company that was founded in 1880. Starrett manufactured micrometers competitively with Brown & Sharpe and both companies undertook the manufacture and sales of steel rules, simplified calipers and Vernier calipers. As a result, both companies had distributed not only micrometers but also calipers at the end of the 19th century.

Figure 18, like Figure 13, shows the configuration of Brown & Sharpe calipers on which the main scale is exposed for its full length^{24) 25)}. The main scale (on the sword) is graduated at 1/64-inch intervals, and can measure up to 2½ inches. Figure 18 also shows the reverse side is designed to serve as a rule, graduated at 1/32-inch intervals from the end of the jaw and up to 3 inches when the jaw is closed. Starrett marketed a rule with a slider index that could be easily operated with a finger, as shown in Figure 19. This type seems to have been used in the same way as those shown above, but might have been intended for different applications. There are two scales on this rule, the lower edge being graduated at 1/8-inch intervals and the upper at 1/16-inch intervals. The slider is guided along a narrow groove running down the center of the rule.

In contrast with this type, a rule with an adjustable hook attached to each end (1/64-inch graduations on the upper edge, 1/32-inch on the lower edge) as shown in Figure 20, and a rule with a fixed hook on one end (1/8-inch graduations on the lower edge, 1/16-inch on the upper edge) as shown in Figure 21, were also manufactured. If we combine these two types (i.e. those shown in Figures 19 and 20) we obtain a type of sliding caliper. A type of caliper that may be called an example of this, as shown in Figure 22, was also manufactured. Since the measuring instruments shown in Figures 17 to 22 are included in the catalogs of Brown & Sharpe and Starrett, it is apparent that they were manufactured and marketed^{24-26) 29) 30)}.

Figure 23 shows a simplified caliper made by Brown & Sharpe in 1910. It has scale graduations of 1/32 inch and is capable of measuring up to 3 inches. The jaw on the slider has engraved index lines for reading outside and inside measurements directly. The slider jaw is adjustable, and the slider is provided with a screw-feed device for fine adjustment. This caliper is on display in the Mitutoyo Museum. Simplified calipers of the same type are found in a catalog issued in 1924, which shows that 6- and 9-inch measurement-range models were added to the same 4-inch models with fine graduations of 1/64 inch on the front side and 1/100 inch on the reverse side. To slow down the effect of wear that occurs during repeated use the jaws are hardened and the fine-feed mechanism has a somewhat



Figure 20 Rule with Adjustable Hook from L.S. Starrett Co. (United States) (Maximum Scale Value: 6 to 48 in, Graduation: 1/32, 1/64 in) 1927



Figure 21 Rule with Hook from Brown & Sharpe Mfg. Co. (United States) (Maximum scale: 4 to 36 in, Graduation: 1/8, 1/16 in) 1924



Figure 22 Sliding Caliper from Brown & Sharpe Mfg. Co. (United States) (Maximum scale: 4 in, Graduation: 1/32 in) 1924



Figure 23 Simplified Caliper from Brown & Sharpe Mfg. Co. (United States) (Measuring Range: 3 in, Graduation: 1/32 in) 1910, Same type in 1924

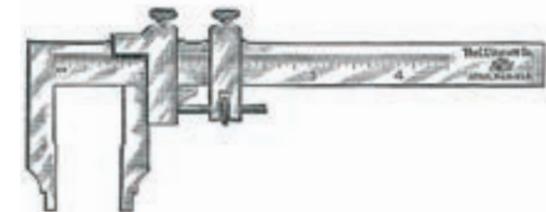


Figure 24 Simplified Caliper from L.S. Starrett Co. (United States) (Measuring range: 3, 4, 6 in, Graduation: 1/64 in on front, 1/100 on back) 1927

robust construction.

The same type of simplified caliper was also manufactured by Starrett, as shown in Figure 24. This caliper also has index lines, on the upper part of the slider, for reading outside and inside measurements directly. This caliper was

made around 1927. Its graduations are 1/64 inch on the front and 1/100 inch on the reverse side. The caliper came in three measuring ranges: 3, 4 and 6 inches. Figure 25 shows a simplified caliper made by Starrett in 1890. One model has a measuring range of 3 inches and is graduated in 1/64 and 1/100 inch, while the other has a measuring range of 6 inches, graduated in 1/64 inch. Both are on display in the Mitutoyo Museum²³⁾. The same type is found in the company's 1927 catalog. The jaw on the left side is moved as required and then fixed with the thumbscrew. The workpiece is then pinched between this jaw and the slider jaw to perform measurement while making fine feed adjustment as necessary. A similar type was also manufactured by Brown & Sharpe. Figure 26 shows a Starrett simplified caliper fitted with screw-clamping at the end of each jaw for attaching needle points to allow measurement of inside features on automobile tire molds. This multi-purpose caliper can also be used as a distance setting gage for spring-loaded internal and external



Figure 25 Sliding Caliper from L.S. Starrett Co. (United States) (Measuring range: 3~6 in, Graduation: 1/64, 1/100 in) 1890, 1927

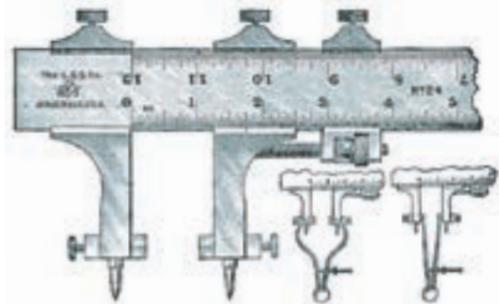


Figure 26 Simplified Multi-purpose Caliper for Measuring Tire Molds, etc. from L.S. Starrett Co. (United States) (Graduation: 1/32 in, Reverse graduations on upper side) 1927



Figure 27 Simplified Pocket Caliper from L.S. Starrett Co. (United States) (Measuring range: 4 in, Lower graduation: 1/32 in, Upper graduation for circumference: 1/64 in) 1960

calipers, as shown at lower right in the figure. It is also possible to attach a scribe as required. The beam is 1 1/4 inch wide and 0.85 inch thick. Five measuring ranges from 12 to 48 inches were available with graduations of 1/8, 1/16, 1/32 and 1/64 inch to allow a wide range of application.

Figure 27 shows a simplified pocket caliper made by Starrett in 1960, which is on display in the Mitutoyo Museum. It is capable of measuring the diameter of round parts to a precision of 1/32 inch and the circumference to a precision of 1/16 inch. The caliper is provided with a scale feed knob and a clamp mechanism. This caliper is included in Starrett's 100th anniversary catalog published in 1979³¹⁾, indicating that it had been used until recently. Similar types of simplified calipers for measuring diameter and circumference were manufactured by other companies. One such example is shown in Figure 28³³⁾. This caliper was made by The Lufkin Rule Co. in 1958. Since the company was established in 1869, it is assumed



Figure 28 Simplified Pocket Caliper from The Lufkin Rule Co. (United States) (Graduation: 1/32 in on lower side, 1/16 in on upper side for circumference) 1958



Figure 29 Wooden Sliding Caliper (Made in France. Upper graduation for diameter: 1 cm with maximum scale of 25 cm, Lower graduation for circumference: 2.5 cm with maximum scale of 80 cm) 1930

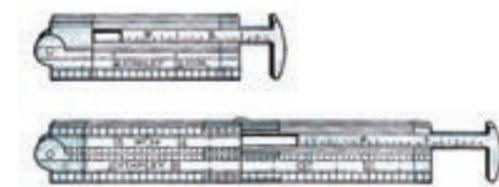


Figure 30 Folding Scale with Simplified Caliper from the Stanley Rule & Level Co. (United States) (Made of wood, ivory or horn. Graduation: 1/16 in, Folding scale graduation: 1/10, 1/8 in) 1920

that this caliper was manufactured from the second half of the 19th century to the 1960s. Dating from before the products mentioned above, simplified wooden calipers that could measure both round bar diameter and circumference were made in 1930 in France. One such caliper, shown in Figure 29, was intended for measuring trees. It is on display in the Mitutoyo Museum²³⁾. Wooden rules equipped with a simplified caliper on one end existed in the United States and Europe. Figure 30 shows a folding rule with a sliding caliper³⁴⁾. In addition to wood, this caliper was also made of animal horn and ivory, and it can be adapted to measure various lengths. Figure 31 shows a caliper made by the Dunlop Co. (United States) in 1920. Although the main beam is made of a thin material, the shape is similar to today's vernier calipers including the jaws for inside measurement, provided on the upper edge, which are of knife-edge form. This caliper also has a thumbwheel feed for the slider and a lever to lock the slider in position.



Figure 31 Simplified Caliper from Dunlop Co. (United States) (Measuring range: 5 in, Graduation: 1/16 and 1/32 in) 1920



Figure 32 Simplified Caliper from Chesterman Sheffield (UK) (Measuring range: 4 in, 120 mm, Graduation: 1/32 in, 0.5mm) 1900



Figure 33 Simplified Caliper from Parker (UK) (Measuring range: 5 in, 130 mm, Graduation: 1/32 in, 1 mm) 1920

Although we have mainly discussed the situation in the United States, a similar tendency is observed in Europe following the calipers made in Germany shown in Figures 15 and 16. Simplified calipers made in the UK and Germany are shown in Figures 32 to 36, which are on display in the Mitutoyo Museum. Most of them have both millimeter and inch graduations. Figures 16, 32 and 33 show a type where the slider with a jaw is moved by sliding, and readings are taken from the left-hand edge of the slider. The calipers in Figures 31 and 33 have beak-shaped jaws on the upper edge for inside measurement of workpiece features such as holes.

Figure 36 shows a common type of caliper that does not have vernier graduations²³⁾. It was manufactured more recently in 1950, which explains this structure. This shape may be retained if the caliper continues to be manufactured. Thus, simplified calipers had been used for more than 100 years before 1950.



Figure 34 Simplified Caliper from Rabone and Sons (UK) (Measuring range: 3 in, 80 mm, Graduation: 1/32 in, 1mm) 1920



Figure 35 Simplified Caliper from Cotterell GmbH (Germany) (Measuring range: 2 in, 50 mm, Graduation: 1/16 in, 1 mm) 1930



Figure 36 Simplified Caliper from Sheffield (UK) (Measuring range: 5 in, 13 cm, Graduation: 1/32 in, 0.5 mm) 1950

8.2 Sliding Calipers with a Diagonal Scale

A caliper diagonal scale is constructed by engraving the scale as a series of short, parallel lines of equal length across the beam at an angle to the direction of slider travel, with the end of one line being coincident with the start of the next, so that the reading edge of the slider always intersects one of the lines. Each of these lines is numbered according to its start distance from the origin, which will be an integer number of units, and the slider is graduated along its reading edge with a measurement being the sum of the nearest graduation to a line at its point of intersection and the number on the line. This arrangement has the effect of making the scale longer and so produces greater resolution. It is said that the diagonal scale was invented by a Hebrew (Israelite) named Levi ben Gershon in the 14th century⁹⁾. This means that the diagonal scale is two centuries older than the vernier scale. It was used in devices such as Jacob's staff (a type of distance measuring device), compasses and sextants. It is well known that when Tycho Brahe, the famous Danish astronomer, built an observatory on Heveen Island in 1576, he made a wall quadrant having a diagonal scale with a 2 meter radius⁵⁾ to improve observation accuracy. Given that diagonal scales were used in astronomy and survey equipment, it is not surprising that they were used on calipers to improve resolution. However, since there are few calipers that use a diagonal scale remaining in the world, they are considered to be a rare type of caliper. Figure 37 shows a caliper with a diagonal scale, which is included in the Ted Crum collection in France^{35) *4)}. This caliper is assumed to have been manufactured from 1850 to 1890. The units used are millimeter and pouce. Transition to the metric unit, which was forced through by law, had been under way in France since 1840. The

Note *4: When we made an inquiry to dozens of overseas researchers of metrology about the existence of calipers with a diagonal scale, Prof. Dr. Robert J. Hocken (University of North Carolina at Charlotte, USA) told us about the Ted Crum Collection in France.

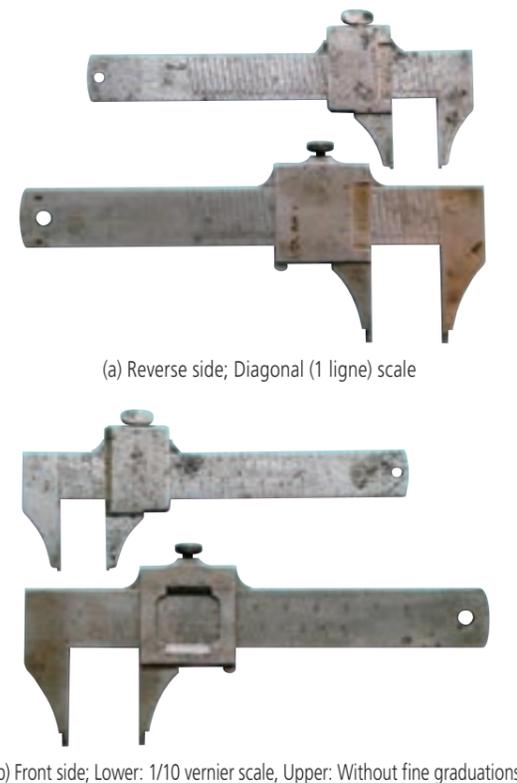


Figure 37 Caliper with Diagonal Scale (Ted Crum Collection, France) 1850~1890

above assumption about the period of manufacture is questionable because it was after this time. However, as the pouce unit was used in optics for lens features such as focal distance and thickness, this caliper might have been manufactured solely for the measurement of lenses. In addition, Napoleon III restored the empire, and may have relaxed the regulations on weights and measures around 1850, which seems to have led to the above assumption on the manufacturing period. The calipers shown in Figure 37 are very similar but with the important difference that one uses vernier scales. They both have diagonal scales graduated in the pouce unit on their reverse sides (a). The front sides (b) have a millimeter scale on the upper edge and a pouce scale on the lower edge, with one graduation only subdivided by a diagonal scale. The lower caliper shown in (a) and (b) is different in that both main scales on the front are read using a vernier auxiliary scale. The graduation of the pouce scale is 1/24

pouce (0.5 ligne), and its diagonal scale uses 1 ligne (1/12 pouce) graduations and has 12 vertical graduations on the reading edge of the slider, allowing one twelfth (2 points) of one graduation to be easily read.

The pouce scale of the lower caliper shown uses a vernier scale where 11 graduations over 0.5 ligne are divided into 12 graduations to provide a resolution of 1 point. It appears that this resolution was intended to match that of the diagonal scale. The millimeter vernier scale allows 1/10 of a main scale graduation to be read. This caliper, having both diagonal and vernier scales, may have been produced for a specific purpose other than for general use.

Considering the usage of the pouce unit and diagonal scales, it is reasonable to assume that the upper caliper in Figure 37 was manufactured before 1840. In Japan, Noriyuki Ohno-Yasaburo made a caliper with a diagonal scale (shown in Figure 76) in the 1840s. This caliper is described later.

8.3 Sliding Caliper with a Vernier Scale: the Vernier Caliper

As described in Chapter 6, the oldest sliding caliper with a vernier scale, or vernier caliper, in existence was made in France around 1840. Figures 38 to 42 show vernier calipers made in the 1890s, which are on display in the Mitutoyo Museum²³⁾. As with the oldest vernier caliper in existence, all of these vernier calipers were made in France, which indicates that France was advanced in terms of the development of calipers with a vernier scale.

The vernier caliper in Figure 38 has a shape that is similar to that of vernier calipers from Roc in France. Its measuring range is 150 mm and the vernier scale evenly divides 9 main scale 1 mm graduations into 10 vernier graduations to provide a resolution of 0.1 mm. It has an inside measurement face on the end of each jaw, allowing measurement of inside diameters greater than



Figure 38 Vernier Caliper (Made in France) (Measuring range: 150 mm, Minimum reading 0.1 mm by dividing 9 mm into 10), Around 1890



Figure 39 Vernier Caliper (Made in France) (Measuring range: 150 mm, Minimum reading 0.05 mm by dividing 19 mm into 20), Around 1890



Figure 40 Vernier Caliper (Made in France) (Measuring range: 100 mm, Minimum reading: 0.1 mm), Around 1890



Figure 41 Vernier Caliper with Round Jaws (Made in France) (Measuring range: 150 mm, Minimum reading: 0.1 mm), Around 1890

10 mm. The slider is provided with a clamp mechanism. The vernier caliper shown in Figure 39, which is similar to the one in Figure 38, has the same measuring range of 150 mm but its beam and jaws are somewhat larger. This caliper uses a vernier scale that divides 19 mm into 20 graduations to provide a resolution of 0.05 mm, which is finer than that of the vernier caliper shown in Figure 38 and matches that of today's vernier calipers.

This use of 0.05 mm resolution is considered to be quite early at a time when 0.1 mm was common. The smaller vernier caliper in Figure 40, made in France, has a measuring range of 100 mm and a resolution of 0.1 mm. The vernier caliper in Figure 41 has, in addition to ordinary outside measuring jaws, round jaws that allow measurement of thickness in hard-to-reach places. Its measuring range is 150 mm with a resolution of 0.1 mm. Also around 1900, Helios Co. in Germany was selling a vernier caliper similar to the one in Figure 38.

Figure 42 shows a vernier caliper made by Rawco Co. in the UK around 1900. Similar to today's vernier calipers, it has a depth bar and can serve multiple purposes including inside, outside, depth and step measurements. In addition, it has a slider fine-feed mechanism to precisely set the jaw for higher measurement accuracy. Its measuring ranges are 100 mm and 4 inches with a resolution of 0.1 mm. The inch vernier scale divides 7 main scale graduations over 1/16 inch into 8 vernier graduations to provide a resolution of 1/128 inch. This caliper is similar to the Columbus Caliper described below.



Figure 42 Multi-purpose Vernier Caliper from Rawco Co. (UK) (Provided with a depth bar, Maximum scale on lower edge: 120 mm, Upper scale: 5 in, Measuring range: 100 mm, 4 in, Minimum reading: 0.1 mm, 1/128 in (dividing 7 graduations over 1/16 inch into 8) 1900

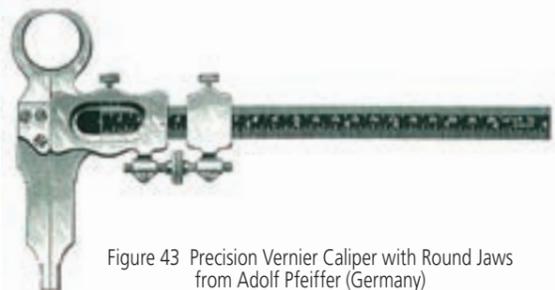


Figure 43 Precision Vernier Caliper with Round Jaws from Adolf Pfeiffer (Germany) (Maximum scale on upper edge: 200 mm, Lower scale: 8 Zoll, Measuring range: 150 mm, 6 Zoll, Minimum reading: 0.1 mm, 1/128 Zoll (dividing 7 graduations over 1/16 Zoll into 8) 1905

Figure 43 shows a precision vernier caliper³²⁾ made in 1905, which was marketed by Adolf Pfeiffer. Like the vernier caliper in Figure 41, it has round jaws for measuring the thickness of tubes and pipes while avoiding interference with their edges. In a variation of this caliper, this part consists of knife-edged jaws to allow measurement of thin workpieces. This caliper is equipped with a slider fine-feed mechanism that allows precise contact of the jaws with a workpiece. There is also a type of vernier caliper that has a fine-feed mechanism with graduations.

The vernier caliper in Figure 43 has millimeter graduations on the main scale with a vernier scale that divides 9 mm into 10 vernier graduations to provide a resolution of 0.1 mm. The lower edge has 1/16 Zoll graduations. The Zoll unit (1 Zoll = 26.1 mm) was used before the metric unit in Germany (Preussen). Seven graduations on the Zoll scale are divided into 8 increments to provide a resolution of 1/128 Zoll. In the period of unit transition, both the old and new units were used on these calipers for the convenience of users.



Figure 44 Vernier Caliper from Adolf Pfeiffer (Germany) (Measuring range: 150 mm, 6 Zoll, Minimum reading: 0.1 mm, 1/128 Zoll) 1905



Figure 45 Multi-purpose Vernier Caliper from Adolf Pfeiffer (Germany) (Provided with a depth bar, Named Columbus Caliper, Measuring range: 100 mm, 4 Zoll, Minimum reading: 0.1 mm, 1/128 Zoll) 1905

The vernier caliper in Figure 43 was manufactured in two versions: one with a vernier on the Zoll scale on the lower edge, and one without it. There was also a version with an inch scale in place of the Zoll scale. Today, the inch scale is called the Zoll scale in Germany. Three measuring ranges, 200, 250 and 300 mm, with different jaw lengths were available for this caliper.

Adolf Pfeiffer also provided the vernier caliper shown in Figure 44 for general use. This caliper came in two versions: one with pointed tips on the upper jaws for groove measurement and the other without. Just like the example in Figure 43 it carries both millimetre and Zoll scales with resolutions of 0.1 mm and 1/128 Zoll. Figure 45 shows a vernier caliper that Adolf Pfeiffer marketed with the brand name Columbus Caliper around 1905³²⁾. There are millimetre and Zoll (1/16 Zoll) or inch (1/16 in) scales. The outside and inside measuring jaws are separated. This vernier caliper also has a depth bar, making it a multipurpose caliper to allow measurement of depth, steps, etc. It belongs to the first instances of calipers with a depth bar, which may be the reason for its naming which seems to have been associated with Columbus' Egg (i.e. it's easy to say that a seemingly

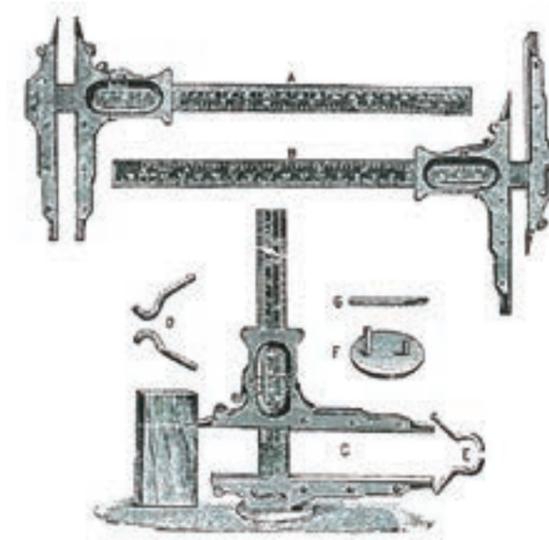


Figure 46 Example Use of Vernier Caliper for Work from Adolf Pfeiffer (Germany) 1905



Figure 47 Vernier Caliper Made in Russia (Measuring Range: 150 mm, Minimum reading: 0.05 mm (dividing 39 mm into 20) 1910



Figure 48 Vernier Caliper from Brown & Sharpe Mfg. Co. (Measuring Range: 5 in, Minimum reading: 0.001 in.) 1910

impossible action is trivial only after it is demonstrated how it can be done). Similar to the vernier caliper made by Rawco Co. in Figure 42, it has an advanced structure for the time, providing measurement functions comparable to those of today's vernier calipers. Rawco's vernier caliper in Figure 42 was made around 1900. Adolf Pfeiffer's vernier caliper in Figure 45 was in their 1905 catalog, indicating that Rawco's caliper with depth bar is older. However, the naming of their Columbus Caliper (Figure 45) by Adolf Pfeiffer might have been associated with a new function that no one had thought of before, so it is possible that Adolf Pfeiffer released a vernier caliper with a depth bar before Rawco, although there is no evidence that shows which was first.

Figure 48 shows a vernier caliper made by the Brown & Sharpe Mfg. Co. in 1910, which is on display in the Mitutoyo Museum. Its measuring range is 5 inches, and the vernier scale divides 24 graduations over 1/40 inch into 25 graduations to provide a resolution of 1/1000 inch, as described in Chapter 7. A vernier caliper with similar specifications is shown in Figure 49, which is included in the 1924 Brown & Sharpe catalog²⁴⁾. It has larger measuring ranges of 6, 12, 24 and 36 inches, and models with corresponding millimeter ranges, that is: 150, 300, 600 and 900 mm models were also available.

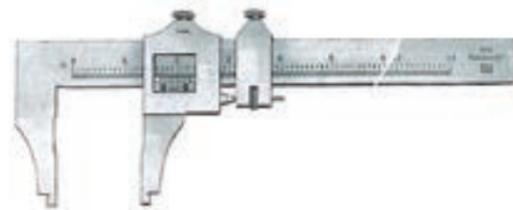


Figure 49 Vernier Caliper from Brown & Sharpe Mfg. Co. (United States) (Minimum reading: 0.001 in, Measuring range: 6, 12, 24, 36 in) 1935



Figure 50 Caliper from L.S. Starrett Co. (The main scale has 1/40 inch graduations and the jaw feeding screw has 25 graduations over its circumference to provide a minimum reading of 1/1000 inch.) Around 1900

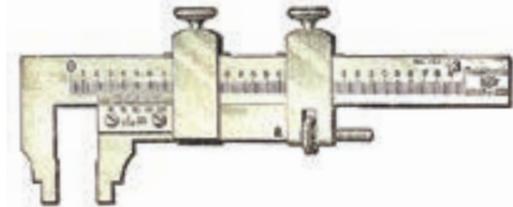


Figure 51 Pocket Vernier Caliper from L.S. Starrett Co. (Measuring range: 1-1/2 in) 1927

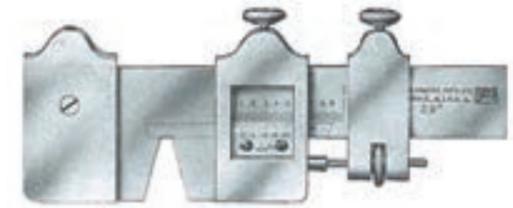


Figure 52 Threading Tool Measurement Vernier Caliper from L.S. Starrett Co. (United States) (For thread angles of 60°, 55° and 29°, The caliper is set to fit onto the thread to measure pitch, etc.) 1924

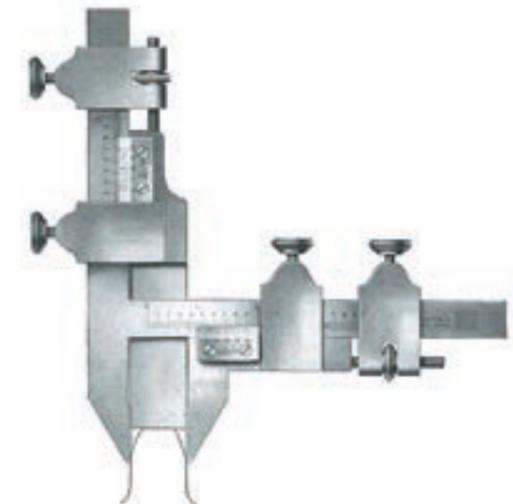


Figure 53 Tooth Thickness Vernier Caliper from Brown & Sharpe Mfg. Co. (United States) (Module: 1-1/4-12(Circular pitch: 20-2 in), Minimum reading: 1/1000 in) 1924

Figure 50 shows a very unusual caliper made by the L.S. Starrett Co. around 1900, which is on display in the Mitutoyo Museum²³. This was called the micrometer caliper^{29) 30)} and provides a resolution of 1/1000 inch without using a vernier scale. The main scale has 1/40-inch graduations and a measuring range of 6 inches. One graduation is equivalent to one revolution of a slider jaw adjustment nut provided below the main screw, and this is divided into 25 graduations around its circumference, in the same way as on a micrometer thimble. The use of such a micrometer screw enables a resolution of 1/40 x 1/25 inch, or 1/1000 inch, to be achieved. This is one of the rare types of caliper. In addition to the 6-inch measuring range model in Figure 50, this caliper was available in 4-inch and 12-inch models. It seems that this caliper had been used for more than 30 years.

The standard types of vernier calipers made and sold by the L.S. Starrett Co. around 1930 included the one shown in Figure 51, as well as calipers with the same structure as those from the Brown & Sharpe Mfg. Co. shown in Figure 48. The measuring ranges of Starrett's vernier calipers are 4, 6, 9, 12, 24, 36 and 48 inches, accommodating the need for measuring large workpieces. Their largest caliper for the metric system has a measuring range of 600 mm, equivalent to 24 inches. The resolution of these calipers is 1/1000 inch, provided by equally dividing 24 main scale graduations of 1/40 inch into 25, as in calipers from Brown & Sharpe. As if to challenge this large measuring range, Brown & Sharpe started to manufacture a caliper with a measuring range of 48 inches²⁶⁾ in 1935. On the other hand, Starrett manufactured not only calipers with a structure similar to the one shown in Figure 48, but also a type of vernier caliper with a graduated plate outside the slider clamp, as shown in Figure 51²⁹⁾, instead of inside a box type slider. Its measuring ranges are 1½ inches and 40 mm with resolutions of 1/1000 inch and 0.02 mm.

In addition to the above types, Brown & Sharpe also

set out to manufacture vernier calipers for checking the pitch and thread shape of threading tools (Figure 52) and calipers for measuring gear tooth thickness (Figure 53)²⁴⁾. The screw thread caliper shown in Figure 52, which is used by setting it to the required pitch width of a thread, allows inspection with a precision of 1/1000 inch. The gear-tooth caliper in Figure 53 is almost the same as today's calipers of the same type. Starrett also marketed a gear tooth caliper as well as a dovetail caliper, as shown in Figure 54²⁹⁾. The latter caliper uses rollers which make contact with the angled sides of a dovetail to determine its width. Production and use of calipers intended for specific workpieces started sometime after 1900. Figures 55 and 56 show calipers integrated with a micrometer head. These calipers are used to extend the measuring range of the micrometer head to 6 or 12 inches. They were probably easier to use than the model

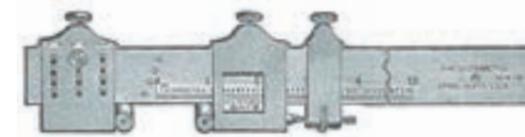


Figure 54 Dovetail Caliper from L.S. Starrett Co. (United States) (Dovetail angle: 45, 55, 60°, Measuring range: 0-12 in, Minimum reading: 1/1000 in) 1927



Figure 55 Caliper with Micrometer Head from Brown & Sharpe Mfg. Co. (United States) (Measuring range: 12 in max.) 1920

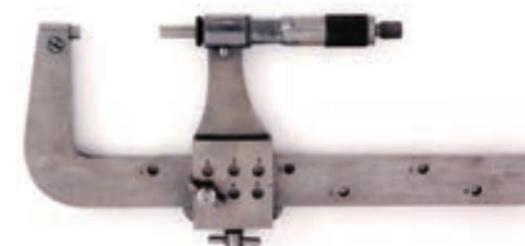


Figure 56 Caliper with Movable Micrometer Head from L.S. Starrett Co. (United States) (Measuring range: 6 in max.) 1920

shown in Figure 50. Thus, calipers with jaws designed for specific workpieces appeared around 1920, thus expanding the application of calipers.

Figure 57 shows an outside vernier caliper made in Holland around 1920, which is on display in the Mitutoyo Museum²³⁾. This caliper is provided with a thumb rest for moving the slider and a clamp. It has millimeter and 1/16 inch scales with resolutions of 0.1 mm and 1/128 inch. The measuring faces are screwed to the jaws and are replaceable.

Figures 58 and 59 show two vernier calipers manufactured by the Helios Co. in Germany between 1920 and 1940, which are on display in the Mitutoyo Museum²³⁾. Helios was established in 1910, and the first caliper was made at the time of the company's foundation; the second is an advanced model. These are similar in shape to the simplified calipers shown in



Figure 57 Outside Vernier Caliper (Holland) (Measuring range: 6 in, 120 mm, Minimum reading: 1/128 in, 0.1 mm) 1920



Figure 58 Vernier Caliper from Helios Co. (Germany) (Measuring range: 120 mm, 4 in, Minimum reading: 0.1 mm, 1/128 in.) 1920



Figure 59 Swivel Jaw Caliper from Helios Co. (Germany) (Measuring range: 5 in, Minimum reading: 1/128 in, 1/1000 in) 1940

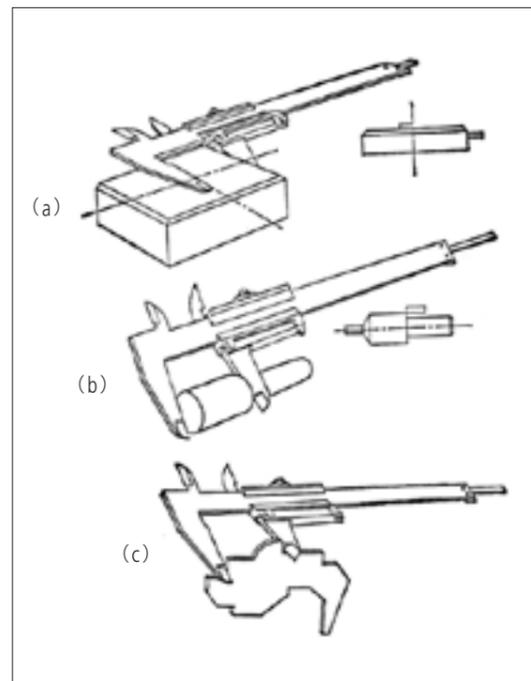


Figure 60 Using a swivel jaw caliper that allows the slider jaw to be swiveled

Figures 32 and 34, but provided with a vernier scale. The vernier caliper made in 1920 has measuring ranges of 120 mm and 4 inches with resolutions of 0.1 mm and 1/128 inch. Although it does not have a depth bar, it is provided with a lever-type slider clamp and thumb rest. The second caliper, made in 1940, is a swivel-jaw type where the slider jaw can be rotated around the measurement axis to allow complex features to be measured.

The swivel-jaw caliper is useful for measuring workpieces with steps or whose measurement axis is not straight, as shown in Figure 60. Thus, the shape or movement of jaws can expand the range of workpieces to be measured. This caliper, made in the United States, has an inch scale only with a resolution of 1/1000 inch (main scale graduation of 1/40 inch; 24 graduations divided into 25) and 1/128 inch (main scale graduation of 1/16 inch; 7 graduations divided into 8). While the Helios caliper made around 1920 has a lever-type clamp, the caliper made around 1940 employed a screw clamp, as

in today's models, and allows measurement of inside, outside, depth and other features.

Figure 61 shows a vernier caliper manufactured by Micro-Precision Vernier Co. in the UK, which dates from around 1929³⁷. It is similar in structure and resolution to the vernier caliper from Starrett shown in Figure 51. Figure 64 shows a vernier caliper manufactured by Mauser-Messzeug GmbH in Germany around 1940⁴⁰. Its shape is similar to the one shown in Figure 62³⁸, which seems to have been a trend since the 1920s. It has both millimeter and inch scales with a maximum scale value of

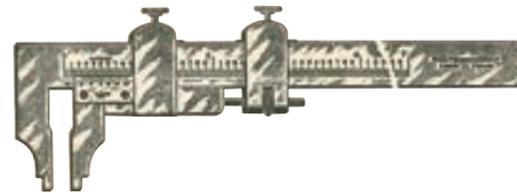


Figure 61 Vernier Caliper from Micro-Precision Vernier Co. (UK) (Measuring range: 5 in, Minimum reading: 1/1000 in) 1929



Figure 62 Pocket Vernier Caliper from Carl Mahr Esslingen a. N. (Germany) (Measuring range: 120 mm, 5 in, Minimum reading: 0.05 mm, 1/128 in) 1931

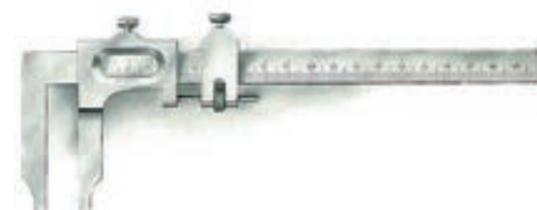


Figure 63 Vernier Caliper from Carl Mahr Esslingen a. N. (Germany) (Measuring range: 400, 500, 1,000 mm, 5 in, Minimum reading: 0.1 mm) 1931



Figure 64 Vernier Caliper from Mauser-Messzeug GmbH (Germany) 1940

160 mm. Its measuring range is 135 mm with resolutions of 0.1 mm or 0.05 mm and 1/128 inch. Calipers with millimeter and Zoll scales were also available in older models. As shown in Figures 62 and 64, it is assumed that vernier calipers of this shape were widely used in Germany in the early 20th century.

Figure 65 shows a gear tooth vernier caliper from Carl Mahr Esslingen a. N., which has equivalent functions to the Brown & Sharpe vernier caliper shown in Figure 53. Modules from 1 to 17 (circular pitch 25 to 1.5) and 5 to 35 (circular pitch 5 to 0.75) are supported.

Figure 66 shows a German vernier caliper with an inch scale only²³. It is stamped with the brand logo of "CES," but the manufacturer is not known. Its measuring range is 5 inches with a resolution of 1/1000 inch. A vernier scale for outside measurement is provided on the lower side of the slider and a scale for inside measurement is on the upper side. Knife-edge jaws for measuring grooved workpieces are provided alongside the usual flat jaws. It also has a slider fine feed mechanism to ensure accuracy. As described above, calipers in Europe and the United States practically assumed the modern form, both in function and shape, between 1900 and 1930.

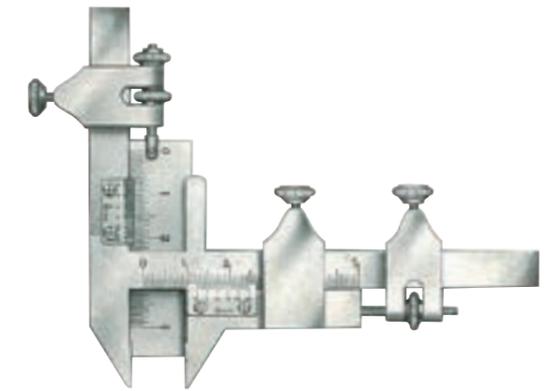


Figure 65 Gear Tooth Caliper from Carl Mahr Esslingen a. N. (Germany) (Module: 1-17 (Circular pitch: 25-1.5), Minimum reading: 0.02 mm, 1/1000 in) 1931



Figure 66 Vernier Caliper with Brand Logo of CES (Germany) (Measuring range: 5 in, Minimum reading: 1/1000 in) 1940

9. Depth and Height Gages

Other types of measuring instrument with a sliding element similar to that used on calipers include depth gages and height gages which measure a workpiece not by pinching it between jaws, but either by moving the main scale itself (depth gage) or by moving a slider along the main scale (height gage) to make contact with the workpiece with a single jaw (scriber). That height measurement was carried out with a simplified scabbard type sliding caliper using the graduations engraved on the jaw, main scale, and scabbard at around 1850 is described previously in Chapter 5. And, that some calipers as shown in Figure 46 were used as a kind of height gage is also described previously.

We can easily suppose that depths and heights could be measured by adapting those methods, which in turn developed to suggest the production of depth gages and height gages. However, there is no definite evidence about the time of their development and initial deployment. Presuming from the catalogs published by Adolf Pfeiffer around 1905 and by Brown & Sharpe Mfg. Co. around 1924, it seems that depth gages started to be manufactured and marketed around 1900, and height gages around 1919. This chapter describes the instruments that started to appear at these times.



Figure 67 Depth gage from Adolf Pfeiffer (Germany) (Measuring range: 100 to 300 mm) 1905



Figure 68 Depth gage from Adolf Pfeiffer (Germany) (Measuring range: 10 mm, Minimum reading: 0.1 mm) 1905



Figure 69 Depth gage from Brown & Sharpe (United States) (Measuring range: 4.5 in, Graduation: 1/32 in, 1/64 in) 1924



Figure 70 Depth gage from Brown & Sharpe (United States) (Measuring range: 3 1/2 in, 88 mm, Minimum reading: 1/64, 1/1000 in, 0.02 mm) 1924

There were several types of depth gages, as shown in Figure 67, having a measuring range from 100 mm to 300 mm; and the one shown in Figure 68 having a pin contact for measuring up to 10 mm in 0.1 mm increments. Much later (in 1924) however, Brown & Sharpe released the depth gages shown in Figures 69 and 70.

Figure 69 shows a simplified depth gage without a vernier scale but, thanks to the 6-inch long main scale, it is possible to measure up to about 3 1/2 inches. The model shown in Figure 70 was available in 6- or 12-inch versions.

There were two types of main scales having either or both metric and inch graduations to give resolutions of 0.02 mm or 1/1000 inch. Starrett manufactured similar depth gages with almost equivalent functions. Some depth gages, conveniently called "depth angle gages", which are nearly equivalent to that shown in Figure 68 could tilt the main scale to ± 60 degrees for easy measurement.

Figure 71 shows a depth gage older than that corresponding to the one shown in Figure 68. It had either a 4 inch or 6 inch main scale with an alternate clamping position as shown for measuring in restricted situations. Simplified-type depth gages provided with a stock 3- to 10-inches long were also manufactured.

Figure 72 shows an adjustable depth gage manufactured by Carl Zeiss (Germany). This was designed to measure internal features indirectly by indicating the tilt angle of

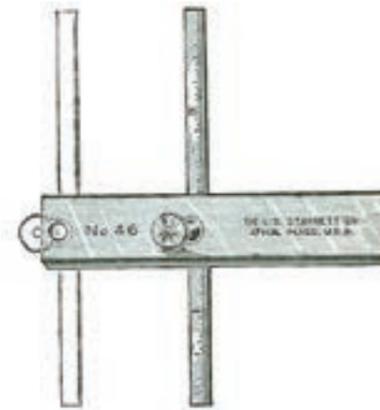


Figure 71 Depth gage from Starrett Co. (United States) (Graduation: 1/32, 1/64 in, the main scale length: 4, and 6 in) 1924

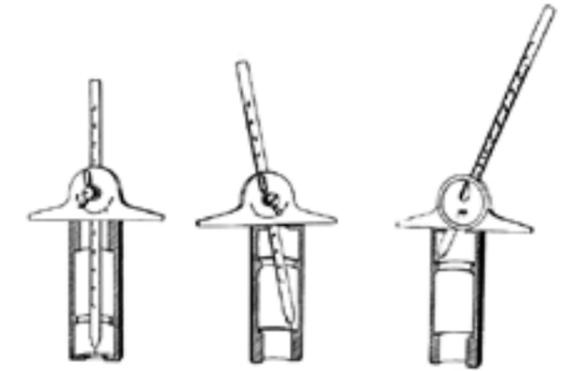


Figure 72 Carl Zeiss universal depth gage (Germany) (Main scale length: 6 in, 160 mm, Minimum reading: 1/64 in, 0.1 mm) 1928



Figure 73 Adolf Pfeiffer (Germany) Touskan 1905



Figure 74 Brown & Sharpe 18 in Height gage (United States) (Graduation 1 / 1000 in) 1924

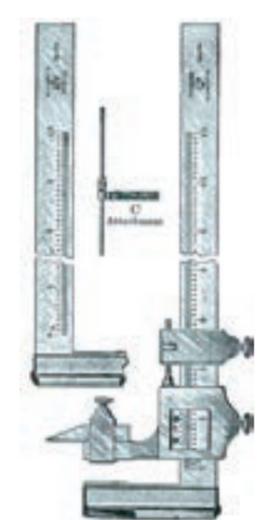


Figure 75 Depth gage from Starrett (United States) (Upper left of the figure is the back face. Accessories are show under "C", Minimum reading: 1/1000 in) 1924

the pointed rod as well as the depth-scale reading, and then multiplying this reading by the cosine of the tilt angle the required depth was calculated.⁴¹⁾⁴²⁾

Although it was known that Carl Zeiss was manufacturing depth micrometers, it is seldom related that the company also supplied depth gages. Most of these depth gages were made to measure in inches. The maximum scale value was 6 inches or 160 mm, and graduation 1/64 inch or 0.1 mm. Besides the depth gage shown in this figure, other forms of depth gage on which the main scale moves vertically or is made to use a definite angle were also marketed. One where the main scale moved vertically had 1/40 inch graduations, and the resolution was 1/1000 inch using a vernier scale. The status of height gages cannot be clearly seen in the catalog of Adolf Pfeiffer in 1905. However, as shown in Figure 73, an example of

attaching a scale onto a stand (Touskan) existed, and this idea together with the usage as seen in Figure 46 was developed further to form a height gage.

Figure 74 shows an 18 inch height gage from Brown & Sharpe and Figure 75 shows a 10 inch height gage from Starrett. Just as Brown & Sharpe was manufacturing a 10 inch height gage, the company manufactured height gages too with the same specifications as Starrett. The reverse face of the 10 inch height gage also has scale graduations which indicate heights from 1 to 11 inches. As shown in the reverse side view of Figure 75, the graduations extend from 1 inch above the base surface, i.e., the zero point is 1 inch above the datum surface. The depth rod accessory, as shown in Figure 75 (C), is intended to enable height measurement of a shrouded workpiece feature.

10. The Beginning of the Sliding Caliper in Japan

When was the sliding caliper first used in Japan? Unfortunately, there is no clear evidence on this point. Generally, the beginning should be dated at the time when this kind of instrument was first manufactured or used, but the commonly held view is that it was when they were imported for the first time during the Taisho period. However, judging from the fact that machine tools were imported and first used in Japan at the end of the Edo era, it is reasonable to suppose that the beginning was much earlier than the Meiji period. Examining the time when machine tools were first imported, together with the so-called machining method in Japan, we find the beginning was when the Edo Shogunate founded the Nagasaki Iron Mill as their modern shipbuilding and machine manufacturing factory under the guidance of the Netherlands in 1857 (Ansei 4).^{43) 44)} In 1853 (Kaei 6) the United States' Perry mission arrived at Uraga with his Black Ships to request the opening of Japan to trade. In the same year the 2nd World Expo was held in New York. At this event Japan requested the Netherlands, which had favorably advised on the opening of Japan a few years before (1844 and 1847), to send engineers to visit the Nagasaki Iron Mill and this took place in 1856 (Ansei 3). The first phase of construction of the Nagasaki Iron Mill was completed in 1861 (Bun kyu 1) and the whole plant became the Nagasaki Shipyard Corporation under the command of the then Ministry of Engineering in 1871 (Meiji 4). This plant was disposed of by the government and became Kanrinmaru and still is today, the Mitsubishi Heavy Industries, Ltd. Nagasaki Shipyard in 1888 (Meiji 20). On the other hand, the construction of the Uraga Shipyard was commenced under the guidance of France in 1857 (Ansei 4) and was completed as the first dry dock in Japan 1859 (Ansei 6). It is well known that this dock was used in fitting out the warship Kanrin Maru. In 1856 (Ansei 3) a dozen machine tools manufactured in Amsterdam were imported together with the Kanrin Maru, which was also constructed in the Netherlands.^{42)~44)}

At the steel Works, they carried out casting operations with furnaces and forging with steam hammers, cutting using mechanical machinery and boiler manufacture with iron and bronze plate. It is highly likely that manufacturing operations required the use of measuring instruments, in addition to machine tools, that had precise graduations, therefore scales and calipers to this standard were imported. It is recorded that a whole plant was imported from France to the Uraga Shipyard in 1861. It is thought that the French must have contributed to Japanese measuring device development. Some records on the machine tools remain in the Nagasaki Shipyard but, unfortunately, none about calipers or other measuring instruments.⁴⁵⁾ The Edo government sent 15 samurai and engineers to the Netherlands as students studying abroad in 1862 (Bunkyu 2). It is true that some individual feudal clans secretly sent students to study abroad as well. However, eventually the Government issued a notification in 1866 (Keio 2) to officially permit studying abroad. After that the isolation policy ended and an increased number of students went overseas, beginning with the Netherlands, to study in the United States, the United Kingdom, France, and Germany. By the way, it was the Saga clan that built the first reverberatory furnace that might be considered the origin of modern technology in Japan. The clan built this furnace in 1850 (Kaei 3) using a technical document obtained from the Netherlands. This was followed by the Government constructing the same kind of furnace at Nirayama, Izu, which was followed by the Satsuma clan in the same year, then by the Mito clan (Nakaminato) for casting iron and bronze cannon. Since the Netherlands had introduced the metric system extensively in 1821, the technical details would have been in metric units. France also moved to the use of the metric system in 1840.^{46) 47)} As a consequence, the reverberatory furnace came to be built using metric units. In other words, it is quite natural that the meter became the preferred unit of length in Japan because machine tools from the Netherlands and France were imported and the engineers

of those countries also came to teach people machining technology.^{43) 44)} Considering these facts, we cannot think it true that sliding calipers developed in the United States came into Japan via Europe at the end of Edo era, since the advent of calipers in the United States was in 1851 and the number manufactured was very limited. Although it is reasonable to suppose that calipers were imported both from France and the Netherlands this is not clear. Completely separate from the above considerations, Shungaku Matsudaira, who was appointed general manager for political affairs, which corresponded to Tairo (General Manager) of the Government in the end of the Edo era, possessed a sliding caliper called "Tamajaku" (i.e. "Gem Scale") created by Norichika Ohno-Yasaburo-

who was employed by Matsudaira's clan in Fukui. This caliper was donated to the Fukui Municipal Hometown Historical Museum and remains there today, and is shown in Figure 76. The maker's name, Norichika Ohno-Yasaburo, is stamped on the end of the beam (see Figure 76 (d)). Toshio Kajiwara, who is an industrial archaeologist and collector of scale and length measuring instruments, says that this stamp was undoubtedly made by Norichika Ohno himself and the year of manufacture of this caliper was sometime between 1855 and 1861 (Ansei 2 - Bunkyu 1), which is before the time when he went abroad to study in the Netherlands.⁴⁸⁾ In conclusion, this is the oldest sliding scale with vernier graduations, or vernier caliper, in Japan. It was manufactured independently from the establishment of

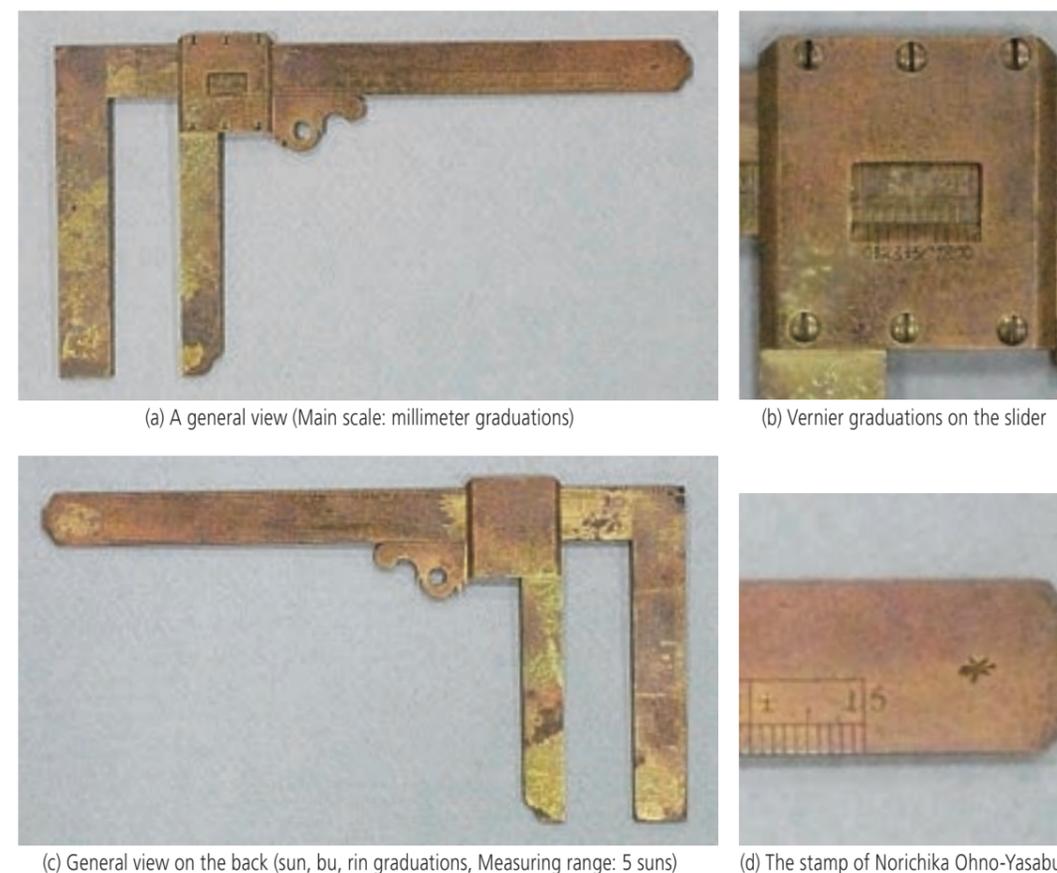
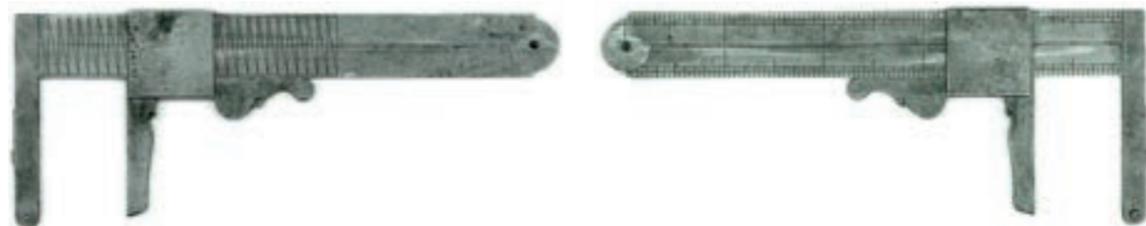


Figure 76 Sliding caliper which Shungaku Matsudaira possessed. This was called "Gem Scale" manufactured by Ono Yasaburo Norichika. The maximum graduation value is 150 mm. (Measuring range; 130 mm. Back surface main graduations: 5 rins over the entire measuring range of 5 suns 5 bus) Manufactured around 1855 to 62 (Ansei period) and possessed by the Fukui Municipal Hometown Historical Museum.

the above-mentioned Iron Mill and Shipyard. Considering that the year when Brown & Sharpe in the United States first manufactured a caliper was 1851³⁾, that the manufacture by Norichika Ohno is supposed to be around 1858, and that the sliding caliper with diagonal graduations was manufactured by the father of Norichika Ohno, mentioned later, around 1843 (Tempo 14), we may say that sliding calipers were manufactured in Japan not much later than in other industrialised countries. Norichika Ohno was born as the third generation of a family that was good at making astronomical instruments, where his grandfather Norisada Ohno-Yagoro and his father Noriyuki Ohno-Yasaburo were the Official Clock Engineers of the Edo Shugonate Clock Bureau for two consecutive generations. His grandfather Norisada Ohno-Yagoro and father Noriyuki Ohno-Yasaburo also fabricated some of the survey measuring instruments that were used by Tadataka Inoh. In 1855 (Ansei 2), Norichika Ohno was invited by Shungaku Matsudaira of the Echizen Clan to serve as an instructor, teaching instrument manufacturing techniques to the feudal retainers or warriors. The main scale graduations on the front face of the sliding caliper shown in Figure 76 are in mm, with a maximum value of 150 mm. Measuring range is 130 mm, and the vernier scale engraved on the edge of the cutout in the slider gives a resolution of 0.1 mm as the result of dividing one interval of 9 mm by ten. The zero position of the vernier graduations is placed at a position approximately



(a) Surface diagonal graduations with a minimum reading of 1 rin

(b) Reverse-side sun graduations. Minimum reading is 5 rins, and maximum graduation value is 5 suns

Figure 77 Sliding caliper with a diagonal scale made by Noriyuki Ohno-Yasaburo... If you remove the slider by rotating the lower part of the main scale and use the graduations on the reverse face, you can use it as a 1-shaku rule. Dates from the first half of the 1840s (Tempo 11).

10 mm from the slider measuring surface. The back face has shaku and bu graduations. Graduations on the lower row are given in 2 rin increments up to 4 suns, and further given in 1 rin increments for the interval of 1 sun up to the end corresponding to 5 suns. Graduations on the upper row are given in .5 rin increments from the corner of the fixed jaw up to 5 suns 5 bus. Absence of vernier graduations means that this gage can be used as a rule. The material is brass, the width of the main scale is 15 mm (5 suns), thickness is 2.2 mm, width of the main scale-side jaws is approx. 15 mm, width of the slider-side jaws is 11.5 mm and the length of the jaw is 80 mm, thus the total width of this gage is about 100 mm including the slider, or 97 mm excluding the full width of the slider. Noriyuki Ohno, the father of Norichika Ohno, also manufactured a sliding caliper with a diagonal scale, that is to say "Nogisu" calipers as shown in Figure 77, and this caliper was made of brass. The engraved diagonal graduations of the scale provide a resolution of 1 bu, and the total measuring range is 3 suns. In order to ease reading of measurement at the point where a diagonal graduation line intersects the slider's edge, these subdividing graduations are engraved along the edge of the slider, which therefore make it possible to read in rin units. The back face is graduated up to 5 suns with a resolution of 5 rins. If it is extended by turning the graduation part at the lower part of the main scale after removing the slider, it can be used as a 1-shaku graduated scale, or rule. This sliding scale is thought to have been

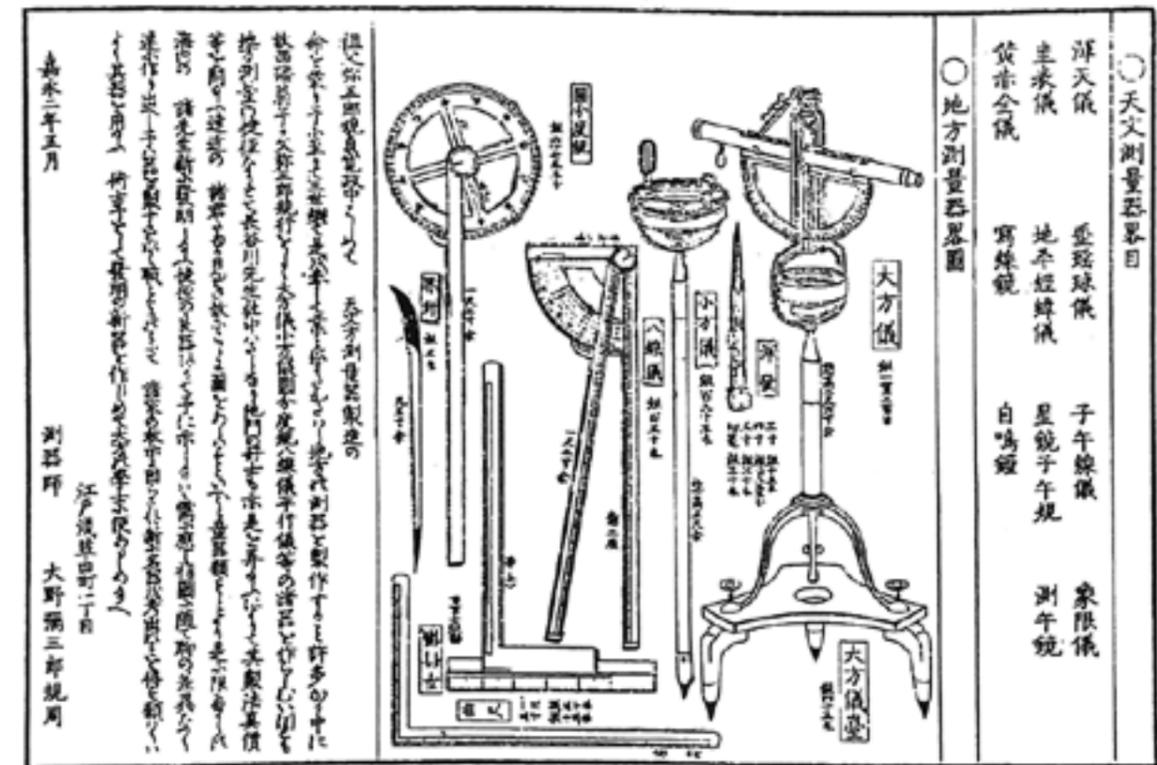


Figure 78 Hikihuda (flyer) issued by Norichika Yasaburo-Ohno in 1849 (Kaei 2)

manufactured during the first half of the 1840s. The abovementioned Toshio Kajiwara assumes its year of manufacture judging from the life of Noriyuki Ohno, and preserves the instrument carefully. Although the caliper with a diagonal scale is kept in the Ted Crum Collection in France is mentioned in Figure 37 of Section 8.2, the current existence of others is unknown. This particular example of Noriyuki Ohno's sliding caliper is remarkable since several units, including imperfect ones, are located in several museums in Japan. Although the scale division system is different from the sliding caliper manufactured by Norichika Ohno mentioned above, it can be said to be the oldest sliding caliper in Japan since it can read down to 1/10 of a graduation. Judging from the fact that the form of this sliding caliper very closely resembles the form shown in Figure 76, it seems that Norichika Ohno manufactured this by imitating his father Noriyuki Ohno's sliding caliper. Furthermore,

I wonder about the origin of this form. Was it from an original idea of Noriyuki Ohno or from a source unknown? This is unknown at present. However, judging from the fact that a tapered jaw was used for a Mon jaku (Mon rule) for Japanese tabi, which was made based on Kanei Tsuho (1624 to 1643), although the graduations are rough he might well have invented it. Figure 78 shows a Hikihuda (a "flyer" document) which Norichika Ohno issued in 1849 (Kaei 2). According to this flyer, it turns out that astronomical survey instruments, ground compasses, etc., were manufactured, and vernier scales can be seen on the Hassen-ghi (Octant), En bundokhi (Semicircular protractor) and Heikou-ghi (horizontal situation indicator) described therein. The sales message explains that Hiroshi Hasegawa taught the theory of the vernier scale and the diagonal scale, etc. to the father of Noriyuki Ohno. The theory of the vernier scale was described as "it is already introduced to Nagasaki" in "Shogenghiyoho"

(Quadrant Usage) translated by Yoshinaga Motoki and published in 1783 (Tenmei 3). In addition, so as to endorse the contents of the book, examples of such items as a telescope, surveying instrument, astronomical observation equipment, etc., were presented to the Government and vernier scales were also added for each main scale. For example, it is said that an octant provided with a vernier scale was presented by the Netherlands to the Government in 1791 (Kansei 3) but was long neglected because no one knew how to use it. Probably, father Ohno and his son would have seen that equipment. The oldest vernier scale in Japan may have been made by people trained by Hazama Shigetomi in Osaka in 1793 (Kansei 5). The quadrant star observation mirror they made is currently preserved in the Kobe City Museum. After that, Michikata Eizaemon-Kume from Sanuki manufactured a Chiheigi (horizontal theodolite) with a vernier scale in 1806 (Bunka 3), and he also

produced octants and quadrants equipped with vernier scales. The house of Otani in Osaka, which is described below, was founded in 1838 (Tenpo 9) and manufactured rulers. There seems to be a document stating that they used the diagonal scale that was the predecessor of the vernier scale⁵⁰⁾.

Accepting the order of Hiroshi Hasegawa, Noriyuki Ohno manufactured a horizontal situation indicator and a protractor with a vernier scale. Moreover, some literature states that Tadataka Inoh used diagonal scales in his land survey. Therefore, this is no wonder if Norichika Ohno manufactured these instruments.

It is no wonder, too, if millimeter graduations were used for calipers since the drawings of guns, cannons or blast furnace, etc., coming from the Netherlands were dimensioned in metric units even in those days. Moreover, a Hikihuda (flyer) for survey instruments was issued from the Tamaya Kichijiro Store, located at Edo

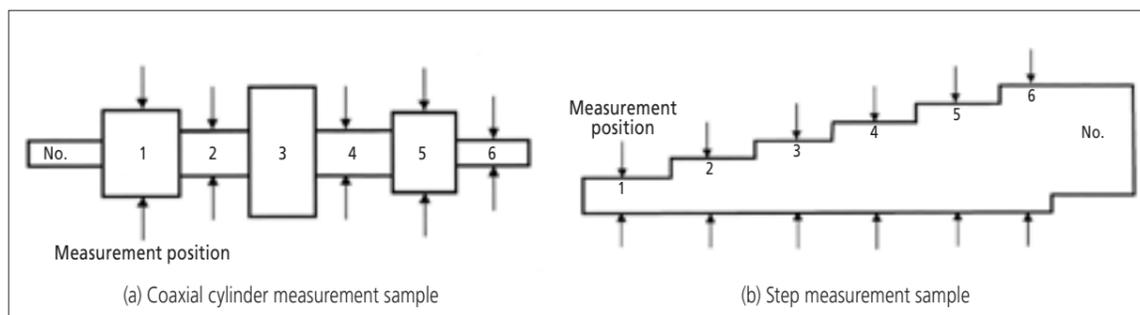


Figure 79 Forms of test workpieces and measurement positions

Table 1 Cylinder workpiece measurement results (Temperature at the time of measurement: 25.5-26.7 °C) Unit: mm

| Measurement position | Position 1 | Position 2 | Position 3 | Position 4 | Position 5 | Position 6 |
|-------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Calibrated value | 15.97 | 13.92 | 24.94 | 13.76 | 18.02 | 11.96 |
| Measured value | 15.9~16.0 | 13.9 | 24.9~25.0 | 13.7~13.8 | 18.0~18.1 | 11.9~12.0 |
| Mean of measured values | 15.9 ₆ | 13.9 ₀ | 24.9 ₈ | 13.7 ₈ | 18.0 ₂ | 11.9 ₈ |

Table 2 Measurement results from stepped workpiece sample, and gage block (G. B.) (temperature at measurement: 25.5-26.7 °C) Unit: mm

| Measurement position | Position 1 | Position 2 | Position 3 | Position 4 | Position 5 | Position 6 | G.B. 1 | G.B. 2 | G.B. 3 |
|-------------------------|------------------|------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|--------------------|
| Calibrated value | 6.34 | 9.59 | 14.54 | 18.22 | 22.10 | 24.16 | 30.000 | 75.000 | 105.000 |
| Measured value | 6.3~4 | 9.6 | 14.5~6 | 18.2~3 | 22.1 | 24.2 | 30.0 | 74.9~75.0 | 104.9 |
| Mean of measured values | 6.3 ₈ | 9.6 ₀ | 14.5 ₄ | 18.2 ₄ | 22.1 ₀ | 24.2 ₀ | 30.0 ₀ | 74.9 ₄ | 104.9 ₀ |

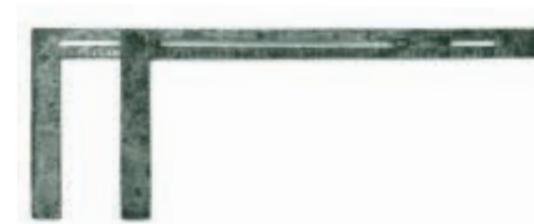


Figure 80 Brass simplified calipers, late Edo era



Figure 81 Shiga, Nagahama, Kyubei Kunitomo's hereditary brass sliding calipers



Figure 82 Brass sliding calipers manufactured by Tohachi Kunitomo, Nagahama Shiga (Toyota Commemorative Museum of Industry and Technology Toyota Collection) 1855

Ryogoku Yokoyama-cho 3-chome (near present Ryogoku Bridge Nishidsume) in 1852 (Kaei 5), that gave the name of instrument engineer Norichika Ohno-Yasaburo as the manufacturer and illustrated astronomical survey instruments and local land survey instruments. These instruments were used to survey local land for the purposes of agricultural administration⁵¹⁾. Graduations on the Norichika Ohno's caliper can be seen to have good quality as a whole but the vernier graduations for 2, 7, and 8 are slightly thicker than the rest. With this caliper the author measured the calibrated dimensions of test workpieces consisting of coaxial cylinders of various diameters, stepped blocks and standard gage blocks, and obtained the results as shown in Tables 1 and 2.⁵²⁾ These results were obtained from 5 sequential measurements and the range and mean of the measured values is shown in the tables. The calibration values were obtained very accurately by the Mitutoyo Measurement Laboratory and rounded to match the measurements actually obtained from the subject caliper of this test. The mean value of each measurement was compared with the calibrated value to test the accuracy of the caliper. Variation in measurement when taken at the root or tip of the jaw was checked but was found to be less than 0.1 mm.

Since the room temperature at the time of measurement was between 25.5 and 26.7°C the influence of the difference in the thermal expansion coefficients of steel and brass can be neglected because it turns out to be 0.001 mm, supposing the mean of the measured lengths be 25 mm. The extended measurement uncertainty of measurement of this caliper was found to be 0.08 mm, and so its accuracy can be said to be comparable to present-day vernier calipers. It was noticed that the graduations closer to 70 mm are slightly extended, which will tend to give a smaller measurement value here. In any case, the measurement performance is good. Around this time some calipers without a vernier scale were made that used a slot to guide the slider, as the simplified caliper in Figure 80 shows. This caliper is in Toshio Kajiwara's collection, together with the caliper shown in Figure 77. The name of the maker and year of manufacture are unknown. The main scale resolution is 2 rins, and the maximum measuring value 4 suns. Graduations on the slider side give a resolution of 1 bu and measure up to 5 suns. This instrument can also be used as a rule. The back face graduations are provided up to 5 suns 5 bus, and the resolution is 2 rins. The graduations seem somewhat uneven. The slot-specification calipers are based on the oldest Chinese



Figure 83 Wooden simplified calipers (Gem Scale) Meiji period



Figure 84 Wooden simplified calipers (Gem Scale) Meiji period



Figure 85 Wooden simplified calipers (Gem Scale) Meiji period

sliding caliper, as shown in Figure 5. Considering that the variation of scale size occurred about 150 years later than in China^{13) 53) 54)} and that money was being transferred etc., this structure leads us to suppose that sliding calipers appeared in Japan considerably later.

Together with simplified calipers of the same form, the simplified caliper shown in Figure 81 belonged to Kyubei Kunitomo, a gunsmith who manufactured and supplied a large number of matchlocks to Nobunaga Oda, of Ohmi, the present day Nagahama city, Shiga prefecture.⁵⁵⁾

Although Kunitomo worked with Toyotomi and Tokugawa from the Age of the Civil Wars, the time at which such simplified calipers were first used is unknown. Moreover, Figure 82 shows a brass sliding calipers made by Tohachi Kunitomo. This simplified caliper is stored in the Toyota Commemorial Museum Industry and Technology Toyota Collections⁵⁶⁾. Since this simplified caliper is a measuring instrument said to be supplied during the Ansei period when Sotomori Hayashi, one of the vassals of the Hojos of Kawachi country of Sayama clan who was serving served as chief retainer, was working in this isolated clan in 1855



Figure 86 Metal small-size simplified calipers (Gem Scale) Meiji period



Figure 87 Brass long-jaw simplified calipers, Meiji period

(Ansei 2), it is thought it dates from the same period as those manufactured by Norichika Ohno.

In contrast to these calipers manufactured independently by such as Noriyuki Ohno, Norichika Ohno and Kunitomo the gunsmith, wooden simplified calipers were made by imitating the simplified calipers considered to have arrived in Nagasaki or Uraga at the end of the Edo era or early stages of the Meiji period. Figures 83 through 87 show some of the simplified calipers possessed by the Hakari No Yakata in Mie Prefecture, which also possesses the old sliding calipers transferred from France as described previously. These calipers are made of wood and brass, and most of them are sliding calipers without vernier scales, therefore are thought to have been manufactured in the Meiji period. The wooden calipers shown in Figures 83 to 85 can also be seen to resemble the simplified calipers of the American Brown & Sharpe and Starrett models shown in Figures 18 and 22. Figure 86 shows an instrument manufactured to measure specific items such as pearls and jewels, etc. We can say that there was a time when simplified calipers (sliding calipers without

vernier scales) and calipers with vernier scales coexisted in Japan just as in Europe.

The sliding caliper said to be the oldest in Japan in the record of sliding calipers for industrial use is the one that can be found among the instruments which Professor Francis (W.C.A. Francis, Pratt & Whitney engineer) carried with him from the United States when he was invited to the Tokyo High Technical School (presently the Tokyo Institute of Technology) in August, 1903 (Meiji 36).

Accordingly, it is a fact that sliding calipers were used from this time in the school. If they were introduced into Japan for the first time then, the instrument's name might have been something corrupted from "vernier caliper" to the local jargon, not "nogisu" which was actually corrupted from German or Dutch. There is a record that Mr. Ohtani of Osaka Minami-ward Junkei-cho exhibited a sliding caliper made of steel and brass into the 5th Domestic Industrial Exposition held in Osaka in 1903 (Meiji 36).³⁾

It was 60 years after the calipers made in France in 1840, 52 years after the American Brown made sliding calipers, and 45 years after Norichika Ohno manufactured a similar instrument. Probably, Ohtani was a manufacturer of measuring tools, since he exhibited at the same opportunity inside and outside calipers, compass, square, straight edge in addition to the "nogisu" (caliper) mentioned above. Or we can say that the name of "nogisu" had been already spread considerably at that time. It is supposed that it was an imitation of the one imported before 1903, since it was probably not manufactured according to the traditional method with which Norichika Ohno made his calipers, or otherwise originally manufactured separately. Or it is said that it might be based on the one which was carried by an employed German engineer in the early Meiji period. When Ikegai Iron Factory (presently the IKEGAI Corporation) manufactured to the order of Tokyo High Technical School two Bradford-type 14-inch lathes in 1905 (Meiji 38), the machine manufacturers at that time measured dimensions using passes (calipers) and rules, not using either "nogisu" or micrometers. However, since the

measuring tools carried with Professor Francis were used for the acceptance test of these two lathes, they could hardly pass the test, were troubled with repeated reworks, and the quality of measuring tools was far from reaching the required level of inspection. That is, probably, it should be concluded that sliding caliper were hardly used in our country till those days except at specific places. Even so, I wonder whether some calipers were used in the Kansai area since one manufacturer in Osaka had exhibited them at the exposition. It is hard to understand this situation because even the Ikegai Iron Factory, the leading machine tool manufacturer, did not use them. By the way, the "Practical Manufacturing Techniques" written in 1907 (Meiji 40) by Tatsue Ikeda, the author and one of the representatives of Ikegami Manufacturing, as the textbook for apprentice workers of the Kure Naval Arsenal Machine Manufacturing Division Machine Factory clearly describes the "Vernier Caliper" (commonly called "nogisu"). In the figure the form of the Brown & Sharpe-made calipers is shown.

11. Industrial Production Startup and Proliferation of Vernier Calipers in Japan

It is said the fully fledged use of vernier calipers in Japan began with an ordinary type of vernier caliper imported from the UK in the early Taisho era.³⁾⁵⁷⁾, and hence known as the British-type vernier caliper. Figure 88 shows an ordinary vernier caliper made in Japan in imitation of the British type. Although the manufacturer is undefined, this product is engraved with "Tokyo ㊦-mark" and was manufactured about 1935 and is now displayed at the Mitutoyo Museum.²³⁾ This vernier caliper has inch graduations on the front face, providing subdivisions of 1/8 inch, a resolution of 1/64 inch and a measuring range of 1 foot. It also has millimeter and sun/bu graduations on the rear face providing subdivisions of 1 mm and 1 bu, a resolution of 0.05 mm and 1 rin and a measuring range of 300 mm and 1 shaku. In 1944, Sugiura Shoten manufactured almost the same caliper as above, having inch graduations with a resolution of 1/128 inch and a measuring range of 12 inch. As shown in Figure 89, a specially shaped vernier caliper was manufactured with a round bar formed into a plate-like surface as the main scale. Although this type of main scale is subject to warping, this scale features less deformation basically due to being a round bar. It has a measuring range of 150 mm, providing a resolution of 0.02 mm with 49 mm evenly divided into 50. This caliper is structured so that the fixed jaw can change position up to 5 mm and both jaws are replaceable for users' convenience. The Mitutoyo Museum also displays another ordinary type

vernier caliper of the same age as in Figure 90, which has a measuring range of 1 m with "NIIGATA and サ-mark under a three-triangular mountain symbol" engraved on it.²³⁾ This caliper can measure up to 40 inches with 1/16 inch graduations and a resolution of 1/128 inch on the lower edge of the front face, and graduations of 1/20 inch with a resolution of 1/200 inch on the upper edge. It also has graduations up to 1000 mm and 3 sun 3 bu on the rear face, providing a resolution of 0.05 mm and 5 moh, respectively. The graduations of this caliper are well-engraved up to 1 m considering its age. Most ordinary calipers at that time had inch graduations on the upper edge and millimeter graduations on the lower edge. Quite a lot of calipers have inch graduations on the front face, providing vernier scales for a resolution of 1/100 in on the upper edge and 1/128 in on the lower edge. They also have millimeter and sun/bu graduations on the upper and lower edges of the rear face. In those days most vernier calipers with a measuring range up to 300 mm applied so-called "3-country 4-step scales", which had millimeter and inch graduations on the front face and inch and sun/bu graduations on the rear face. Some other vernier calipers with a longer measuring range than 300 mm applied so-called "2-country 4-step scales", which had inch and millimeter graduations on both front and rear faces with a resolution of 1/128 in and 0.05 mm, respectively. These types of vernier calipers had been more commonly used until the end of WW II.

A long-jaw ordinary-type vernier caliper similar to an ordinary type replaced with a longer jaw as shown in Figure 91⁵⁷⁾ was available. This type was generally applied to vernier calipers with a measuring range of up to 300 mm to be able to measure the diameter of steel pipe up to 160 mm. In 1944 during WWII, a round-jaw ordinary-type vernier caliper (as shown in Figure 92) was manufactured in imitation of those in Figures 41 and 43. A vernier caliper with round and angular jaws as shown in Figure 93 was also made for measuring the thickness of steel pipe and flanged workpieces. Various jaws shapes seem to have been applied to ordinary-type vernier calipers because their structure could be easily manufactured. The proliferation of American vernier calipers in Japan was far later than that of British ones. In the early Showa era, vernier calipers made by Brown & Sharpe and Starrett to a similar pattern were imported and both makes were commonly used. As shown in Figure 49, this type of caliper was equipped with a box-type slider and incorporated anvils for inside measurement on each jaw tip. The vernier caliper in Figure 94, which is displayed at the Mitutoyo Museum, was manufactured in 1944 in imitation of the Brown & Sharpe caliper. German vernier calipers made by Mauser-Messzeug GmbH were imported

in the 4th to 5th year of the Showa era, and calipers of this type seem to have been extremely widespread. This type seems to be the European style, particularly the German pattern as seen in calipers from the UK firm of Rawco (Figure 42) and the German firms of Adolf Pfeiffer (Figure 45), Carl Mahr (Figure 62) and Mauser (Figure 64), etc. Consequently, this type was codified in the JIS standards structure that was established in postwar days. Many domestic vernier calipers started out in imitation of the German style, specifically the Mauser type. In order to discriminate between these American and German products, there was a period in Japan during which a vernier caliper of the American product style (JIS CB Type) was called "Caliper" and that of the German product style (JIS M Type) was called "Nogisu". In any case, until about 1930 (Showa 5) only foreign products had satisfied market demand although domestic products made by Otani existed in the Meiji era as mentioned above. The company that entered into industrial production of calipers was Tajima Seisakusho⁵⁸⁾⁻⁶⁰⁾ that first launched vernier calipers in 1930 (Showa 5). At that time Tajima Seisakusho was renamed Matsuo Seisakusho and played an active role as a maker of length standards and also graduated calipers using a linear



Figure 88 Tokyo ㊦-marked (Japanese) Ordinary-type Vernier Caliper, 1935



Figure 89 Ninken-made (Japanese) Round Bar-type Vernier Caliper, 1940



Figure 90 NIIGATA ヤマサ-marked 1 m Ordinary-type Vernier Caliper, 1935

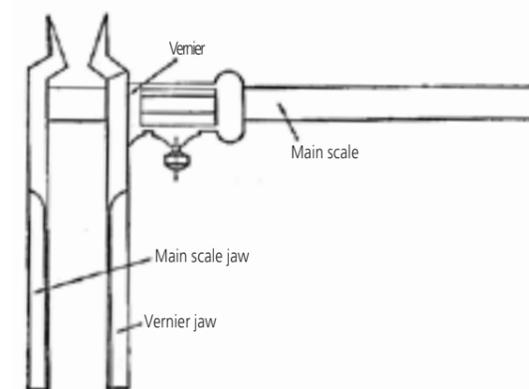


Figure 91 Long-jaw Ordinary-type Vernier Caliper, Japan, Early in Showa



Figure 92 Fujiyama Mfg. Co. Round-jaw Ordinary-type Vernier Caliper, 1944

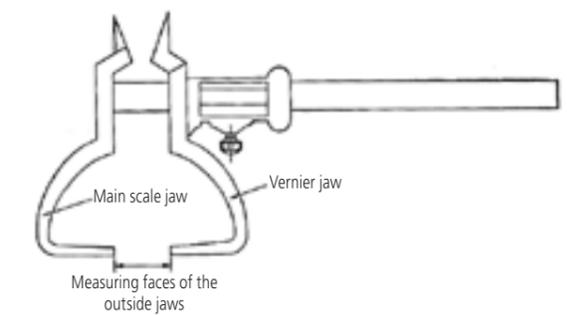


Figure 93 Round & Angular-jaw Ordinary-type Vernier Caliper (for Thickness), Japan, Early in Showa



Figure 94 Okada Yasukichi Shoten (Japan) Brown & Sharpe-type Vernier Caliper, 1944

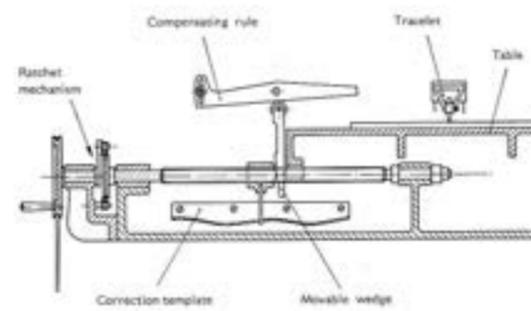
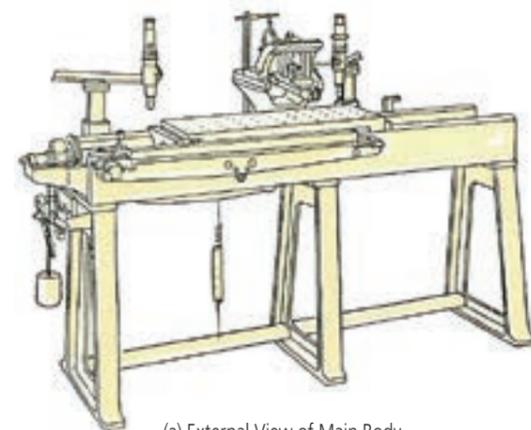
graduating engine⁶¹⁾ from the Swiss firm SIP (Societe Genevoise d'Instruments de Physique) as shown in Figure 95(a). This machine was equipped with a template mechanism to correct for the random lead error in the machine's leadscrew, as shown in Figure 95(b), thereby achieving very high feed accuracy of the table on which the scale to be graduated was mounted⁶²⁾.

The second company that manufactured vernier calipers was the current Nakamura Mfg. Co.⁵⁸⁾ in 1938 (Showa 13). Iwao Nakamura started business on someone's advice with an eye to commercialization of vernier calipers while establishing the KANON caliper laboratory, where he had made a Mauser-type vernier caliper along with researching optical graduating technology. At first, the production capacity of vernier calipers was about 100 pieces per month, selling under the name of Kanon Caliper. Kanon means standard/reference in Latin. The company name was changed to Nakamura Mfg. Co., Ltd. in 1943 (Showa 18). The fact that the precise engraving of caliper graduations is far from an easy job has already been covered in regard to Brown & Sharpe calipers. Nakamura Mfg. Co. advanced the research and development of optical graduating technology and succeeded in creating a graduating method by means of photo-etching.⁵⁷⁾ This allowed mass production of vernier calipers. The company started mass production of them in 1943 (Showa 18) to meet the demand. The use of vernier calipers had increased during WWII, significantly spreading throughout Japan.

Since a great number of vernier calipers are required during wartime, the number of caliper manufacturers increased until the end of WWII. At that time in Tokyo, there were many caliper manufacturers such as Sugiura Shoten, Citizen Watch, Takayama Seimitsu, Saisuke Tatebayashi (personal), Takeuchi Seisakusho, Tamaya Shoten, Togoshi Seiki, Nakamura Mfg. Co., Nihon Seisokuki, Matsuura Seisakusho, Yamayo Measuring Tools Co., (Kamoshita Doki until Showa 39) in addition to Tajima Seisakusho (Matsuo Doki until Showa 15).⁶³⁾

Many other manufacturers also existed in Niigata, Gifu and Osaka, etc.

In those days, vernier calipers were categorized as rules and manufactured by vendors who obtained a manufacturing license conforming to the Weights and Measures Act. Individual vernier calipers needed have a certificate of inspection from the national or alternate prefectural inspection laboratory and calipers could only be sold with the certification mark engraved on them. The instrumental error was determined by this inspection. Imperial ordinance No. 222 issued in 1945 (Showa 20), when the war situation was deteriorating, had decreed that vernier calipers were to be treated as new type of measuring device with an acceptance tolerance independent of the category of rules⁶⁴⁾ on January 1, or later, of the same year. Tooth thickness vernier calipers were also added as a special measuring device category. However, soon after the end of the war, manufacture of measuring tools such as vernier calipers was interrupted by the suspension of manufacturing industry.



(b) Lead Error Correction Mechanism
Figure 95 SIP's Lear Graduating Machine

12. Trends in Vernier Calipers after the End of WWII and the Establishment of JIS

In Europe and the United States after the war, various special-purpose vernier calipers were manufactured in parallel with basic ones. Some examples of these are described here, selected from among those displayed at the Mitutoyo Museum²³⁾.

Figure 96 shows a UK-made vernier caliper from Zeus that is provided with contact points for pitch measurement between lines or points as well as jaws for inside and outside measurement. The thumb rest on the slider both releases and clamps it in position, as required.

Figure 97 shows a German-made vernier caliper with compass points. This caliper can be used for point-to-point measurement as well as scribing applications, allowing measurement of size up to 6 inches with a graduation of 1/1000 inch.

Manufacturing industry in Germany seems to have recovered more quickly than in Japan after the war. Figure 98 shows the German Multipro Inc.'s vernier whose fixed jaw can slide transversely on the end of the main beam and be fixed at an accurately known position, using a 0.1 mm resolution vernier scale, to support measurement of stepped workpieces. The main scale (lower edge) can



Figure 96 Zeus's Vernier Caliper (UK)
(Measuring Range: 140 mm/5 in, Resolution: 0.02 mm/0.001 in), 1950



Figure 97 Vernier Caliper with Compasses (Germany)
(Measuring Set Length: 6 in, Resolution: 0.001 in), 1950



Figure 98 Multipro Inc. (German-made) Offset Vernier Caliper, 1967

measure up to 250 mm with a resolution of 0.02 mm and the upper scale can measure up to 10 inches with a resolution of 1/128 inch.

Figure 99 shows a Swiss-made Etalon vernier caliper provided with hardened contact points on the upper pair of jaws for measuring a chamfered or flanged workpiece thickness or groove width⁶⁵⁾. With those 0.4-inch length pins, this caliper can measure up to 10 inches and 250 mm with a resolution of 1/1000 inch and 0.02 mm, respectively.

Figure 100 shows a German-made Mauser vernier caliper specific to inside measurement, which is provided with fine contact points for inside groove measurement. This caliper can measure inside size up to 140 mm with a resolution of 0.05 mm using the lower-edge scale and up to 5 inches with a resolution of 1/128 inch using the upper-edge scale⁶⁶⁾.

Figure 101 shows a Mauser vernier caliper with a round-bar main scale, which can measure the width of a thin workpiece or a step in a bored hole with a resolution of 0.05 mm. This is a type of bore-gaging, flanged-jaw caliper⁶⁶⁾.



Figure 99 Etalon (Swiss-made) Vernier Caliper, 1956



Figure 100 Mauser-Messzeug GmbH (German-made) Vernier Caliper for Inside Groove, 1961



Figure 101 Mauser-Messzeug GmbH (German-made) Vernier Caliper for Thin Width/Hole-inside Step, 1961

In this country, in competition with these Euro-American manufacturers, Tajima Seisakusho and Nakamura Mfg. Co. restarted production of vernier calipers in 1946 (Showa 21)⁵⁸⁾. After this time, Mitutoyo Manufacture started trial production of vernier calipers in 1949 (Showa 24), and started commercial production in November of the same year upon receipt of the manufacturing license in conformity with the Weights and Measures Act. At first, Mitutoyo manually graduated caliper scales in the same way as in many other companies. In Japan, the graduating of vernier scales was changed to the mechanical-feed graduation method from 1954, and that of main scales to the photo-etching graduation method by sunlight from the beginning of 1955 (Showa 30). This work was further developed by using a mercury-vapour lamp instead of solar rays^{58) 67)} from 1958, allowing mass production of main scales.

The Korean War started in June 1950 (Showa 25) and due to its demand for equipment gave the Japanese machine industry a new impetus. Under those circumstances, the demand for vernier calipers increased again and upon request of industry, Japanese Industrial Standards (JIS) for vernier calipers was established in March, 1954⁶⁸⁾. In those days, the foot-pound system was used in a lot of industrial fields under the Allied Forces occupation, diminishing the Japanese effort to apply the metric system. However, under the orders of GHQ Economic and Scientific Section, Japan restarted efforts to legislate for

metric weights and measures. In June 1951 (Showa 26), shortly before the conclusion of the San Francisco Peace Treaty in September 1951, the Weights and Measures Act was revised and was enforced in March 1952. Then, the measurement units were unified to be those of the metric system on and after January 1st, 1959 (Showa 34). Consequently, the production of vernier calipers in other than metric units, such as the abovementioned 2-country 4-step scale caliper, were discontinued in December 1958. The verification of measuring instruments were also discussed and those national verifications were gradually delegated to prefectural governments from August 1953. Niigata and Tokushima Prefectures started metrological verification in September of the same year. Subsequently, vernier calipers were excluded from verification in conformity with the Measurement Act and changed in verification so as to be compatible with JIS.

The types that were certified by JIS established in 1954 (Showa 29) were the M type, the CM type and the CB type. The ordinary-type vernier caliper imported from the UK in the early Taisho era as described in Chapter 11 was not certified by JIS as the result of taking its accuracy, mass production potential, etc., into consideration. Therefore, the vernier calipers of this type were gradually falling into disuse, finally going off the market. This might also depend on the fact that the units had been unified as those of the metric system.

The M-type vernier calipers adopted the German Mauser

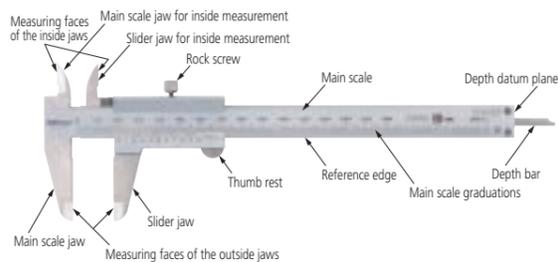


Figure 102 JIS M1-type Vernier Caliper, 1954

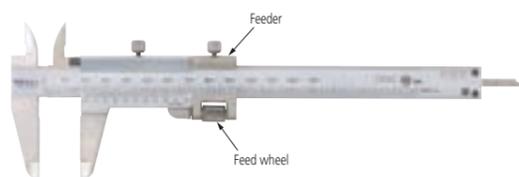


Figure 103 JIS M2-type Vernier Caliper, 1954

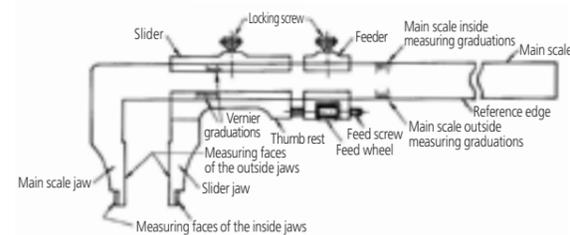


Figure 104 JIS CM-type Vernier Caliper, 1954

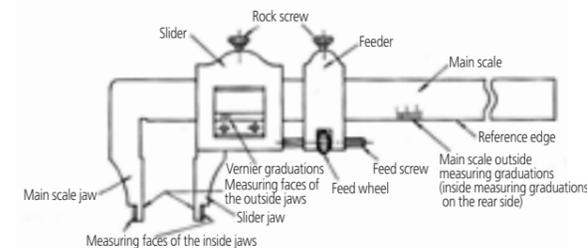


Figure 105 JIS CB-type Vernier Caliper, 1954

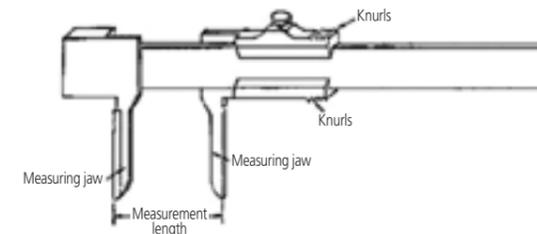


Figure 106 Inside Measuring Vernier Caliper, Around 1960

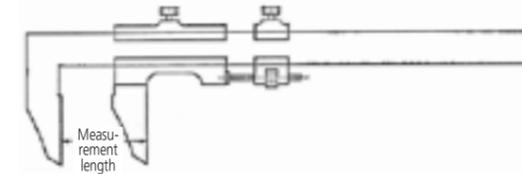


Figure 107 Roller Chain Pitch Measuring Vernier Caliper, Around 1962

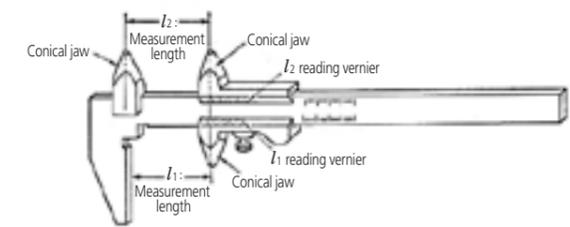


Figure 108 Circular-hole Central Distance Measuring Vernier Caliper, Around 1960

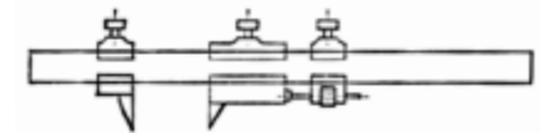


Figure 109 Beam Trammel (Scribing) Vernier Caliper, 1960

style, named by taking that company's initial⁵⁷⁾. As shown in Figure 102 and Figure 103, these are the most commonly used vernier calipers that can be used for a wide variety of measurements such as outside, inside and depth measurement. This type was also known as the depth-measurable type. The M type is divided into the M1 type (Figure 102) and M2 type (Figure 103), both of which have a groove-type slider and inside measurement jaws on the upper side. The M1 and M2 types are different in that the former does not have the fine-adjuster of the latter.

As shown in Figure 104, the CM-type vernier caliper has a screw-adjuster that can finely feed the slider, thus allowing precision setting as a feature. The CM-type vernier calipers have a groove-type slider identical to the M-type calipers, and also have inside measurement anvils on the tips of the outside measurement jaws, in contrast to the M-type, but have no depth bar.⁶⁸⁾ Most of the long-length measuring calipers are CM types: the C stands for caliper and M stands for Mauser. It was also known as the German type by the country of origin. The CB-type vernier caliper is as shown in Figure 105⁵⁷⁾. Its type name CB being taken from the "C" of Caliper and "B" of Brown & Sharpe Mfg. CO. This type is also known as the Starrett type. The inside measuring anvils are situated on each tip of the outside jaws, identically to the CM type. Equipped with a box-type slider, the CB type is limited to a short vernier scale due to restrictions caused by the box size. The slider also has a window opening on the rear side, being structured so as to be graduated.

Some CB-type vernier calipers had an outside measuring scale on the front side and an inside scale on the rear side. This type differs in structure from the M and CM types in that it has no thumb rest. Therefore, the curved section on the slider head is used as an alternate. The CB type also has a screw-adjuster that allows the slider to be finely fed.

After 40 years since the establishment of JIS, the current JIS has defined the M- and CM-type vernier calipers and deleted the CB type.

In 1955 (Showa 30), the Nakamura Mfg. Co. was certificated as a JIS-symbol display license factory and following this, other companies obtained the license. NSK Co., Ltd. started manufacture of vernier calipers in 1961 and received the JIS symbol display license in 1964. SWAN Co. Ltd. commercially manufactured a special vernier caliper for OD measurement of sheet-metal coils in 1966. The establishment of JIS has improved the quality of vernier calipers in Japan. Concurrently, stainless steel was used as the construction material, the entire quenching/ grinding process was implemented and scales were graduated by means of photo-etching, thus improving the accuracy and durability of vernier calipers and enabling successful export to Europe and the United States. Under these circumstances, a great variety of vernier calipers made in imitation of special-purpose calipers with non-standard jaws shaped for the intended use, as shown in Figures 96 to 101, were also manufactured in Japan. Some typical vernier calipers of this type are shown in Figures 106 to 113^{57) 69)}. Figure 106 shows a vernier



Figure 110 Mitutoyo Tube Thickness Caliper, 1970



Figure 111 Mitutoyo Hook Type Vernier Caliper, 1974

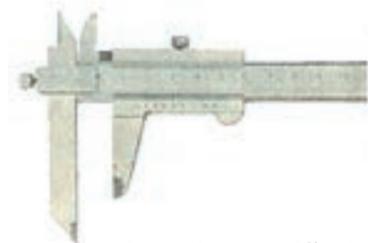


Figure 112 Mitutoyo Offset Caliper, 1960



Figure 113 Mitutoyo Universal Vernier Caliper, 1970



Figure 114 Mauser-Messzeug GmbH (Germany-made) Dial Caliper, 1960



Figure 115 Helios Co. (Germany-made) Dial Caliper with a Dual Inch/Millimeter Indicator, 1960

caliper specific to inside measurement, Figure 107 shows a roller chain pitch measuring vernier caliper with the slider jaw attached in reverse orientation, and Figure 108 shows a circular-hole center-to-center distance measuring vernier caliper which can directly obtain spacing of circular holes by merely inserting the conical jaws in the holes. That shown in Figure 109 is called a beam trammel vernier caliper available for scribing and equipped with contact point jaws which enable measurement by insertion in very narrow grooves. Figure 110 shows a vernier caliper for measuring the thickness of a tube by inserting the fixed round-bar jaw in the tube. Figure 111 shows a hook-type vernier caliper for measuring shallow step and inside distances.

Many other special calipers have been manufactured, e.g. an offset vernier caliper as shown in Figure 112, which can move the fixed jaw transversely to handle a stepped workpiece and a swivel vernier caliper as shown in Figure 59, which can also measure a step between surfaces at different distances from the measurement axis by rotating the slider jaw. Figure 113 shows a universal vernier caliper with a cylindrical main scale that improved the pipe vernier caliper manufactured in 1967, allowing versatile use for such as inside, outside, depth, height, step and angle measurement and circle scribing. A specific vernier caliper for measuring commutator clamping grooves in a motor was also manufactured in which the main scale was graduated uniquely in terms of $1 \times \text{cosec} \theta$ and the tips of the round & angular jaws as shown in Figure 93 were sharpened to contact points.

In 1960 (Showa 35), when Japan seemed to have recovered after the war, Mauser-Messzeug GmbH developed the dial caliper as shown in Figure 114, mainly for the United States market⁶⁶⁾. The Helios Co. in Germany also started manufacturing dial calipers during much the same period. Figure 115 shows the Helios dial caliper displayed at the Mitutoyo Museum.²³⁾ It is uncertain at present which of these two companies first manufactured dial calipers. The dial indicator of the Mauser dial caliper shown in Figure 114 has two pointers on the dial that work together to indicate the value of a measurement in inches. The longer pointer reads the outside scale at 1/10 inch per half revolution and is graduated in units of 1/1000 inch. The

shorter pointer reads the inside scale up to 6 inches per revolution in graduations of 1/10 inch. The metric version of this caliper reads the outside scale in units of 0.05 mm and the short pointer reads the inside scale at 100 mm per revolution. Adopting the dial indicator has eliminated the parallax error problem, inherent with vernier readout, and enabled efficient inch-system measurement by displaying decimal values instead of inch fractions.

The Helios dial caliper shown in Figure 115 is different in that it is a dual-unit instrument, with a dial that reads both in millimetres and inches. The longer dial pointer reads the outside inch scale (black) at 1/10 inch per half revolution and is graduated in 1/1000 inch. The shorter pointer reads the inside millimeter scale (red) at 10 mm per full revolution and is graduated in units of 0.1 mm. Corresponding to the dial scales, the main scale has an inch scale graduated up to 7 inches on the lower edge and a metric scale graduated up to 175 mm on the upper edge. This dial caliper very conveniently allows concurrent readout of inch and millimeter values. In addition to this dual-scale dial caliper, Helios also offered dedicated inch-scale and millimeter-scale dial calipers.

Starrett, Brown & Sharpe and the Modern Tools Co. in the United States, and TESA in Switzerland sequentially developed, manufactured and distributed dial calipers by around 1965 following Mauser's lead. As an example from the United States, Figure 116 shows a Starrett dial caliper manufactured in 1979³¹⁾. Mitutoyo developed a dial caliper for the U.S. market in 1962 (Showa 37) that went on sale the following year⁵⁸⁾⁵⁹⁾. Figure 117 shows Mitutoyo's dial caliper with a graduation of 1/1000 inch and a measuring range of 5 inches (a graduation of 0.05 mm and a measuring range of 139 mm was used for the metric model).

Successively, in 1967, Ozaki Mfg. Co., Ltd., NSK Co., Ltd., and others, developed dial calipers and started production and distribution. Figure 118 shows an unusual Starrett dial indicator caliper of 1979³¹⁾. This measuring tool reads in units of 1/1000 inch and, just as it is, this caliper can precisely measure a maximum value, minimum value and the difference between them of inside/outside diameters in units of 1/100 inch, 1/1000 inch, or even 1/10000 inch using the dial indicator. The combination of a caliper with



Figure 116 The L. S. Starrett Company's (U.S.-made) Dial Caliper, 1970



Figure 117 Mitutoyo's Dial Caliper, 1962

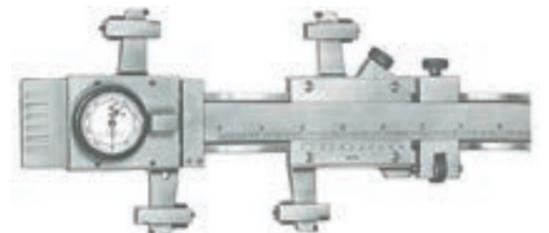


Figure 118 The L. S. Starrett Company's (U.S.-made) Dial Indicator Caliper, 1979



Figure 119 Mitutoyo's Low-force Caliper, 1965

other measuring tools has created convenience in length measurement.

Generally, the measuring force applied by a caliper is somewhere between 0.1 and 11 N, depending on the operator⁷⁰⁾⁷¹⁾. It is known that some operators measure with a large force of 15 N and even the same operator uses a different measuring force for each measurement⁷⁰⁾⁷¹⁾. This variation will not make much difference for metal parts, which have high stiffness, but a large or variable force may cause a great difference in measurement due to the deformation caused by excessive pressure induced in a plastic part. For this reason a caliper that applies a low and constant measuring force is required. Figure 119 shows Mitutoyo's low-force vernier caliper of 1965 that can maintain a measuring force between 0.5 and 1 N or allow the user to set any desired force, within limits, by incorporating a dial indicator in the fixed

jaw. This caliper achieved stable measurement of soft components, such as plastic parts. Figure 120 shows a constant-force dial caliper in which the fiducial indicator (on the left) indicates a measuring force that has been set between 0.5 to 1 N and the dial indicator records the measurement^{72) 73)}. Interestingly, calipers in which a dial indicator is attached to the slider jaw have also been produced^{72) 73)} and in this form the instrument becomes a comparator that is found convenient for repetitive measuring operations. Figure 121 shows a Mitutoyo limit gage caliper of this type. The caliper is set to a nominal dimension and the dial indicator shows any variation



Figure 120 Mitutoyo Constant-force Dial Caliper for Plastic, 1973



Figure 121 Mitutoyo Limit Gage Caliper, 1970



Figure 122 Mitutoyo Micrometer Head-equipped Caliper, 1962



Figure 123 Mitutoyo Counter/Dial Caliper Measuring Range: 135, 190, 300 mm, 1980



Figure 124 Mitutoyo Counter/Dial Caliper Measuring Range: 300 to 600 mm, 1980

from this dimension, not the dimension value itself. Some manufacturers use an electric micrometer in place of this dial indicator.

Similarly, Mitutoyo manufactured a caliper using a micrometer head in place of a dial indicator in 1962. Figure 122 shows this caliper, which was distributed under the name of "micrometer-equipped caliper"⁷⁴⁾. This caliper type has an advantage in that a long workpiece with a length more than 5 times the micrometer measuring range of 25 mm can be measured to a resolution of 0.01 mm. However, this caliper disappeared in a short time from the catalog due to problems in use such as taking a long time to move more than 100 mm using the standard screw pitch of 0.5 mm, the complex structure, accuracy and cost.

Figure 123 shows a counter/dial caliper for a measuring range of 300 mm or less, and Figure 124 shows a version of the same type that was available with a measuring range of between 300 and 600 mm⁷³⁾. The counter reads the whole millimeters part of a measurement value and the dial reads the decimal part in 0.02 mm increments. As mentioned above, not only standard-type vernier calipers but also various special types of calipers were manufactured, thus allowing supply according to user demand along with extremely high quality. The caliper material was changed from brass or steel to stainless steel while implementing an entire quenching and grinding process. The photo-etch graduating method was applied to scale manufacture and resulted in increased accuracy and durability^{59) 67)}.

Accordingly, it was accepted that Japanese vernier calipers were of equivalent quality to the best Euro-American products by around 1965, and in many case superior. After this time Japanese vernier calipers were widely exported to many other countries including the United States and Europe. Additionally, scale graduating advanced to use the laser machining method from photo-etching, showing evident technical progress. Japanese manufacturers, as mentioned above, had opened individual markets and their vernier calipers were used around the world as well as in Japan. By around 1985, Japanese manufacture had grown so much that vernier calipers made in Japan made up about 70% of those in use throughout the world.

13. Development of Height Gages in Japan

Early in the Taisho era in Japan, it was standard practice that height measuring and scribing operations were frequently implemented as shown in Figure 125, where a scale stand and Touskan (surface gage) were used on a surface plate. Height gages which unified the above two tools were imported from the U.S.³⁶⁾ and Germany^{59) 60)} in the middle of the Taisho era. Depth gages were also imported almost in the same period. Accordingly, the vernier caliper manufacturers started manufacturing height gages and depth gages with vernier scales early in the Showa era. After the end of WWII, JIS standards for height and depth gages were instituted in 1960 (Showa 35), 6 years later than that for calipers^{75) 76)}. Three types, HM, HB and HT were adopted for height gages, and three types, DM, DB and DS were adopted for depth gages⁵⁷⁾. These height gages are shown in Figures 126 to 128 and depth gages in Figures 129 to 131. As in the case with vernier calipers, the HM-type height gage and the DM-type depth gage adopted the German Mauser style, and the HB-type height gage and the DB-

type depth gage adopted the U.S. Brown & Sharpe style, respectively.

In the beginning, the HM type was also known as the German type or Carl Mahr type as well as the Mauser type, and the HB type was also known as the Brown & Sharpe type or Starrett type. The HT-type height gage capable of moving the main scale for adjustment had been called the Takayama-type height gage since the pre-war period, thus the letter T was suffixed to the type name.

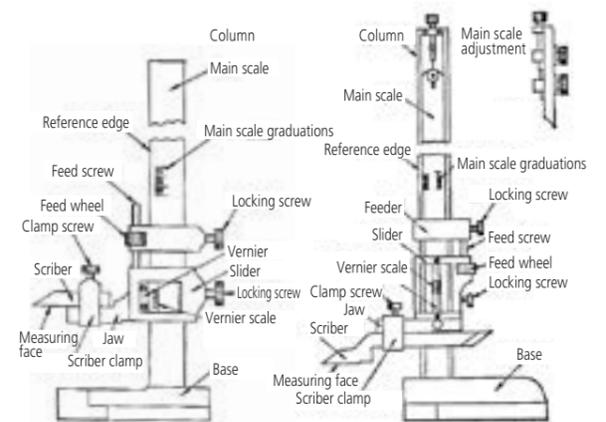


Figure 127 JIS HB Type Height Gage, 1960

Figure 128 JIS HT Type Height Gage, 1960

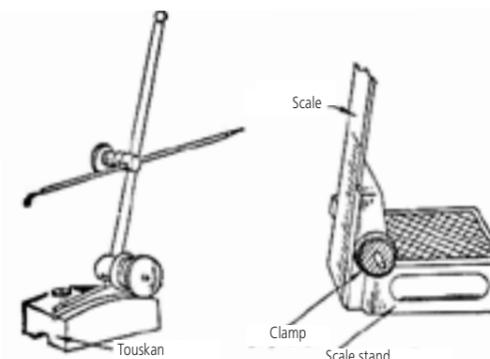


Figure 125 Touskan and Scale Stand

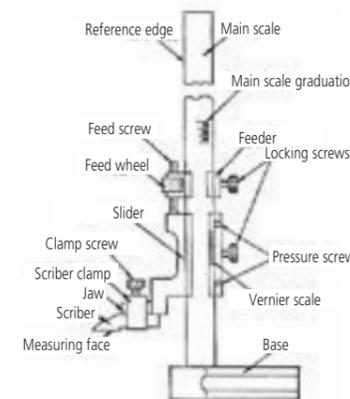


Figure 126 JIS HM Type Height Gage, 1960

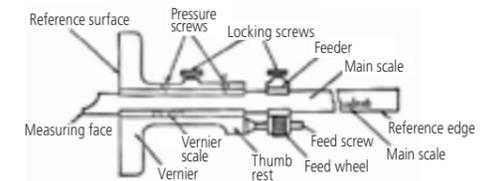


Figure 131 JIS DM Type Depth Gage, 1960

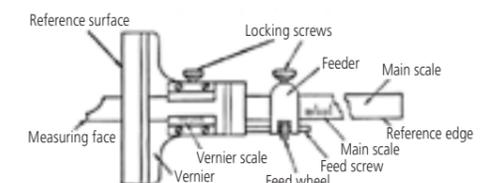


Figure 131 JIS DB Type Depth Gage, 1960

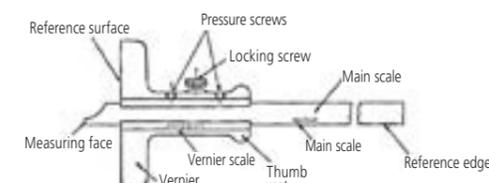


Figure 131 JIS DS Type Depth Gage, 1960

The DM-type depth gage is structured so that the measuring face can be finely fed relative to the reference surface. The DS-type depth gage is sort of a simplified DM-type depth gage which is not equipped with a fine-feed device. Since JIS regulations were revised, the current main products are the HM height gage and the DM and DS depth gages. In consideration of user-friendliness, the indicator progressed from the counter display/dial scale readout⁷⁷⁾ shown in Figure 132, to digital display⁷⁸⁾ as in Figure 133. The historical situation of digital height gages follows on from the application of a digital system to vernier calipers. For comparative information, refer to the next chapter. Current digital height gages are equipped with a scale read by photoelectric encoder. The influence of coordinate measuring machine technology has led some of them developing into multifunction, precision height gages that can determine maximum/minimum values as well as a single height, or calculated dimensions, etc. through data processing⁷⁹⁾, as shown in Figure 134. This type of height gage has improved in accuracy so that inside/outside diameters, pitch and other dimensions can be measured to a resolution of 0.1 μm , while being provided with a rich choice of accessories such as various forms of probe.



Figure 132 Mitutoyo Counter/Dial Height Gage
Graduation: 0.01 mm, Measuring range: 300mm, 1970



Figure 133 Mitutoyo Digital Height Gage
Resolution: 0.01 mm, Measuring range: 300mm, 1982



Figure 134 Mitutoyo Digital Height Gage (Linear Height LH)
Resolution: 0.001 mm, Stroke: 600mm, 1998

14. Development and Advancement of Digital Calipers

In Japan, an electric micrometer using a differential transformer was developed in 1956 and its digital display immediately afterwards⁸⁰⁾. This trend toward digitalization was applied to various types of length measuring tools and instruments. Methods such as Analog to Digital conversion of voltage by means of analog displacement detection and digital measurement using an encoder were applied to length measurement, thereby achieving digital display and processing. Under these circumstances, president H. U. Meyer of Swiss Sylvac Co. had developed and marketed an electrostatic capacitance-type electric micrometer⁸¹⁾. The displacement detecting device in that micrometer used the principle of the variation in capacitance between a moving sleeve and a series of fixed coaxial cylinders aligned with the direction of measurement, over which the sleeve slid. The sleeve was attached to the micrometer spindle and an alternating voltage proportional to the distance the sleeve moved was digitized to drive the digital display. He also invented a variation of this method in which the coaxial cylinders were replaced by multiple flat plates. A moving plate sliding over the fixed plates replaced the sleeve to give the same detecting effect. This was in 1972, and refinements to the method made it possible to detect large displacements by 1980^{82) 83)}.

Using a more elaborate detection method along the same lines as outlined above, I. Andermo of the Swedish Royal Institute invented the relative position measuring method, as shown in Figure 135, in 1977.⁸⁴⁾ In this device, three alternating voltages of differing phase are applied to a

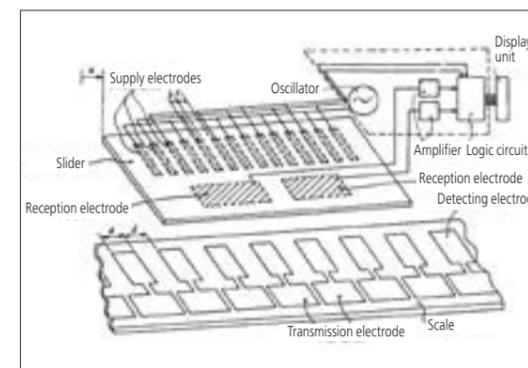


Figure 135 Outline of Electrostatic Capacitance-type Incremental Relative Position Detection Method

system of supply electrodes on the slider and detecting electrodes are arranged to form the scale at a pitch corresponding to that of three supply electrodes. The supply electrodes slide over the detecting electrodes and the detected voltages and corresponding phases are transmitted from transmission electrodes to reception electrodes on the slider. The signals thus received are passed to electronic logic circuitry to determine slider position, which represents displacement. This measuring method using phase analysis would come to exert a powerful influence on detection stability. Meyer and his company, Sylvac, and Andermo of the Swedish company AB C. E. Johansson applied this method to their vernier calipers, which were commercialized as an incremental digital caliper with a resolution of 0.01 mm and marketed from around 1980. Many digital calipers used in Europe and the U.S. from a little earlier than that year adopted the digital system with a photoelectric-type encoder. Figure 136 shows the TESA S. A. digital caliper displayed at the Mitutoyo Museum⁸⁵⁾. The battery for the lamp used as a light-source in this type of digital caliper needed frequent replacement due to its small capacity. The electrostatic capacitance type encoder has less power consumption than the photoelectric type, thus maintaining sufficient operating time even with a small battery, and for this reason calipers using this encoder have spread throughout the world.



Figure 136 TESA S. A. (Switzerland) Incremental Digital Caliper (Photoelectric-type), 1978



Figure 137 Mitutoyo Incremental Digital Caliper, 1983



Figure 138 TESA S. A. Incremental Digital Caliper, 1987



Figure 139 Mitutoyo Digital Caliper with Main Scale Graduations, 1987



Figure 140 Mitutoyo Solar-powered Digital Caliper, 1988

Mitutoyo formed a technology-based alliance with the Swedish Royal Institute and developed an incremental digital caliper with a resolution of 0.01 mm, as shown in Figure 137, in 1983, upon acquisition of its patent license. Since the problem in determining slider displacement in the electronic caliper was now largely overcome, reliable and low cost calipers could now be supplied and by August 1984 Mitutoyo had manufactured and distributed 100,000 digital calipers.

Under the tie-up agreement with Johansson, who had close relations with the Swedish Royal Institute, Mitutoyo also manufactured digital calipers in Germany, for supply mainly to Europe. On the basis of this agreement, The Royal Institute, Johansson and Mitutoyo implemented collaborative development. During this collaboration, Johansson had severe financial difficulty, and thus Mitutoyo alone carried on a joint business with the Royal Institute. As an example of digital calipers in Europe and the U.S., Figure 138 shows a TESA-made digital caliper from 1987⁸⁶. This caliper was developed under the technology alliance agreement with Sylvac. Its resolution and performance are almost identical to that of Mitutoyo's



Figure 141 Mitutoyo DIY Digital Caliper (DIGIPA), 1994



Figure 142 Mitutoyo Mini Home-use Digital Caliper (DIGIPA Mini), 1995



Figure 143 Mitutoyo Body Fat Scale, 1998

caliper. After that, the digital caliper inventor, Andermo, became independent of the Swedish Royal Institute and, in 1987, established Micro Encoder Inc. at Kirkland in the suburbs of Seattle, Washington State in the U.S., with support from Mitutoyo. His company mainly contributed to the groundwork for further development of Mitutoyo digital calipers.

In 1987, Mitutoyo's gray digital caliper main scale cover was provided with millimeter quick-reference graduations, as shown in Figure 140, to improve user-friendliness. The small battery that powered the caliper was followed by a solar cell in 1988 to create the light-powered digital caliper which eliminated the inconvenience of battery changing⁸⁷. Mitutoyo also developed lightweight digital calipers partly constructed from carbon-fiber reinforced plastic to make longer calipers easier to handle. Then, digital calipers with a large measurement display panel were manufactured in 1992 to improve readability⁸⁸. The improvements outlined above were eventually implemented by many other companies in the market. Mitutoyo developed cheaper digital calipers aimed at the Do It Yourself (DIY) market under the brand name DIGIPA,



Figure 144 Mitutoyo Absolute Digital Caliper, 1993

with a resolution of 0.1 mm. Its main body was made of plastic (Figure 141) and was sold from 1994 onwards while a business-use digital caliper marketed as DIGIPA Mini, a caliper designed to fit into a personal organizer (Figure 142), was commercialized in 1995. Moreover, Mitutoyo developed a digital body-fat caliper in 1994. Since then this caliper has been used at health clinics for measuring subcutaneous fat for which, until then, digital calipers designed for machine work had been used. This caliper alternatively serves as the fat scale by attaching the necessary switching buttons as well as changing the shape of jaws and material so as to be compatible with fat-thickness measurement. This digital caliper is also available for home use to help maintain personal health. As an aside, due to this development, a survey on the relationship between subcutaneous fat and exercise was implemented in the urban, agricultural and fishing communities. It was found that people in agricultural and fishing communities used their cars even for short distances of 100 m due to the effect of motorization but, in contrast, people in urban communities walked longer distances thanks to good access to public transport. China also started production of vernier calipers and supplied them at extremely low cost. As a result of improved diplomatic relations between China and the United States in 1979, China obtained precision measuring tool manufacturing technologies and as a result was able to manufacture and export measuring instruments to Europe and the United States. China manufactured digital calipers from about 1985 and started their export and sale. At the beginning of this export drive, imitations of Japanese makers' products appeared including digital calipers, which also carried the JIS-mark. The export of large volumes of cheap product to the United States

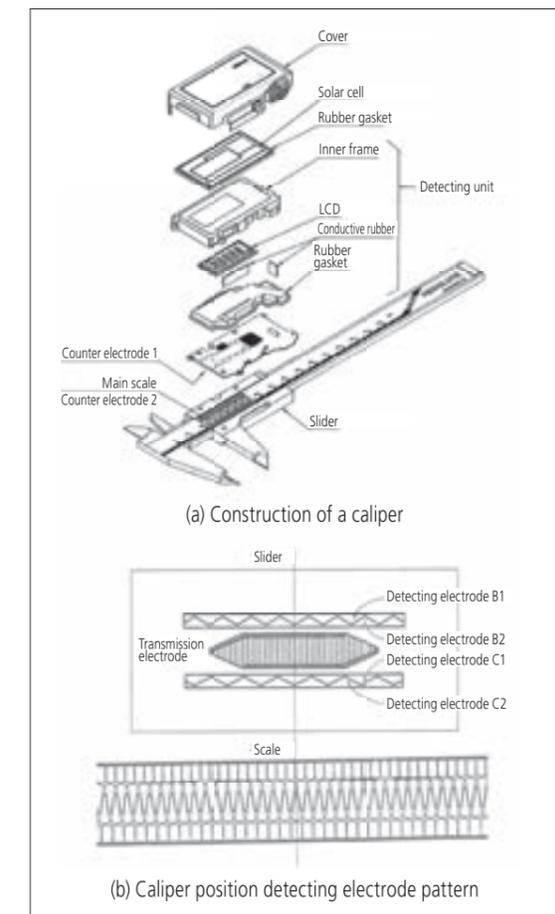


Figure 145 Outline of Mitutoyo Electrostatic Absolute Encoder Position Detection Method, 1991

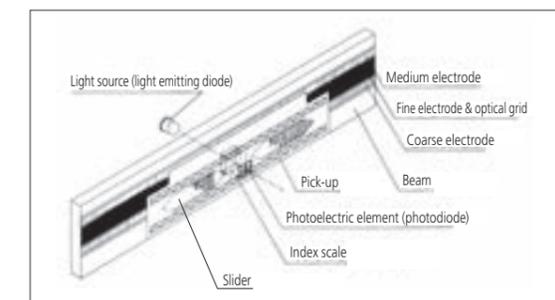


Figure 146 Outline of Mitutoyo Electrostatic Capacitance Photoelectric-type Encoder Absolute Position Detection Method, 1991

dealt a lasting blow to measuring tool manufacturers in many countries, including Japan. Some manufacturers in Europe supplied some Chinese products as OEM products. Due to these circumstances, Brown & Sharpe, TESA and others came under the control of Hexagon in Sweden. Japan also came to the situation where NSK

Co., Ltd. withdrew from the caliper market and only two companies, Nakamura and Mitutoyo, continued manufacturing calipers.

The abovementioned digital calipers are all of the incremental type, but in 1993 an “absolute system” digital caliper was developed. Figure 144 shows a Mitutoyo Absolute Digital Caliper with a resolution of 0.01 mm⁸⁸⁾. The detection method used is shown in Figure 146⁹⁰⁾. An ABSOLUTE linear scale with a 1 μm display was also developed at the same time using a method similar to this method⁸⁹⁾⁻⁹¹⁾. The detection method comprises an electrostatic capacitance electrode scale with three tracks for coarse, medium, and fine details, and a one-track optical grid scale powered by an LED source as shown in Figure 147⁸⁹⁾⁻⁹¹⁾. The optical grid shares the fine electrostatic capacitance electrode track. Absolute digital calipers have the advantage that operation is equivalent to that of vernier calipers, i.e. no zero setting is needed at switch on. Solar-type absolute digital calipers are also commercially available. This same detection method is used on absolute linear scales for machine tools to provide a resolution of 1 μm⁸⁹⁾⁻⁹¹⁾, with the advantage



Figure 146 Mitutoyo IP54 Waterproof Electrostatic Capacitance-type Absolute Digital Caliper, 1997

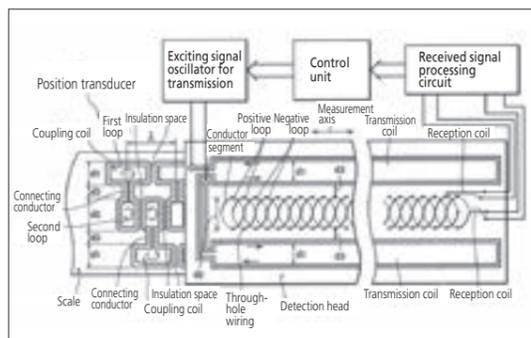


Figure 147 Outline of Electromagnetic Induction-type Absolute Digital Caliper Detection Method, 1997

over the incremental type scales that the origin position is held indefinitely.

On the machine shop floor, coolant is often splashed over tools and workpieces and sometimes dimensional measurement is performed under the splashing coolant. Although a vernier caliper is inherently immune to such harsh conditions, a digital caliper would be more convenient if it could be used. The conventional electrostatic capacitance-type caliper is not ideally suitable for this environment due to its sensitivity to contamination. However, to meet the user's extremely high requirements, Mitutoyo developed a waterproof absolute digital caliper of the electrostatic capacitance-type, as shown in Figure 147, in 1997. This caliper incorporated special enclosure technology to allow operation under shop floor use. The IP54 protection-code level achieved was usually enough for a general purpose digital caliper, but in situations where large amounts of coolant splashed on the floor this caliper was gradually subject to deterioration.

To overcome this drawback, Mitutoyo developed the coolant-proof digital caliper shown in Figure 149 in the year 2000⁹³⁾ by changing the displacement detection



Figure 148 Mitutoyo IP65 Coolant-proof Absolute Digital Caliper, 2000



Figure 149 Mitutoyo IP67 Coolant-proof Absolute Digital Caliper, 2002



Figure 150 A&D Company IP54 Drip-proof Digital Caliper, 2007



Figure 151 TESA S. A. (Standard Gage) IP54 Coolant-proof Absolute Digital Caliper, around 2010



Figure 152 TESA S. A. IP67 Coolant-proof Absolute Digital Caliper, 2012



Figure 153 Sylvac Co. IP67 Coolant-proof Absolute Digital Caliper, 2011



Figure 154 Sylvac Co. IP67 Coolant-proof Micrometer Absolute Digital Caliper (Product Name: Micron Caliper), 2012

method to an electromagnetic induction-type method⁹²⁾, as shown in Figure 148. This technique produces a caliper that is inherently immune to the effects of coolant or dust contamination on the scale.

Figure 148 illustrates the principle: a voltage is induced in the sequentially arranged second loops from the first loops of insulated coupling coils on the main scale through the transmission coils from the exciting signal oscillator incorporated in the detection head on the slider. The reception coils on the detection head receive the voltage induced from the overlapped coils on the scale. After processing the signals from the reception coils, the caliper determines the position of the slider. The absolute digital caliper shown in Figure 149 achieved a protection code of IP65 and a further improved caliper with a protection code of IP67 is shown in Figure 150⁹⁴⁾. Recently, these absolute digital calipers that easily meet machine shop floor requirements have been widely used. Waterproof digital calipers had been manufactured previously in Europe and the United States, but the level of waterproofing did not reach the level of the caliper in Figure 149. The detection method illustrated in Figure 148 has steadily improved in resolution and today is used in linear scales reading in micrometers (μm).

In 2007, the Japanese company A&D manufactured and marketed incremental-type digital calipers called Drip-proof Digital Stainless Calipers, as shown in Figure 151⁹⁵⁾.

The company stated that the waterproofing was equivalent to IP54, which means no problem in use under general circumstances but care must be taken depending on where, and how, to use the caliper. The A&D Company also supplied other stainless steel and plastic incremental digital calipers with the same functions. Additionally, the company marketed low-cost digital calipers. This increased the number of Japanese caliper manufacturers to three. As described above, European companies such as Sylvac and TESA in the Hexagon group had marketed absolute digital calipers⁹⁶⁾ with a water resistance of IP54, similar to the caliper shown in Figure 152. In 2012, TESA improved their IP54 digital caliper (called Standard Gage) with an IP67 coolant-proof electromagnetic induction-type absolute digital caliper with large-character display as shown in Figure 153, in competition with Mitutoyo, while also launching various models with a different measuring ranges⁹⁷⁾.

Sylvac started marketing electromagnetic induction-type digital calipers as in Figure 154 equivalent to the above calipers ahead of them around 2005 in Europe and around 2011 in Japan. This company also developed and marketed an IP67 absolute digital caliper as shown in Figure 155 (called the Micron Caliper) with a resolution of one μm⁹⁸⁾.

Although its repeatability is 3 μm, three times the resolution, the maximum permissible error including the



Figure 155 Mitutoyo Absolute Digital Caliper, 2013

instrumental error of this caliper is 20 μm for a measuring range of up to 100 mm and 30 μm up to 150 mm. Therefore this caliper is equivalent in accuracy to common digital calipers with a resolution of 0.01 mm and thus its accuracy is not in line with its resolution. This shows the difficulty of increasing the accuracy of a digital caliper, mainly due to the limitations of its form as it does not comply with Abbe's Principle. To improve accuracy a caliper would require a very much stronger structure to resist deformation because its scale is not coaxial with the measurement axis. This could perhaps be done by using a substantial cylindrical main beam as shown in Figures 89, 101 and 113.

Recent Mitutoyo digital calipers are mainly electromagnetic induction-type absolute digital calipers with their inherent superior environmental performance. While improving the performance of each element, along with adopting solar power, Mitutoyo produced an absolute digital caliper as shown in Figure 156, which can maintain operation for about 3.5 years without a battery change under normal use, thereby becoming widely acceptable as a general-purpose absolute caliper.

An instrument able to output measurement data to computational devices such as computers enables incorporation into statistical process control and measurement control systems. From around 1980, discussions about establishing caliper standards had been ongoing at the International Organization for Standardization (ISO) and vernier calipers with a resolution of 0.02 mm were being considered for deletion from ISO Standards because of the difficulty in maintaining accuracy due to the flat form of the main beam. Then, discussions about the accuracy of calipers changed as digital calipers appeared in the mid-1980s and Chinese calipers were launched in the 1990s.

A major influencing factor was that the cheap Chinese calipers improved in quality after their introduction to the point where, due to their low price, the inferior accuracy and quality were acceptable to non-professional users who did not require the higher accuracy and superior quality of the mainstream vendors' product.

Although these discussions almost achieved a final draft, this was scrapped several times due to rotation of the technical committee chairperson and the general manager of the draft creation working group and eventually the effort proved fruitless. After this discussion period, a much-revised draft was circulated in 2011, finally becoming International Standard ISO 13385-1: 2011⁹⁹. This covers Sliding Calipers (Nogisu in Japanese) consisting of vernier sliding calipers, dial sliding calipers and digital sliding calipers. In this standard, although performance values are to be indicated by manufacturers, the performance of sliding calipers is specified in detail, which also includes some data that could be error factors but can be neglected in measurement accuracy. This is similar to the descriptions of Nogisu standards set out in 1954 (Showa 29) as Japanese Industrial Standards JIS. Since performance values are to be indicated by manufacturers, the requirements of this standard are no better than reference descriptions in a textbook. Generally, users will need to know that one factor may be included in other factors in some cases. The ISO standard does not specify the permissible values of the errors, but the JIS standards will specify the permissible reference values as a reference appendix. Japanese Industrial Standards JIS for Nogisu conforming to ISO will be organized in the near future.

The author believes it is vital that a metrology equipment vendor producing high quality calipers, such as Mitutoyo, only markets product that conforms to the relevant international standards, which themselves should set the highest level of accuracy practicable for these important measuring tools.

15. Summary/Acknowledgments

This paper has described the origin of sliding calipers ahead of Nogisu (vernier sliding calipers), the birth of sliding calipers with vernier graduations and the evolution from vernier to digital calipers. The evolution of sliding calipers in relation to the main historical events is summarized in Table 3. The oldest existing sliding caliper developed by Wang Mau in Xin of China in A.D. 9 seemed to have retained its form for a fairly long time. Wang Mau's sliding calipers might have found their way east and west. Although no evidence remains, it might be imagined that some of them could have been brought to Japan. In this paper, scabbard-type sliding calipers as measuring rules that may be considered to have a close relationship with graduated scales, sliding calipers that have improved measuring accuracy by attaching a vernier scale, then dial calipers and counter calipers, and finally the latest advanced digital calipers have been overviewed. In the process of describing these advances this paper also mentions height gages and depth gages, which have followed similar paths to calipers in reaching their present form. Vernier sliding calipers, along with micrometers, have played an important role in the foundation of modern industries by supporting maintenance of industrial product dimensions and conformity between mating machine parts. Japan should take pride in the fact that Norichika Ohno in Kaga developed a vernier sliding caliper at the end of the Edo period without delay from Europe and the U.S. and that his father Noriyuki Ohno had already developed a diagonal scale sliding caliper and actually used it. The fact that sliding calipers, even without a vernier scale, were widely by blacksmiths making guns was also confirmed. It has become clear that Michitaka Kume in Sanuki, developed survey and observation instruments incorporating a vernier scale in the later Edo period. Also, it has been recognized that the widespread proliferation of sliding calipers required the country's modernization while maintaining the skills of many highly individual artisans. The pressure of social needs is a big factor in the evolution of measuring tools and instruments. This has been verified by the history of advancement of the micrometer. The time has now come when it is necessary to develop a robust position with regard to the low-priced calipers on the market that, although inferior in performance and

quality, are attractive purely because of their pricing. We must carefully watch the developing trends of Chinese-made calipers, which rapidly improved in quality after their introduction, and need to ensure we achieve continual quality and technical improvement through a sustainable development and production plan coupled with a promotional strategy that clearly differentiates our high quality product in the marketplace. I shall be happy if this paper is of service to readers.

Acknowledgments

I gratefully received generous permission from the family of the late Mr. Shokichi Miyazaki, former Mitutoyo advisor, to draw on the terminology of calipers and descriptions of the U.S.'s first caliper made by Brown & Sharpe Mfg. Co. from his documents.

I gained information on the first French vernier caliper by courtesy of Mr. Kenzo Kobayashi, the chief curator of Hakari-No-Yakata (weights and measures museum) in Yokkaichi-shi, Mie prefecture, and obtained great help from Mr. Toshinobu Shibayama, former Mitutoyo member for photography of the caliper. For information about the first Japanese sliding caliper and vernier caliper, I was taught by the archaeologist, Mr. Toshio Kajiwara who is also a collector of length measuring tools.

I received invaluable assistance from assistant chief curator, Mr. Hideyuki Nishimura and curator, Ms. Yumi Takase of Fukui City History Museum for information on measurement using Norichika Ohno's vernier caliper. As for the sliding caliper made by Tohachi Kunitomo, a gun blacksmith, I obtained much information from Mr. Toru Fujiyama in the culture project group of the Toyota Commemorative Museum of Industry and Technology. Thanks to Prof. Dr. Robert J. Hocken, of the University of North Carolina at Charlotte, USA, I obtained information about the French sliding caliper with a diagonal scale. I also owe a great deal of thanks to Mr. Nobuo Suga, Mitutoyo America Corporation adviser, for helping me to get U.S. vernier calipers and related early American catalogs. I deeply appreciate the help and guidance of all persons mentioned above.

Table 3 Origin and Development of Calipers and Transition of Related Matters

| Christian year | Event |
|------------------------|--|
| 0009 | China (Xin) Wang Mau developed a sliding caliper. (Historical Museum, Place Meseum collection) |
| 1542 | Pedro Numez (Portugal) proposed one method of scale segmentalization. |
| 1631 | Pierre Vernier (France) invented vernier scale graduations. |
| 1783 (Tenmei 3) | Yoshinaga Motoki translated Usage of Quadrant (including vernier theory) into Japanese. |
| 1791 (Kansei 3) | Holland presented an octant (with a vernier scale) for the government of Edo. |
| 1806 (Bunka 3) | Eizaemon Michitaka Kume in Sanuki made a horizon indicator with a vernier scale, then an octant quadrant with a vernier scale. |
| 1833 | Brown & Sharpe Mfg. Co. (U.S.) started business (manufacturing of steel rules & tools). |
| 1840 | French Artillery Factory developed and used sliding calipers with a vernier scale in millimeter units on the front side and in pouce units on the rear side (collection of Weights and Measures Museum - Hakari No Yakata). At that time, a scabbard-type sliding caliper (simplified caliper) was made in France. |
| Around 1843 (Tenpo 14) | Yasaburo Noriyuki Ohno in Kaga developed a diagonal-graduated vernier caliper with a minimum reading of 0.1 rin and a measuring range of 5 sun (1-shaku rule by extending the main scale). |
| 1848 | L. J. Palmer (France) invented a micrometer caliper. |
| 1851 | Brown & Sharpe Mfg. Co. developed a vernier caliper with a minimum reading of 0.001 in. |
| 1853 | U.S. ambassador Perry came to Uruga. |
| 1855 (Ansei 2) | Tohachi Kunitomo in Nagahama manufactured a brass sliding caliper and delivered it to Ashigaru head, Hayashi Sotonokami of Sayama-han Hojo-ke in Kawachi. |
| 1857 | Nagasaki Iron Mill was constructed under the guidance of Holland and ten-odd machine tools were imported from Holland to the mill. |
| Around 1858 (Ansei 5) | Norichika Ohno in Kaga developed a vernier caliper with a minimum reading of 0.1 mm, the maximum scale value of 150 mm and a measuring range of 130 mm (sun/bu graduations on the rear side). |
| 1861 | Carl Mahr Esslingen a.N. (Germany) was founded. |
| 1862 | Societe Genevoise d'Instruments de Physique (Switzerland) was founded. |
| 1867 | Regal government was restored by transferring power to the Emperor, entering into Meiji Era. Paris Exposition opened (Brown & Sharpe Mfg. Co. took out the Palmer's micrometer to the U.S.). |
| 1880 | L.S. Starrett Co. (U.S.) started business (steel rules & tools) and developed sliding calipers and vernier calipers. |
| 1883 | John Logan (U.S.) invented a dial gage. |
| 1890 (Meiji 23) | Japan Meter Standard arrived. Next year the Weights and Measures Act (Japanese measuring system (in units of shaku) based on the meter standard) was promulgated. |
| 1896 | Mauser-Messzeug (Germany) and Etalon (Switzerland) were founded. Johansson invented gauge blocks. |
| Around 1900 | Rawco Co. (G.B.) and Adolf Pfeiffer trading company (Germany) developed and delt with multi-purpose Columbus vernier calipers for inside, outside and depth measurement. |
| 1903 (Meiji 36) | Gauge blocks, micrometers, vernier calipers, etc. from Eroupe and the U.S. were displayed at the 5th Domestic Industrial Exhibition (in Tennoji, Osaka). |
| | Otani (Junkei-mati, Minami-ku, Oosaka city) manufactured a vernier caliper and placed it on show along with other tools such as a pass and square at the same Domestic Industrial Exhibition. |
| | American Professor Francis used a vernier caliper at Tokyo Higher Technical School (present-day Tokyo Institute of Technology). |
| Around 1905 | Adolf Pfeiffer Co. sold depth gages and scribing height gages. |
| 1911 | AB C.E. Johansson (Sweden) was founded (invented gauge blocks in 1896). |
| 1917 | Sonoike Seisakusho Co. developed a micrometer between 1914 and 1918 during World War I. |
| 1920 | Brown & Sharpe Mfg. Co. developed a vernier caliper for tooth thickness measurement. |
| 1930 (Showa 5) | Tajima Seisakusho Co. (Matsuo Doki at that time) developed a vernier caliper. |
| 1934 | Mitutoyo Manufacture Co. (present-day Mitutoyo Corporation) was founded. |
| 1937 | The Sino-Japanese war started. |
| 1938 | Nakamura Mfg. Co. and others developed vernier calipers. |
| 1941 | The Pacific War (WWII) started. |
| 1945 | A sliding caliper handled as a kind of straight scale in the Weights and Measures Act was independent and authorized as a vernier (sliding) caliper. WWII ended. |
| 1949 | Mitutoyo Manufacture Co. developed a vernier caliper and Mizonokuchi Factory started production of calipers (started mass-production at Utsunomiya Operations from '52). |
| 1951 (Showa 26) | The Weights and Measures Act was revised to Measurement Law (Units were unified inot the metric system on and after January 1st, 1959). San Francisco Peace Treaty was concluded. |
| 1954 | Japanese Industrial Standards JIS B 7507: Vernier Calipers was instituted. |
| 1960 | Mauser-messzeug (Germany), Helios Co. (Germany) developed dial calipers. Japanese Industrial Standards JIS B 7518 Depth Gages was instituted. |
| 1962 | Mitutoyo Manufacture Co. developed a dial caliper. |
| 1977 | TESA S. A. (Switzerland) developed an incremental digital caliper (photoelectric-type). Ingvar Andermo of Swedish Royal Institute invented an electrostatic capacitance-type incremental digital caliper and AB C.E. Johansson commercialized it. |
| 1978 | Silvac Co. (Switzerland) uniquely developed an incremental digital caliper and started sales. |
| 1983 | Mitutoyo Corporation developed an incremental digital caliper and started production. |
| 1986 | Micro Encoder Inc. (President Ingvar Andermo) was founded in the U.S. by Mitutoyo. |
| 1988 | Mitutoyo Corporation developed a solar-powered incremental digital caliper. |
| 1993 | Mitutoyo Corporation developed an absolute digital caliper. |
| 1997 | I. Andermo and K. Mazreliez invented an electromagnetic induction-type position detecting device. Mitutoyo Corporation developed an IP54 coolant-proof absolute digital caliper. |
| 2000 | Mitutoyo Corporation developed an IP65 coolant-proof absolute digital caliper. |
| 2001 | Brown & Sharpe Mfg. Co. and TESA S.A. came under the control of Hexagon (Sweden). |
| 2002 | Mitutoyo Corporation developed an IP67 coolant-proof absolute digital caliper. |
| 2011 | ISO13385-1 GPS Dimens.meas.equip.Part 1: Calipers-Design and metrological characteristics was instituted. |
| 2012 | Sylvac Co. launched the sale of IP67 coolant-proof micrometer absolute digital caliper. |

References

- ISO 13385-2 : Geometrical product specifications (DPS) – Dimensional measuring equipment – Part 2 : Calliper depth gauges – Design and metrological characteristics, 2011-07-15
- ISO/FDIS 3611 Geometrical product specifications (DPS) – Dimensional measuring equipment – Micrometers for External measurement – Design and metrological requirements
- Shokichi Miyazaki: Visiting the Root of Measuring Instruments – Calipers, Machines and Tools, (1979-10), 14; Same as above, Mitutoyo Corporation, Mitutoyo Museum, (1990), 8
- JIS B 7507: 1979, Calipers, Commentary
- Eiju Matsumoto: History of Precision Reading Diagonal Scale, Measurement History Research, 26-1 (2004), 61
- JIS B 7507: 1993, Calipers, 4
- Komei Kyu edited/authored: Chinese Chronological Weights and Measures Review, Science Publisher, Beijing, (1992), Tow-page spread gravue and 20
- Johsen Toh authored, Junichiro Kashima translated: Transition of Development of Calipers, Measurement History Research, 27-1 (2005), 43
- Shigeru Ueno: History of Length Measuring Gages 2, Calipers, Tool Engineer, 1982-08 issue, 70
- Kesakatsu Koizumi: History of Weights and Measures, Agency of Industrial Science and Technology Central Inspection Institute of Weights and Measures, (1961), 7
- Komei Kyu, Conrad Hermann authored, Eiju Matsumoto translated: "Kosho Ritsukann" and "Ruisho" in Chinese Ancient Weights and Measures, Measurement History Research, 28-1 (2006), 37
- Qiu G. and K. Herrmann: The role of the Huangzhong standard pipes and of millet grains in the metrology of ancient China, Measurement History Research, 28-1(2006), 91
- Masaji Sawabe: History of Precision Measurement I, Transition of Length Unit and Standard, the Japan Society for Precision Engineering, Precision Engineering Basic Course (Web), 2009-11-24, 6
- Mitutoyo Corporation Mitutoyo Museum: Box-type sliding caliper, Mitutoyo Collections Revision 3, (2007), 2
- Kesakatsu Koizumi: History of Weights and Measures, Agency of Industrial Science and Technology Central Inspection Institute of Weights and Measures, Coronasha Co. (1961)
- Shokichi Miyazaki: History of Micrometers, the Japan Society of Mechanical Engineering Journal, 85- 769 (1982), 1358
- Shokichi Miyazaki: Visiting the Root of Measuring Insttuments - Micrometers, Machines and Tools, (1979-7), 81; Same as above, Mitutoyo Corporation, Mitutoyo Museum, (1990), 1
- Shigeru Ueno: Transition of Precision Length Measuring Instruments, the Japan Society of Mechanical Engineering Journal, 85- 764 (1982), 752
- Masaji Sawabe: History of Precision Measurement II, Origin and Transition of Micrometers, the Japan Society for Precision Engineering, Precision Engineering Basic Course (Web), (2010-11-16), 3
- Seiji Takada, Hiroaki Sakate, Kinichi Komiya, Isao Ohtsuna: Harmonization Process of Liquid Measure Volume after the Meiji Era, Measurement History Research, 33-1 (2011), 29
- Isao Ohtsuna's data related to Reference 20) was acquired via private communication.
- Mitutoyo Corporation Mitutoyo Museum: Mitutoyo Collections Revision 3, (2007), 7 to 52
- Brown & Sharpe Mfg. Co.: Small Tools Catalog, No.29 (1924), 84, 89-92, 123-133
- Brown & Sharpe Mfg. Co.: Small Tools Catalog, No.31A (1929), 68, 73-76, 108-113
- Brown & Sharpe Mfg. Co.: Small Tools Catalog, No.32 (1935), 80, 85-88, 122-126
- Brown & Sharpe Mfg. Co.: The Shop Tool Manual, No.2 (1964), 45, 54-57
- Brown & Sharpe Mfg. Co.: The Shop Tool Manual, No.76 (1976), 86-93
- L. S. Starrett Co.: Fine Mechanical Tools, Catalog, No.24 (1927), 22-26, 106-123
- L. S. Starrett Co.: Fine Mechanical Tools, Catalog, No.25 (1930), 26-30, 111-119
- L. S. Starrett Co.: Precision Tools, Gage and Saws, No. 28 (1979), 93-99, 121-123
- Adolf Pfeiffer, Mannheim: Werkzeuge und Werkzeug- Kaschinen, Hanptkatalog, B III (1905), 34
- Lufkin Rule Co.: General Catalog No.14, (1958), 84,85,
- Stanley Rule & Level Co.: Stanley Tools Catalog No.34 (1920), 15
- Ted Crum Collection. France.
- Kintsune Shouten: Fine Mechanical Tools & Watch Materials, (1922), 19, 20
- F. H. Rolt: Gauges and Fine Measurements, Vol.2, Mechanical and Co., Ltd. London, (1929), 69
- Fujita Masaru Co. Tokyo: Carl Mahr G.m.b.H.. High Class Precision Tools, Gauges. Catalog, (1931), 5
- Carl Mahr G.m.b.H.: Feinmesszeuge Katalog, 52 M, (1935), 7-31
- Mauser-Messzeug G.m.b.H.: Feinmesszeug Katalog, (1961), 4-15
- Schuchardt & Schutte A. G. ,Berlin: Zeiss Measuring Instruments, C920 (1928), 47
- Tamotsu Aoki: Precision Measurement and Measuring Instruments, Matuzen Inc. (1937), 382
- The Japan Society of Mechanical Engineering Edition: New Edition - History of Mechanical Technologies The Japan Society of Mechanical Engineering, (2010-12), 382
- Kiyoshi Maeda: Mechanical Legacies in Japan, Ohmsha Ltd., (2000-12), 2
- Juici Kusumoto: Nagasaki Iron Mill - Pioneer of Japanese Modern Industry, Chuko paperback pocket edition, Chuokoron-Shinsha, Inc. (1990)
- Masaji Sawabe: History of Precision Measurement I, Transition of Length Unit and Standard, The Japan Society for Precision Engineering, Precision Engineering Basic Course (Web description), (2009-11-24), 15
- Kesakatsu Koizumi: History of Weights and Measures, Agency of Industrial Science and Technology Central Inspection Institute of Weights and Measures, Coronasha Co. (1961), 164
- Toshio Kajiwara: Shungaku Matsudaira's Sliding Caliper, Japan Industrial Archaeology Society Collected Lecture Papers released at the 25th-round (2001 Yearly) General Meeting, (2011), 33
- Suketosi Yajima: Early Scientific Research in Japan, Journal of History of Science, JAPAN, Second edition (1942-06)
- Kesakatsu Koizumi: History of Weights and Measures, Agency of Industrial Science and Technology Central Inspection Institute of Weights and Measures, Coronasha Co. (1961), 37
- Yasuhide Tsuchida, Kenji Yamada, Shintaro Karasawa, Hiroshi Ogawa: Research of Yasaburo Noriyuki Ohno/Yasaburo Norichika Ohno-series Measures - Measures in Collections of the Sanada Tresures Museum (2nd Information) -, The Society of Historical Metrology General Meeting 2011 Collected Preliminary Lecture Copies (2011), 57

52) Masaji Sawab: Performance of Yasaburo Norichika Ohno-made Sliding Caliper, Journal of History of Science, JAPAN, 34-1(2012), 113

53) Shigeo Iwata: Variations of Measures in China, Journal of History of Science, JAPAN, 1-2 (1979), 1

54) Shigeo Iwata: Length Standard in China/Korea/Japan (1st Information) 300 B.C. to A.D. 1700, Journal of History of Science, JAPAN, 16-1 (1994), 43

55) National Museum of Japanese History: Introduction of Gun in the History, (2006-10), 74

56) Toyota Commemorative Museum of Industry and Technology: Toyota Collections, 113 Measuring Tools & Instruments/Drawing Tools, (2010), 76

57) Hachiro Nishida: Calipers, Yoshio Asanaga Editing Chief; Factory Measuring Instrument Lecture Course (1), Nikkan Kogyo Shimbun, Ltd., (1962), 11

58) Japan Precision Measuring Instruments Manufacturers Association: MICRO, Journal of 20th Anniversary of the Foundation, (1974), 34

59) Japan Precision Measuring Instruments Manufacturers Association: MICRO, Journal of 30th Anniversary of the Foundation, (1984), 20

60) Japan Precision Measuring Instruments Manufacturers Association: MICRO, Journal of 50th Anniversary of the Foundation, (2004), 22

61) Societe Genevoise d'Instruments de Physique: As Eighty Years Went By... History of the Societe Genevoise d'Instruments de Physique, (1946), 29-37

62) Societe Genevoise d'Instruments de Physique: SIP History 1862-1962, (1962), 10

63) Tokyo Metropolitan Inspection Institute of Weights and Measures: Century-old Inspection of Weights and Measures in Tokyo, Measuring Instrument Manufacturers and Repair Shops in Tokyo (1976)

64) Agency of Industrial Science and Technology Central Inspection Institute of Weights and Measures: History of 50-old Central Inspection Institute of Weights and Measures, Coronasha Co. (1961), 56

65) Etalon, Switzerland, Precision Measuring Tools, Catalog, No.155 (1956), 7

66) Mauser-Masseug G.m.b.H.: Feinmesszeuge, (1961), 14

67) Mitutoyo Manufacture Co., Ltd.: History of 50-old Mitutoyo Manufacture, (1985), 173

68) JIS B 7507: 1954, Calipers

69) Akira Igarashi: Calipers, The Reason Why a Measurement Error Occurs, 1. Dimensional Measurement in Line, Japan Machinist Co., (1971), 41

70) Imazu, Yano: Dimensional Measurement of Plastic Products with Vernier Caliper, Synthetic Resin, 18-9 (1972), 4

71) Masaji Sawabe: How to Precisely Measure the Dimension and Shape of Plastic Parts, National Organized Technical Development Research Project Results Widespread Presentation Text, Research on Dimension and Shape Measurement of Plastic Parts, The Small and Medium Enterprise Agency, November, Showa 48 (1973), 131

72) Mitutoyo Manufacture Co., Ltd.: Plastic Product-specific Measuring Instrument Catalog, No.4039, 1973, 2

73) Mitutoyo Manufacture Co., Ltd.: Mitutoyo Calipers/Height Gage Catalog, No.23, Edition 9 (1980), 12, 21

74) Mitutoyo Manufacture Co., Ltd.: Micrometer Caliper, Catalog No.10203, (1962), 1

75) JIS B 7517: 1960 Height Gages

76) JIS B 7518: 1960 Depth Gages

77) Mitutoyo Manufacture Co., Ltd.: Mitutoyo Direct-reading Height Gages Catalog, No.192-101 (1971), 12, 1

78) Mitutoyo Manufacture Co., Ltd.: Digimatic Height Gage HD Catalog (1982), 3; New Product News, Reinforced Digimatic Height Gage HHD30 Catalog (1982), 1

79) Mitutoyo Corporation: Precision Measuring Instruments/ Comprehensive Catalog, No.13-34 (2000), 190

80) Shozo Matsushiro, Hiromi Endo, Masaji Sawage, Yasuo Shimoda, Masahiro Igarashi: Digital Micrometer Using Differential Transformer, Central Inspection Institute of Weights and Measures Reports, 5-4 (1956), 337

81) Mitutoyo Manufacture Co., Ltd.: Mitutoyo-Sylvac 10, Comprehensive Catalog, No.13-17, (1982), 97

82) Hans U. Meyer: Measuring Equipment, CH4241/72 (1972-03-22), Patent Bulletin Showa 56-23090 (1981-05-29)

83) Hans U. Meyer: Capacitive Length and Angular Measurement Method, CH8600/ 80-0 (1980-11-21), Patent Bulletin Heisei 2-41685 (1990-09-19)

84) Ingvar Andermo: Measuring Device for Relative Position of Moving Parts, SE7714010-1 (1977-12-09), Patent Bulletin Showa 64-11883 (1989-02-27)

85) Mitutoyo Corporation Mitutoyo Museum: Mitutoyo Collections Revision 4, (2012), 68

86) TESA Precision Co.: Instruments and systems for quality assurance, Doc. No.103.012.8610 (J), (1988) 1.1

87) Mitutoyo Corporation: Precision Measuring Instruments/ Comprehensive Catalog, No.13-28 (1990), 247

88) Mitutoyo Corporation: Precision Measuring Instruments/ Comprehensive Catalog, No.13-30 (1993), 118

89) Ingvar Andermo, Tracy Hanley: Absolute Position Detection Device Combining Light and Capacitance, US07/661840 (1991-02-26), Patent No.2809545 (1998-07-31)

90) Tetsuro Kiriya, Toshitaka Shimomura, Ingvar Andermo, Yasuo Yamaguchi: Development of Absolute Linear Encoder, The Japan Society for Precision Engineering Journal, 61-10 (1995), 1405

91) I. Andermo, T. Shimomura, T. Kiriya, Y. Yamaguchi: An Absolute Linear Encoder Utilizing a Combination of Capacitive and Optical Encoder Technology, Int. J. of Japan Soc. Prec. Engg., 29-1 (1995), 14

92) Ingvar Andermo, Karl Mazreliez: Induction-type Position Detection Device, US08/834432 (1997-04-16), Patent No.3366855 (2002-11-01)

93) Mitutoyo Corporation: Precision Measuring Instruments/ Comprehensive Catalog, No.13-35 (2001), 118

94) Mitutoyo Corporation: Precision Measuring Instruments/ Comprehensive Catalog, No.13-36 (2004), 120

95) A&D Co., Ltd.: Comprehensive Catalog, Electronic Weight and Measure Equipment, (2007)

96) TESA Precision Co.: Hexagon Metrology, TESA.: Standard Gage, Precision Measuring Instruments Catalog; Standard Gage Catalog, (April 2012), 10

97) TESA Precision Co.: TESA Catalog, Digital Caliper Product Information; TESA Technology, (2012), 1

98) Ishida Precision Ltd.: Sylvac Co. Catalog -12; Sylvac SA, Catalog-12, (2012), 8 & 10

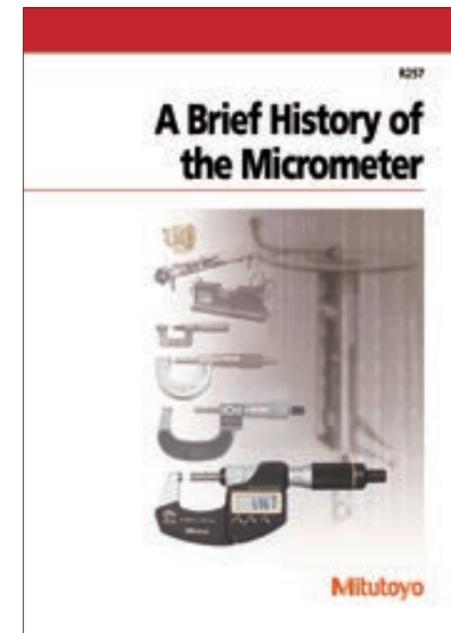
99) ISO 13385-1: 2011 Geometrical product specification (GPS) – Dimensional measuring equipment – Part 1: Calipers – Design and metrological characteristics

This paper reception date: June 3rd, 2013
 Author: Masaji Sawabe Doctor of Engineering
 Mitutoyo Corporation Adviser

A Brief History of the Micrometer/The History of Gauge Blocks

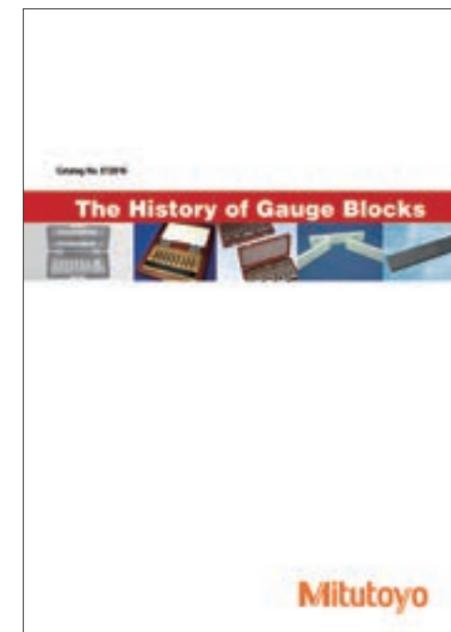
A Brief History of the Micrometer

R257



The History of Gauge Blocks

Catalog No. E12016





**Find additional product literature
and our product catalogue**

<https://www.mitutoyo.co.jp/global.html>

**Our products are classified as regulated items under Japanese Foreign Exchange and Foreign Trade Law. Please consult us in advance if you wish to export our products to any other country.
If the purchased product is exported, even though it is not a regulated item (Catch-All controls item), the customer service available for that product may be affected. If you have any questions, please consult your local Mitutoyo sales office.**

Note: Product illustrations are without obligation. Product descriptions, in particular any and all technical specifications, are only binding when explicitly agreed upon.

MITUTOYO and MICAT are either registered trademarks or trademarks of Mitutoyo Corp. in Japan and/or other countries/regions.

Other product, company and brand names mentioned herein are for identification purposes only and may be the trademarks of their respective holders.

Mitutoyo Corporation

20-1, Sakado 1-Chome, Takatsu-ku, Kawasaki-shi,

Kanagawa 213-8533, Japan

T +81 (0) 44 813-8230

F +81 (0) 44 813-8231

<https://www.mitutoyo.co.jp>