III. METROLOGY

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

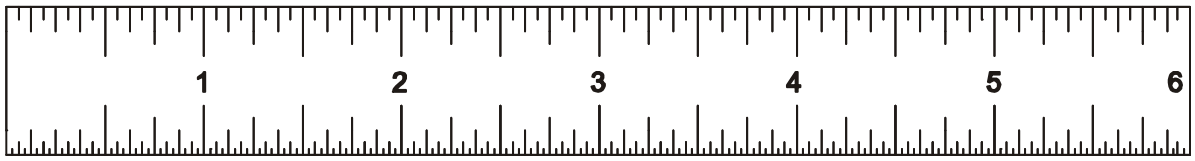
Metrology is the science of measurement. The word metrology derives from two Greek words: matron (meaning measure) and logos (meaning logic). Metrology encompasses the following key elements:

- **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**
- **The regular calibration of measuring equipment, traceable to established international standards**

Variable Gages

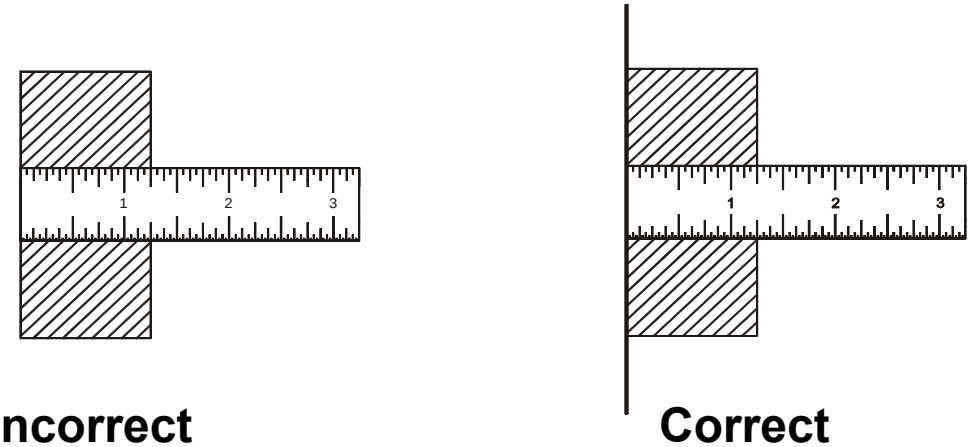
The Steel Rule

Steel rules and tapes are available in different degrees of accuracy and are typically graduated on both edges.



A Typical Steel Rule

The steel rule typically has discriminations of 1/32, 1/64, or 1/100 of an inch. Measurements requiring accuracies of 0.01" or finer should be performed with tools such as a digital caliper.



Incorrect **Correct**

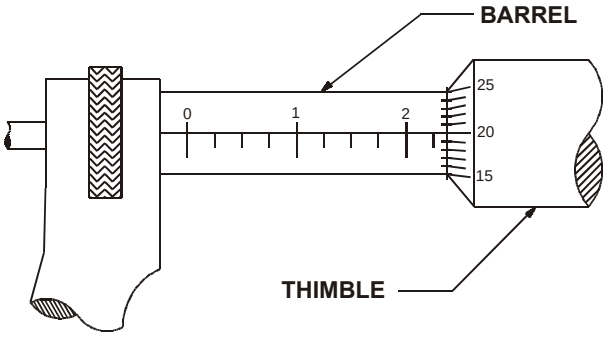
Use of a Flat Surface with a Steel Rule

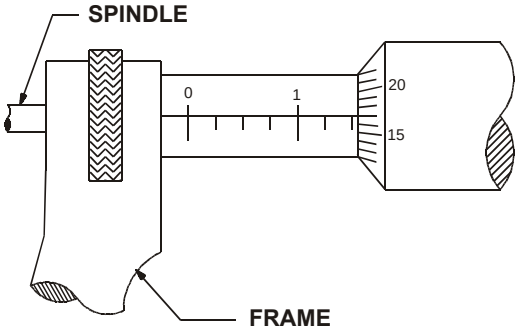
III. METROLOGY
COMMON GAGES / VARIABLE GAGES

II.A.1

Micrometers

Micrometers normally permit a 1" reading span, thus, a 2" micrometer would allow readings from 1" to 2". Most "mics" have an accuracy of 0.001", with the addition of a vernier scale, an accuracy of 0.0001" can be obtained. Digital micrometers can be read to 50 millionths of an inch.





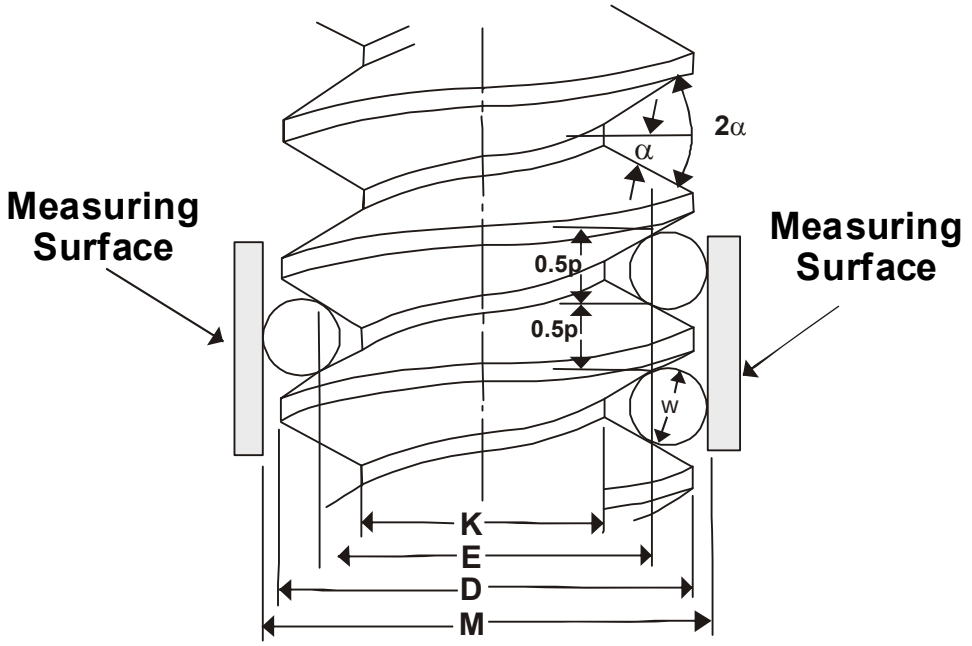
Micrometer set at 0.245"

Micrometer set at 0.167"

0.200"	0.100"
+0.025"	+0.050"
+0.020"	+0.017"
0.245"	+0.167"

Two Micrometer Reading Examples

Three-Wire Method for Pitch Diameter



An Illustration of Three Wire Measurement

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:

$$w = 0.57735\ p$$

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

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

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

E is the pitch diameter.

Gage Blocks

Carl Johansson of Sweden developed steel gage blocks or "Jo" blocks to an accuracy within a few millionths of an inch. 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.

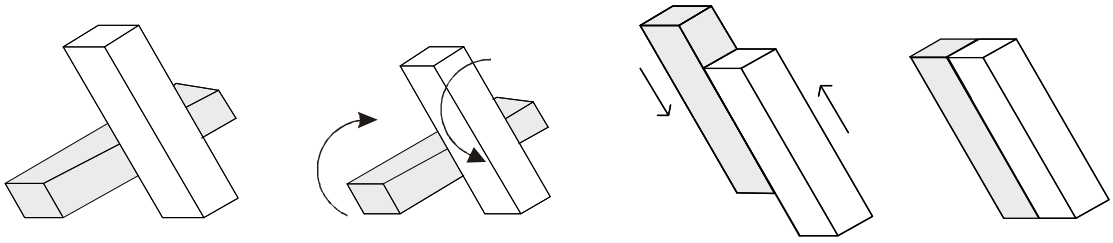
ANSI/ASME B89.1.9, *Gage Blocks*, distinguishes three forms - rectangular, square and round. Gage blocks are made from high carbon or chromium alloyed steel, tungsten carbide, chromium carbide, or fused quartz.

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

Gage Block Grades

Gage Blocks (Continued)

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. The sequential steps for the wringing of rectangular blocks is shown below. Light pressure is used throughout the process.



Hold Crosswise	Swivel the Pieces	Slip into Position	Finished Stack

Illustration of the Wringing of Gage Blocks

Gage Blocks (Continued)

Gage Block Sets

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**

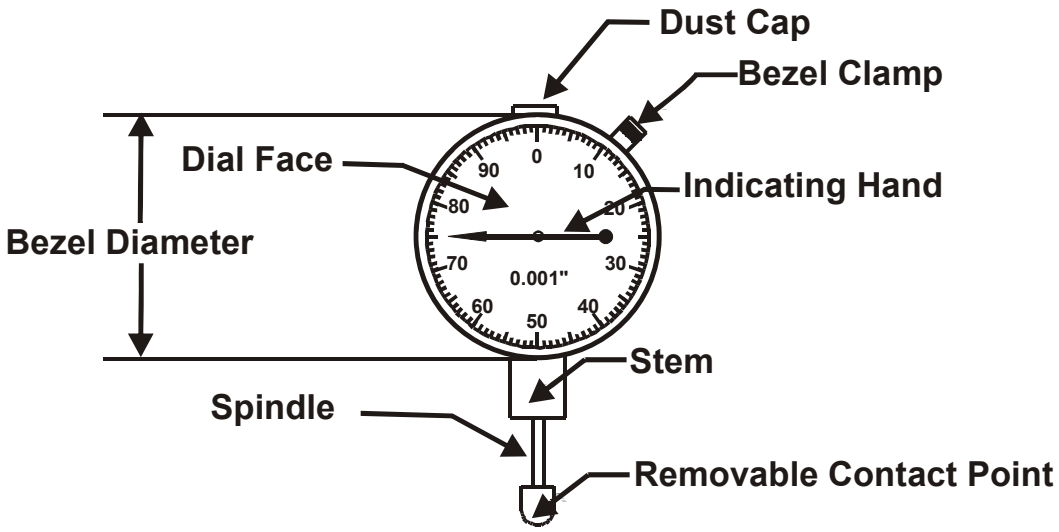
Also included in the set, are two wear blocks that are either 0.050" or 0.100" in thickness.

Minimum Stacking

2.5834	**(desired total)**
- 0.1004	**(use 0.1004" block)**
2.483	
- 0.133	**(use 0.133" block)**
2.350	
- 0.350	**(use 0.350" block)**
2.000	**(use 2.000" block)**

Dial Indicators

Dial indicators are mechanical instruments for measuring distance variations.

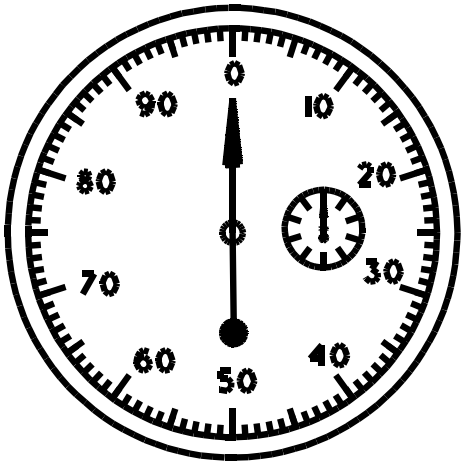


Continuous Dial with 0.001" Graduations

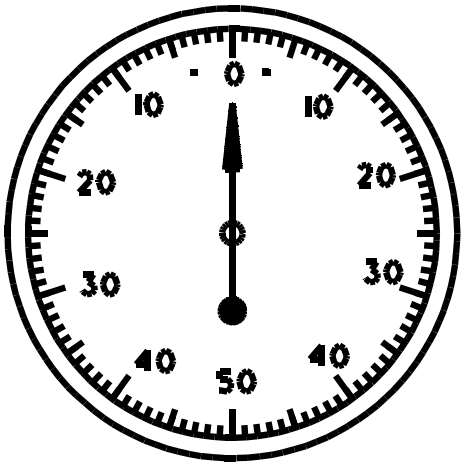
Commonly available indicators have discriminations from 0.00002" to 0.001" with a wide assortment of measuring ranges.

Dial Indicators (Continued)

Two examples of dial indicators:



Continuous Dial With Revolution Counter



Balanced Dial

Contact Tips

Contact points are available in a variety of shapes, e.g. standard, tapered, button, flat, wide-face, etc. The tips are made from a number of wear resistant materials, e.g. carbide, chrome plated steel, sapphire or diamond.

Temperature Probes

Some of the key types are:

- **<u>Pyrometer:</u> A pyrometer is an instrument used for measuring high temperatures.**
- **<u>Thermocouple:</u> Thermocouples consist of two different metal wires, which are joined at one end and connected to a specialized voltmeter at the other.**
- **<u>NTC thermistor:</u> NTC (negative temperature coefficient) thermistor is a temperature sensor that uses the resistance properties of ceramic/metal composites to measure the temperature.**
- **<u>RTD sensor:</u> Resistance temperature detectors (RTDs) consist of a fine wire wrapped around a ceramic or glass core.**
- **<u>Thermopile:</u> Thermopile infrared (IR) sensors are designed to measure temperature from a distance by detecting an object's infrared (IR) energy.**

Borescopes

Borescopes are optical devices used for visual inspection in inaccessible areas. These devices consist of a rigid or flexible tubes with an eyepiece on one end and an objective lens on the other. They are linked by a relaying optical system.

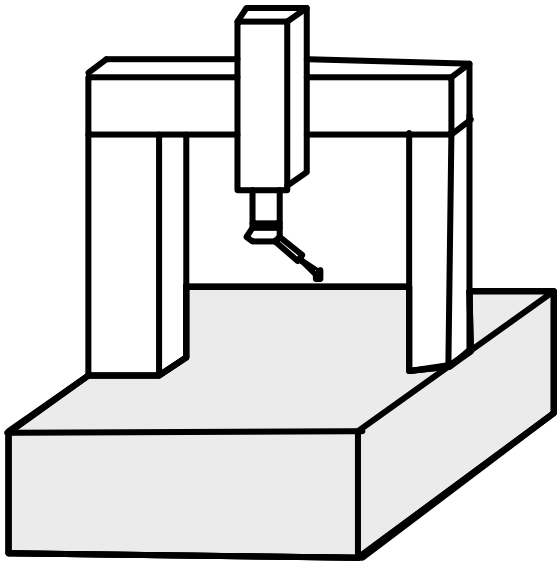
Thermometers

Thermometers measure temperature or temperature gradients. They can display results in degrees Fahrenheit, degrees Celsius, or degrees Kelvin. A thermometer consists of a temperature sensor (such as mercury in glass display) and some means of converting any change into a numeric value.

Coordinate Measuring Machines (CMMs)

A coordinate measuring machine (CMM) is used for dimensional measurements in three dimensions. The CMM has three basic directions of movement, the X, Y and Z axes. The Z axis is vertical, the X axis is horizontal left to right, and the Y axis is horizontal front to back. Some machines have a W axis, which is rotational.

CMMs use either a contact probe or a non-contact method based on optical imaging of the test object. Laser beam scanning of object is used to create a digital, three dimensional image of the surface of complex objects.



Coordinate Measuring Machine

Coordinate Measuring Machines (Cont.)

CMMs are available in three general types (with numerous variations):

1. **Bridge-type CMM. This is the most common type. A horizontal beam is supported vertically. The probe is mounted on the vertical axis, which is connected to the horizontal beam.**

2. **Cantilever-type CMM. The probe is mounted on a horizontal arm. This type is not as accurate as the bridge-type CMM, but is often used for large parts.**

3. **Portable CMM. The probe is mounted on a moveable arm, which has multiple joints.**

The biggest advantage of coordinate measuring machines is that they can quickly and accurately measure complex parts at multiple points.

CMMs can make multiple measurement with a single setup, as compared with conventional surface plate methods, requiring multiple setups.