2. MEASURING TOOLS AND PROCESSES:

In this chapter we will only look at those instruments which would typically be used during and at the end of a fabrication process. Such instruments would be capable of measuring up to 4 decimal places in the inch system and up to 3 decimal places in the metric system. Higher precision is normally not required in shop settings.

The discrimination of a measuring instrument is the number of “segments” to which it divides the basic unit of length it is using for measurement. As a rule of thumb: the discrimination of the instrument should be ~10 times finer than the dimension specified. For example if a dimension of 25.5 [mm] is specified, an instrument that is capable of measuring to 0.01 or 0.02 [mm] should be used; if the specified dimension is 25.50 [mm], then the instrument’s discrimination should be 0.001 or 0.002 [mm].

The tools discussed here can be divided into 2 categories: direct measuring tools and indirect measuring or comparator tools.

2.1 Terminology:

Accuracy:	can have two meanings: it may describe the conformance of a specific dimension with the intended value (e.g.: an end-mill has a specific diameter stamped on its shank; if that value is confirmed by using the appropriate measuring device, then the end-mill diameter is said to be accurate). Accuracy may also refer to the act of measuring: if the machinist uses a steel rule to verify the diameter of the end-mill, then the act of measuring is not accurate.
Precision:	defines the degree of exactness (expressed by the number of decimal places, or, mathematically speaking, the number of significant figures). Therefore there are many degrees of precision, depending on application and design requirements. Typically, measurements in the range of 0.010" or 0.2 mm require precision measuring instruments.
Discrimination:	refers to the degree to which a measuring instrument divides the basic unit of length it is using for measurement. For example: -the odometer of a car divides 1 km into 100 m increments -the micrometer divides 1 inch into 1000 or even 10 000 increments (0.001" or 0.0001").

2.2 Measuring process:

Before measuring:	-determine the degree of accuracy and precision required -determine the necessary discrimination -select the most reliable tool for this application
Measuring:	-ensure the tool is properly calibrated -ensure the tool and the part are clean -perform the measurement in the same manner if repeated measurements are required
After measuring:	-clean (and oil, if necessary) the tools and store appropriately.

2.3 Linear measuring tools:

2.3.1 Steel rule:

Steel rules are very useful for making quick measurements with up to 1/32" or 0.5 [mm] accuracy. They have typical discriminations of 1/16", 1/32", 1/64" or 1/100" for inch based rules and 0.5 [mm] for metric rules and are available in varying lengths. Measurements of 1/64" or 1/100" require practice and are not very reliable; for this kind of accuracy other instruments should be used.

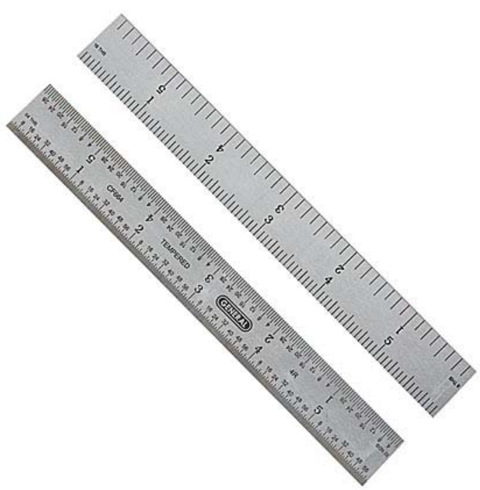

Figure 2.3.1: Front and Back of a Machinist's Rule

The rule shown in Figure 2.1, front and back, has discriminations of 1/8", 1/16", 1/32" and 1/64". Many other discrimination combinations are available, such as inch units on one side and mm on the other side.

Since steel rules have a thickness, it is essential that, whenever using a steel rule, the line of sight must be perpendicular to the face of the rule, otherwise a reading error (parallax error) will be incurred.

2.3.2 Vernier calipers:

Vernier calipers are actually “improved” rules: they use 2 jaws to “identify” the linear distance and an improved scale, the Vernier scale, to arrive at a more precise measurement.

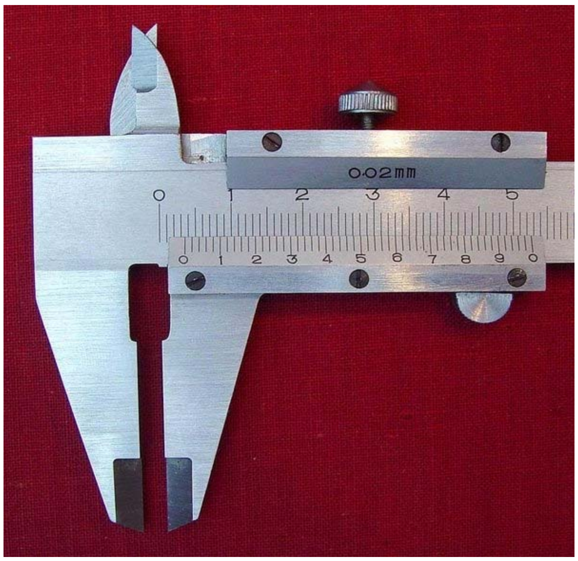

Figure 2.3.2: Metric Vernier Caliper

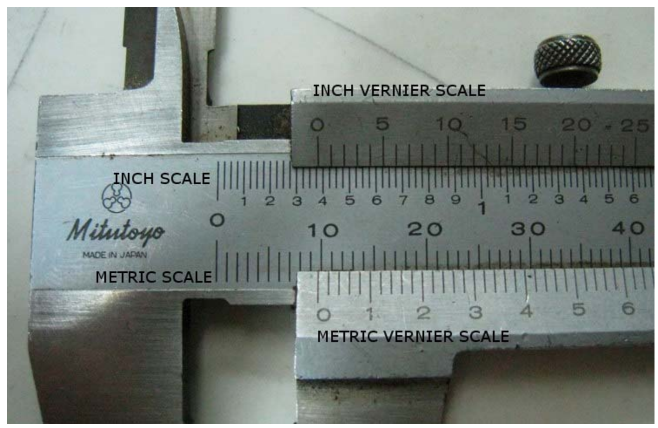

Figure 2.3.3: Dual Unit Vernier Caliper

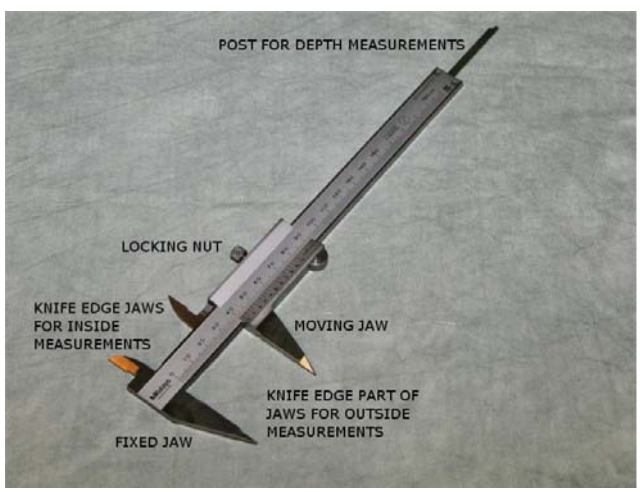

Figure 2.3.4: Components of a Vernier Caliper

Reading Vernier scales:

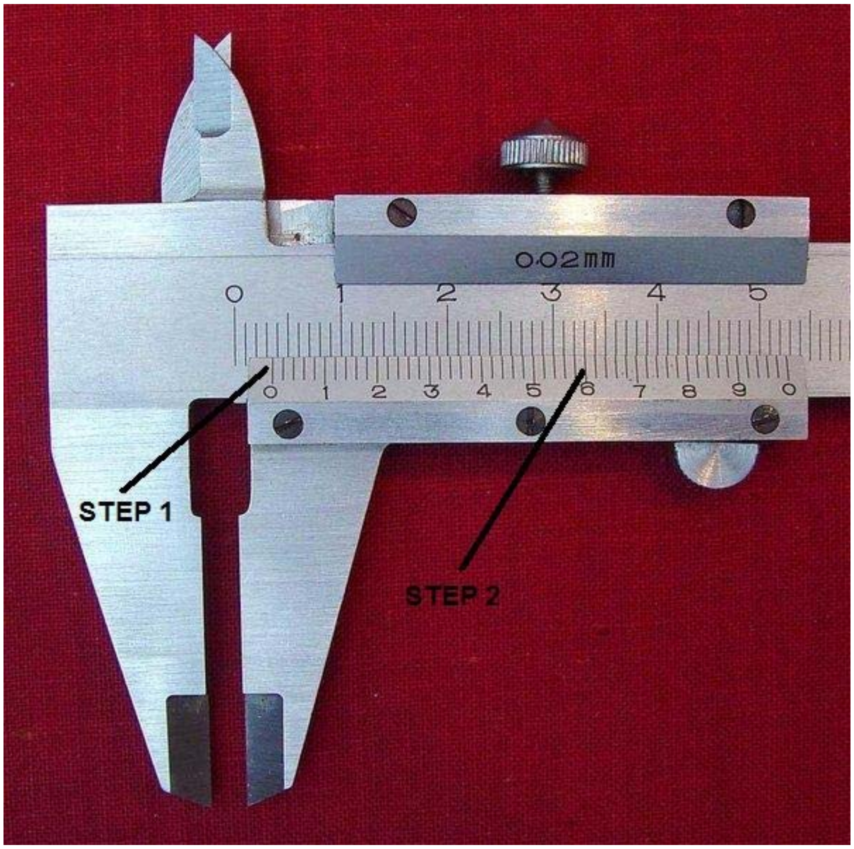

Figure 2.3.5: Reading Vernier Scales

Step 1: On the main scale find the value “below” the zero of the Vernier scale. In the image above, that would be 3 [mm]. Make sure that you know what the graduations on the main scale represent.

Step 2: Determine the graduation line on the Vernier scale, which coincides with a graduation line on the main scale; depending on the quality of your eyesight, this could be the line at the “6" of the Vernier scale or the next line. If it is the “6" line, then the measurement would be:

3 [mm] + 0.60 [mm] = 3.60 [mm] (NOT 3.6 [mm])

If it is the line following the “6" on the Vernier scale, then the measurement would be:

3 [mm] + 0.62 [mm] = 3.62 [mm]

Make sure you are aware of the value of each increment on the Vernier scale, for this case: 0.02 [mm].

Example 1:

This appears to be the Vernier scale on an angle measuring tool; therefore the base units on the main scale will be degrees, on the Vernier scale 0.1 degrees.

Step 1:	*the zero of the Vernier scale is at 19 degrees.*
Step 2:	*the first alignment is at 0.8 degrees.*
Answer:	*the angle is 19.8 degrees.*

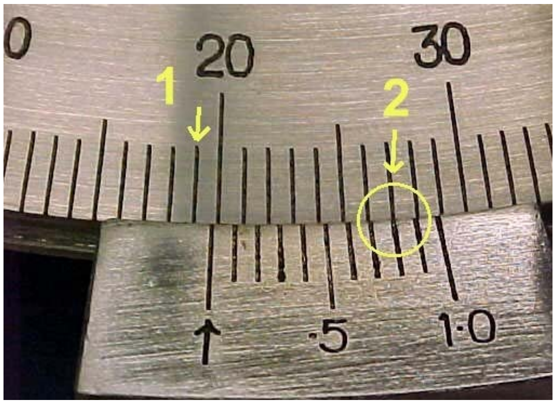

Figure 2.3.6: Angular Vernier Scale

Example 2:

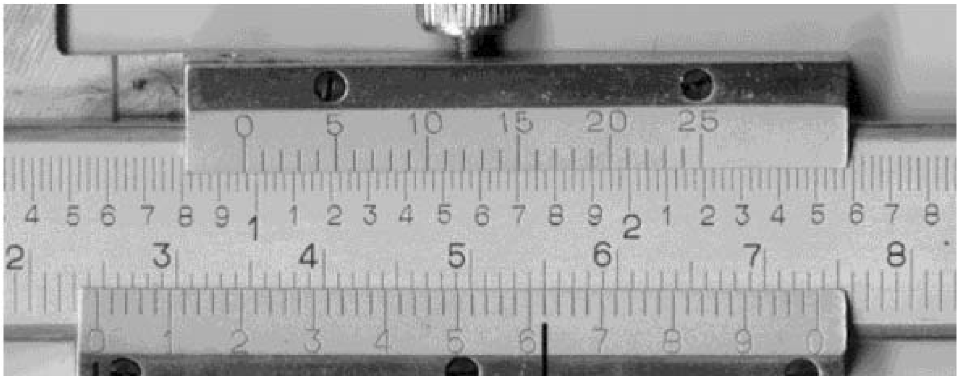

Figure 2.3.7: Dual Vernier Scales

Find both, the inch and the metric value shown in the figure above.

Inch scale:	*again, make sure that you know what the increments on both scales are.*		
		Step 1:	*the zero of the Vernier scale is at: 0.95" on the main scale.*
		Step 2:	*the first alignment is 3 lines past the "15" on the Vernier scale: 0.018"*
		Answer:	*0.968"*
Metric scale:		*Step 1:*	*24 [mm]*
		Step 2:	*0.62 [mm]*
		Answer:	*24.62 [mm]*

Measuring procedure:

-Ensure that the jaws of the caliper are clean: close the jaws, hold them against a light source: there must not be any gap between the jaws. At that point check that the instrument reads zero.

-Whenever possible use the knife edge part of the jaws for your measurements, especially when the two measurement surfaces are not parallel.

-If at all possible, read the caliper while still on the work-piece; else use the locking screw.

-Attempt to exert the same jaw pressure for all measurements.

2.3.3 Dial calipers:

Instead of using a Vernier scale, these calipers use a dial indicator for the higher discrimination aspect of the instrument; otherwise they are no different from Vernier calipers. Since there is a “gap” between the rotating hand and the dial face, the line of sight, when reading the instrument, must be perpendicular to the face of the dial or else a reading error will occur.

Figure 2.3.8: Dial Caliper

2.3.4 Digital calipers:

A digital read-out replaces all scales. It is important to zero the calipers before taking measurements and select the appropriate units (metric or imperial).

Figure 2.3.9: Digital Caliper

If the caliper appears to be well used or even “abused”, ensure that the instrument is still calibrated: take something of known dimension and verify it using the caliper.

2.3.5 Outside micrometers:

Standard micrometers have a discrimination of 0.001" or 0.01 [mm], those with a Vernier scale have discriminations of one magnitude higher. Digital micrometers may have a discrimination as fine as 0.00005". Their only limitation is the limited range: they typically are only capable of measuring over a range of 1" (or ~25 mm). This means in order to make measurements of ~20 mm and ~40 mm, two different micrometers would have to be used.

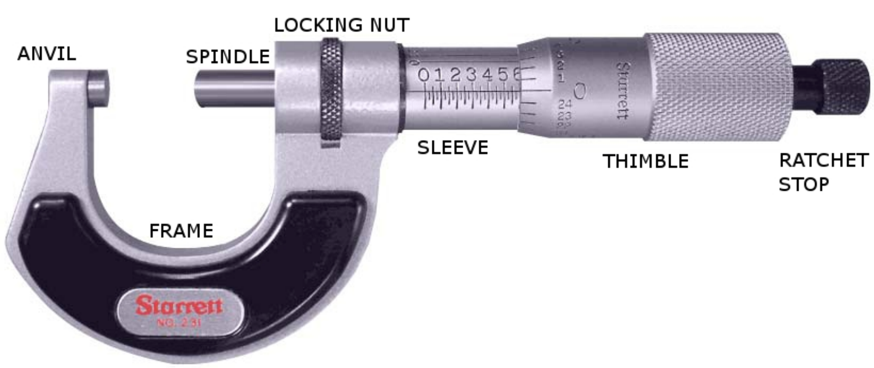

Figure 2.3.10: Outside Inch Vernier Micrometer

The spindle should only be moved using the ratchet stop and not the thimble to prevent any damage to the hardened spindle and anvil faces due to excessive pressure. The ratchet stop contains a slip clutch which will begin to slip at the proper pressure, thus also ensuring constant measurement pressure. The thimble can be used when opening the instrument.

Figure 2.3.11: Micrometer Set 1" to 4"

Figure 2.3.11 shows a set of micrometers, capable of measuring:
-from 0" to 1"
-from 1" to 2"
-from 2" to 3" and
-from 3" to 4".
Note that each instrument has a range of 1" only.
Metric micrometer sets are available in increments of 25 mm.

Micrometers with a discrimination of 0.001", 0.02 [mm] or 0.01 [mm] have the main scale along the sleeve and the secondary scale around the thimble. Instruments with a discrimination of 0.0001" or 0.001 [mm] have an additional Vernier scale around parts of the sleeve.

A description of micrometers and how to read them can be found at:
http://www.jmtest.com/Micrometers-starrettnew222_p1_5.pdf

Note: before using any analogue instruments be aware of the discrimination of each one of the scales and ensure that, when the jaws closed, the instrument reads zero.

Example 1: Shown in the figures below is part of an inch Vernier micrometer. What is the measured dimension?

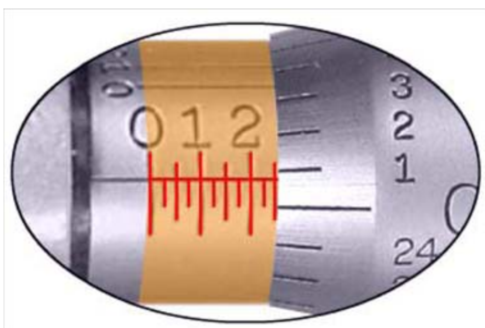

Figure 2.3.12: Main Scale

Figure 2.3.13: Vernier Scale

On the main scale on the sleeve the reading would be 0.250", on the thimble scale the reading is 0.000" and on the Vernier scale the first matching lines are at 0.0007".

Answer: 0.250" + 0.000" + 0.0007" = 0.2507"

Example 2: Ignoring the barely visible Vernier scale on this metric micrometer, determine the measured dimension.

The increments on the main scale are in 0.5 [mm], and therefore we arrive at 5.5 [mm].

On the thimble scale we get a reading of 0.28 [mm].

Answer:
5.5 [mm] + 0.28 [mm] = 5.78 [mm]

Figure 2.3.14: Metric Micrometer Scales

Outside micrometers are also available with digital read-outs.

Figure 2.3.15: Digital Outside Micrometer

Other types of micrometers are the inside micrometer and the depth micrometer. Be aware that the depth micrometer has a “backwards” sleeve scale.

2.4 Comparison Instruments:

Sometimes these instruments are referred to as Transfer Instruments: the tool itself is not capable of producing a measurement, but is used to “simulate” the dimension which needs to be measured. A suitable tool (Vernier Caliper, Micrometer etc.) is then used to determine the actual dimension.

Many instruments fall into this category: simple calipers, telescoping gauges, small hole gauges, thickness gauges, dial indicators and optical comparators.

2.4.1 Transfer calipers:

Transfer calipers are convenient tools when taking measurements of parts which are still mounted in a machine and where it is difficult or impossible to use an actual measuring tool. The process is quite simple: lock the jaws of the caliper in the correct position and then use a conventional instrument to obtain an actual measurement. Their accuracy is somewhat limited.

Figure 2.4.1: Transfer Calipers

2.4.2 Telescoping gauges:

Figure 2.4.2: Telescoping Gauges


Figure 2.4.3: Telescoping Gauge and Vernier Caliper

One or both ends of the telescoping gauge can be pushed inward, the gauge is then inserted into the hole, then the locking nut is used to fix the gauge ends in their position and the instrument is removed from the hole. A standard measuring tool is then used to determine the dimension.

2.4.3 Dial indicators:

Dial indicators show the deviation of a dimension from a “true” dimension.

Figure 2.4.4: Dial Indicator

The dial indicator consists of a plunger which can move up or down moving the dial hand in either a clockwise or counter-clockwise direction. The smaller dial indicates the number of full revolutions of the large hand. Dial indicators have a limited range of travel (the one in Figure 2.2.18 has a travel of 0 - 3 mm), and a discrimination of 0.01 mm or typically 0.001" for inch based dial indicators. Ensure that the plunger axis is always perpendicular to the surface which is being evaluated otherwise a measurement error will be incurred.

Setting up a dial indicator:

Figure 2.2.19 shows a dial indicator mounted on a typical stand which in turn is placed on a rigid surface. A reference (master) specimen of exactly known height is then placed under the plunger and the bezel is rotated so that the instrument reads exactly zero; ensure that the plunger can still travel in both directions and is not "bottomed out" in one direction. The instrument is now set up to compare a specimen to the "calibrated" height. The instrument will indicate the deviation of that dimension from the "calibrated" standard.

Figure 2.4.5: Dial Indicator and Stand

Two main sources of error:

The plunger axis is not perpendicular to the surface of the specimen being measured (cosine error) and the line of sight is not perpendicular to the dial face (parallax error).

As always: ensure that the plunger tip and the surface to be measured are clean.

Dial indicators are also available in digital form.

2.4.4 Dial test indicator:

This instrument is used for the same type of measurements as the dial indicator, but has a finer discrimination: typically 0.0005" to 0.0001" or 0.002 mm to 0.001 mm.

Figure 2.4.6: Dial Test Indicator

Dial test indicators are used exactly the same way as dial indicators.

Because of the pivoting probe, there is the potential for another type of error: the arc versus cord-length error.

To avoid this error, don’t use this instrument when larger variations in the measurement can be expected.

2.4.5 Gauge blocks:

Gauge blocks are a set of precise reference blocks which are used to establish a specified (reference) height. They come in stets of standard sizes and need to be "wrung" together for the correct overall dimension. The process of "wringing" ensures that there is no cumulative error due to the build up of air-films between the gauge blocks.

Gauge blocks must be cleaned before AND after use.

Figure 2.4.7: Gauge Block Set

Figure 24.8: Wrung Gauge Blocks