

THERE IS MEASURE IN ALL THINGS.

**HORACE
SATIRES, BOOK I, 35 B.C.**

Metrology

Metrology is presented in the following major topic areas:

- Introduction
- Common Gages & Instruments
- Special Gages
- Gage Selection & Use
- Surface Plate Tools
- Specialized Equipment

Common Gages & Measuring Instruments is divided into the following subject areas:

- Variable Gages
- Attribute Gages
- Transfer Gages
- Measurement Scales

Introduction

Metrology is the science of measurement. The word metrology derives from two Greek words: matron (meaning measure) and logos (meaning logic). With today's sophisticated industrial climate the measurement and control of products and processes are critical to the total quality effort. Metrology encompasses the following key elements:

- The establishment of measurement standards that are both internationally accepted and definable
- The use of measuring equipment to correlate the extent that product and process data conforms to specification (expressed in recognizable measurement standard terms)
- The regular calibration of measuring equipment, traceable to established international standards

The terms measuring tool and measuring instrument are used interchangeably in this text. Some commonly used measuring tools are described in summary form only. The reader is advised to seek other sources, Griffith (2003)¹², Farago (1982)⁹ and Kennedy (1987)¹⁸, for a more in-depth treatment of specific instruments.

Variable Gages*

Variable measuring instruments provide a physical measured dimension. Examples of variable instruments are line rules, vernier calipers, micrometers, depth indicators, runout indicators, etc. Variable information provides a measure of the extent that a product is good or bad, relative to specifications. Variable data is often useful for process capability determination and may be monitored via control charts.

The Steel Rule

The steel rule is a linear scale which is widely used factory measuring tool for direct length measurement. Steel rules and tapes are available in different degrees of accuracy and are typically graduated on both edges. See Figure 3.1 below.

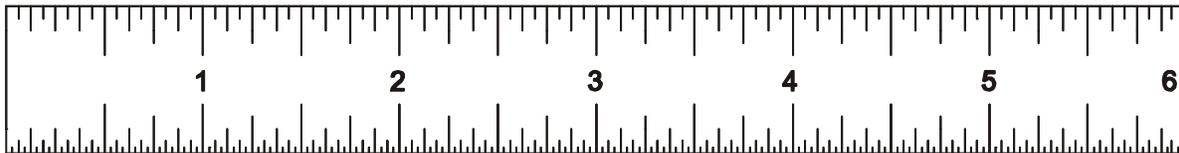


Figure 3.1 A Typical Steel Rule

The fine divisions on a steel rule (thirty-seconds on the one above) establish its discrimination. The steel rule typically has discriminations of $1/32$, $1/64$, or $1/100$ of an inch. Obviously, measurements requiring accuracies of 0.01 " or finer should be performed with other tools (such as a digital caliper).

For maximum accuracy, the rule should measure a part with both butted firmly against a rigid flat surface. The end of a rule may be worn, rounded or damaged which produce errors in measurement. If a flat surface is not available the 1" mark may be used as a reference point.

* The CQI Student should note that CMM and dial indicators listed in the variable gage portion of the BOK are reviewed elsewhere in this Primer Section. CMMs are included in II.E.6 and dial indicators are described in II.A.4.

The Steel Rule (Continued)

Figure 3.2 below shows the correct and incorrect methods of measurement.

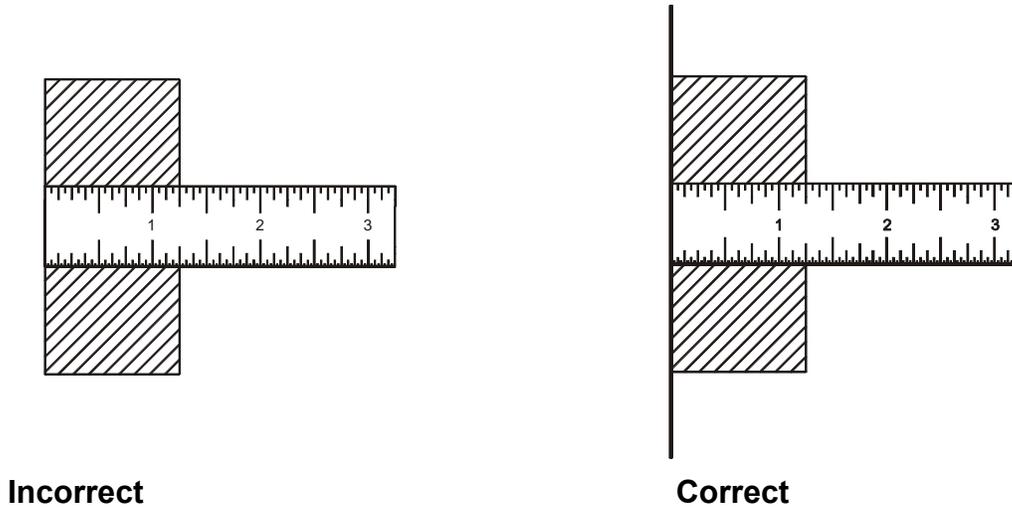


Figure 3.2 Use of a Flat Surface with a Steel Rule

Hook Rules

Steel rules may be purchased with a moveable bar or hook on the zero end which serves in the place of a butt plate. These rulers may be used to measure around rounded, chamfered or beveled part corners. The hook attachment becomes relied upon as a fixed reference. However, by its inherent design, it may loosen or become worn. The hook should be checked often for accuracy.

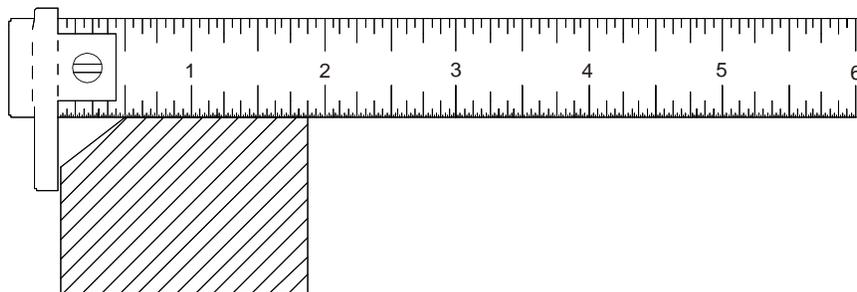


Figure 3.3 Steel Rule with Hook Attachment

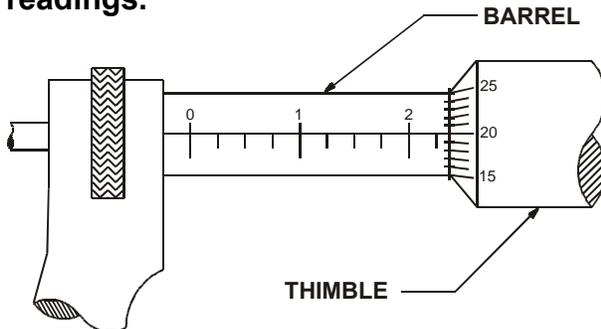
Micrometers

Micrometers, or “mics,” are commonly used hand-held measuring devices. Micrometers may be purchased with frame sizes from 0.5 inches to 48 inches. Normally, the spindle gap and design permits a 1" reading span. Thus, a 2" micrometer would allow readings from 1" to 2". Most common “mics” have an accuracy of 0.001". With the addition of a vernier scale, an accuracy of 0.0001" can be obtained. Fairly recent digital micrometers can be read to 50 millionths of an inch.

Micrometers consist of a basic C frame with the part measurement occurring between a fixed anvil and a moveable spindle. Measurement readings on a traditional micrometer are made at the barrel and thimble interface. Micrometers may make inside, outside, depth or thread measurements based upon the customization desired.

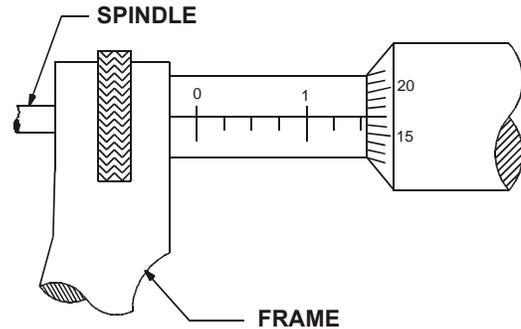
The two primary scales for reading a micrometer are the sleeve scale and the thimble scale. Most micrometers have a 1" “throat.” All conventional micrometers have 40 markings on the barrel consisting of 0.025" each. The 0.100", 0.200", 0.300", etc. markings are highlighted. The thimble is graduated into 25 markings of 0.001" each. Thus, one full revolution of the thimble represents 0.025".

Shown, in the diagrams below, are simplified examples of typical micrometer readings.



Micrometer set at 0.245"

0.200"
+0.025"
+0.020"
0.245"



Micrometer set at 0.167"

0.100"
+0.050"
+0.017"
+0.167"

Figure 3.4 Two Micrometer Reading Examples

Three-Wire Method of Measuring Pitch Diameter

In order to determine the pitch diameter of screw threads by measuring the corresponding over-wire size, the most practical procedure is the use of three wires, actually small hardened steel cylinders, placed in the thread groove, two on one side and one on the opposite side of the screw. The arrangement of the wires, as indicated in the diagram (below), permits the opposite sensing elements of a length-measuring instrument to be brought into simultaneous contact with all three wires, thus providing a dependable measurement of the over-wire distance.

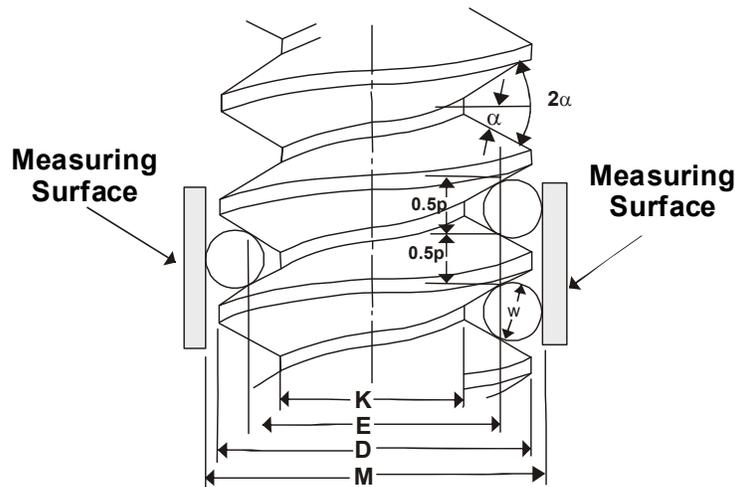


Figure 3.5 An Illustration of Three Wire Measurement

Measuring wires in sets of equal size within a certain diameter range may be used, as long as the wires have a minimum diameter which projects over the crest of the thread, when in measuring position, and a maximum diameter which permits the wires to touch the flanks just below the crest. However, the use of “best-size” wires is recommended. The best wire size may be calculated by:

$$w = 0.5p \sec \alpha$$

Where: w = wire diameter
 α = 1/2 the included thread angle
 p = thread pitch

For a 60° thread, the above formula reduces to:

$$w = 0.57735 p$$

$$p = \text{the thread pitch} = \frac{1 \text{ inch}}{\text{no. of threads/inch}}$$

Three-Wire Method (Continued)

The formula to calculate the pitch diameter after measurement is:

$$E = M + (0.86603p) - 3W$$

Where: E = pitch diameter p = thread pitch
M = over the wire measurement W = wire size used

Example 3.1: Assume that M is 0.360", p is 0.050" and W is 0.030". Calculate the pitch diameter.

$$\begin{aligned} E &= M + (0.86603p) - 3W \\ E &= 0.360 + (0.86603 \times 0.050) - 3(0.030) \\ E &= 0.360 + 0.0433 - 0.090 \\ E &= 0.3133 \text{ inch} \end{aligned}$$

E is the pitch diameter which must be checked with the tolerance limits on the drawing to determine if the part is acceptable.

Gage Blocks

Near the beginning of the 20th century, Carl Johansson of Sweden, developed steel blocks to an accuracy believed impossible by many others at that time. His objective was to establish a measurement standard that not only would duplicate national standards, but also could be used in any shop. He was able to build gage blocks to an accuracy within a few millionths of an inch. When first introduced, gage blocks or "Jo" blocks as they are popularly known in the shop, were a great novelty. Seldom used for measurements, they were kept locked up and were only brought out to impress visitors.

Today gage blocks are used in almost every shop manufacturing a product requiring mechanical inspection. They are used to set a length dimension for a transfer measurement, and for calibration of a number of other tools.

ANSI/ASME B89.1.9 (2002)², *Gage Blocks*, distinguishes three basic gage block forms - rectangular, square and round. The rectangular and square varieties are in much wider usage. Generally, gage blocks are made from high carbon or chromium alloyed steel, however tungsten carbide, chromium carbide, and fused quartz are also used.

Gage Blocks (Continued)

All gage blocks are manufactured with tight tolerances on flatness, parallelism and surface smoothness. Gage blocks may be purchased in 4 standard grades:

Federal Accuracy Grades		Accuracy In Length *
New Designation	Old Designation	
0.5	AAA	± 0.000001
1	AA	± 0.000002
2	A+	+ 0.000004 - 0.000002
3	A & B	+ 0.000008 - 0.000004

* Applies to gage blocks up to 1". The accuracy tolerance then increases as the gage block size increases.

Master blocks are grade 0.5 or 1
 Inspection blocks are grade 1 or 2
 Working blocks are grade 3

Table 3.6 Gage Block Grades

Gage blocks should always be handled on the non-polished sides. Blocks should be cleaned prior to stacking with filtered kerosene, benzene or carbon tetrachloride. A soft clean cloth or chamois should be used. A light residual oil film must remain on blocks for wringing purposes.

Block stacks are assembled by a wringing process which attaches the blocks by a combination of molecular attraction and the adhesive effect of a very thin oil film. Air between the block boundaries is squeezed out. The sequential steps for the wringing of rectangular blocks is shown below. Light pressure is used throughout the process.

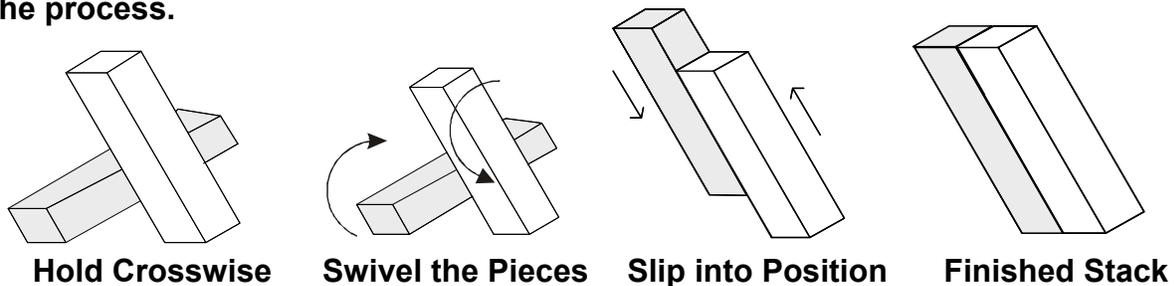


Figure 3.7 Illustration of the Wringing of Gage Blocks

Gage Blocks (Continued)

Wear Blocks

For the purpose of stack protection, some gage manufactures provide wear blocks. Typically, these blocks are 0.050 inch or 0.100 inch thick. They are wrung onto each end of the gage stack and must be calculated as part of the stack height. Since wear blocks “wear” they should always be used with the same side out.

Gage Block Sets

Individual gage blocks may be purchased up to 20" in size. Naturally, the length tolerance of the gage blocks increases as the size increases. Typical gage block sets vary from 8 to 81 pieces based upon the needed application.

Listed below are the contents of a typical 81 piece set:

Ten-thousands blocks	(9)	0.1001, 0.1002 ... 0.1009
One-thousands blocks	(49)	0.101, 0.102 ... 0.149
Fifty-thousands blocks	(19)	0.050, 0.100 ... 0.950
One inch blocks	(4)	1.000, 2.000, 3.000, 4.000

Also included in the set, are two wear blocks that are either 0.050" or 0.100" in thickness.

Minimum Stacking

A minimum number of blocks in a stack lessens the chance of unevenness at the block surfaces. Stack up 2.5834" using a minimum number of blocks:

2.5834	
- <u>0.1004</u>	(use 0.1004" block)
2.483	
- <u>0.133</u>	(use 0.133" block)
2.350	
- <u>0.350</u>	(use 0.350" block)
2.000	(use 2.000" block)

This example requires a minimum of four blocks and does not consider the use of wear blocks.

Attribute Gages

Attribute gages are fixed gages which typically are used to make a go, no-go decision. Examples of attribute instruments are master gages, plug gages, contour gages, thread gages, limit length gages, assembly gages, etc.

Attribute data indicates only whether a product is good or bad (in most cases, it is known in what direction the product is good or bad). Attribute gages are quick and easy to use but provide minimal information for production control.

Snap Gages

Snap gages are used to check outside dimensions in high volume operations. Snap gages are constructed with a rigid frame and normally contain hardened anvil inserts. These gages may have provisions for a small range of adjustments and can be used to make rapid “go, no-go” decisions.

Ring Gages

Ring gages are used to check external cylindrical dimensions, and may also be used to check tapered, straight, or threaded dimensions. A pair of rings with hardened bushings are generally used. One bushing has a hole of the minimum tolerance and the other has a hole of the maximum tolerance.

Frequently, a pair of ring gages are inserted in a single steel plate for convenience and act as “go”, “no-go” gages. A groove is often cut in the outer surface of the “no-go” gage to provide distinction. Ring gages have the disadvantage of accepting out of round work and taper if the largest diameter is within tolerance.

If the part is made to specification, then the go ring gage should slip onto the part, which checks to make sure the part is not too large in size. If the part is made to specification, then the no-go ring gage should not fit onto the part, which checks to make sure the part is not too small in size. Progressive ring gages combine the two gages into one unit, as shown in Figure 3.8. (Griffith, 2003)¹²

Ring Gages (Continued)

A thread ring gage is used to check male threads. The go ring must enter onto the full length of the threads and the no-go must not exceed three full turns onto the thread to be acceptable. The no-go thread ring will be identified by a groove cut into the outside diameter.

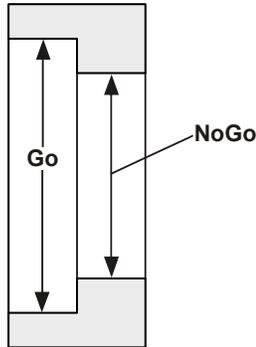


Figure 3.8 Progressive Ring Gage

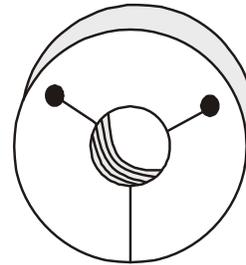


Figure 3.9 A No-go Thread Ring Gage

Plug Gages

Plug gages are generally “go, no-go” gages, and are used to check internal dimensions. The average plug gage is a hardened and precision ground cylinder about an inch long. The “go, no-go” set is usually held in a hexagonal holder with the “go” plug on one end and the “no-go” plug on the other end. To make it more readily distinguishable, the “no-go” plug is generally made shorter.

The thread plug gage is designed exactly as the plug gage but instead of a smooth cylinder at each end, the ends are threaded. One end is the go member and the other end is the no go member. If the go member enters the female threads the required length and the no go does not enter more than three complete revolutions, the threads are deemed acceptable. A threaded plug gage has a feature used to clear chips out of the female threads. This feature is called the chip groove or notch.

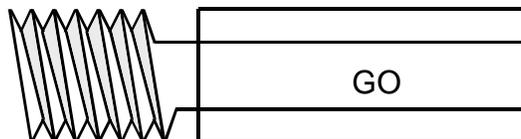


Figure 3.10 A Thread Plug Gage

Spring Calipers

Spring calipers are transfer tools that perform a rough measurement of wide, awkward or difficult to reach part locations. These tools usually provide a measurement accuracy of approximately 1/16 inch.

Although these calipers are referred to as spring calipers, there are different varieties (spring joint, firm joint, lock joint, etc.) which describe the type of mechanical joint that connects the two sides of the unit.

A spring caliper measurement is typically transferred to a steel rule by holding the rule vertically on a flat surface. The caliper ends are placed against the rule for the final readings. See the diagram below.

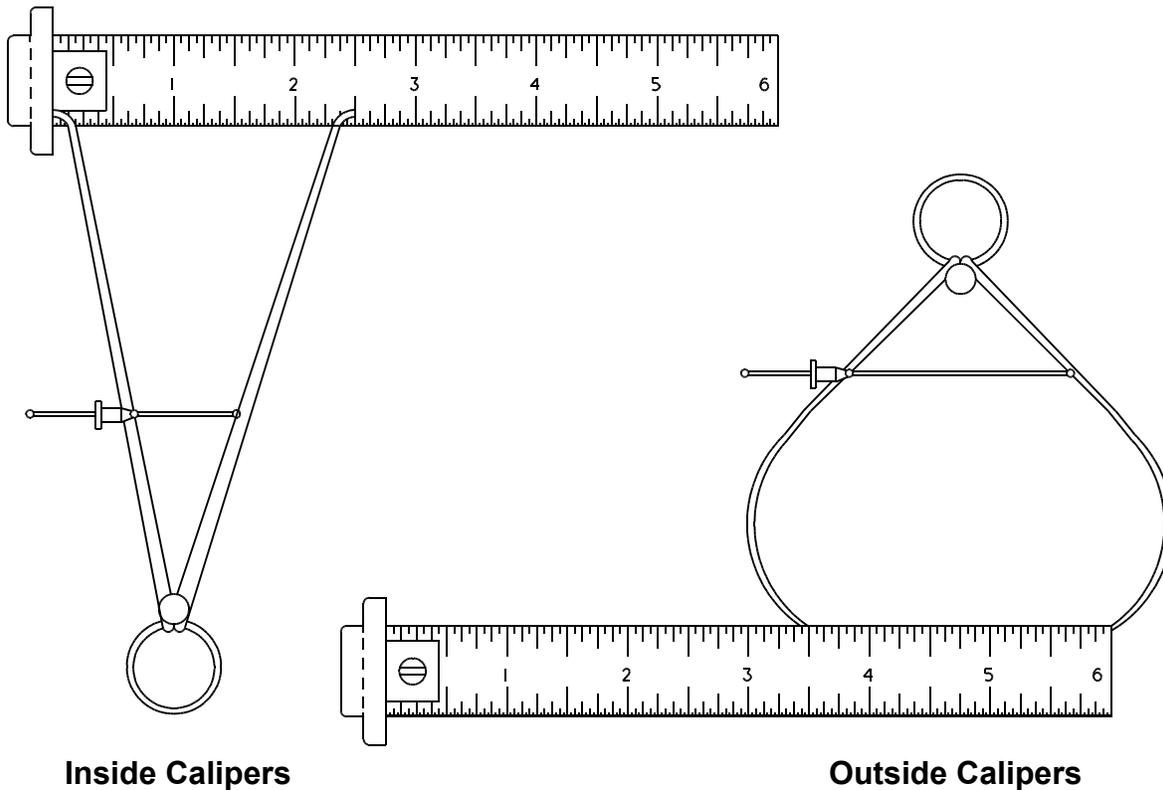


Figure 3.11 Spring Caliper Applications