

Manufacturing and metrology of mechanical parts

- Most of the small (<1 m) parts for optics are made by cutting from oversized stock on a few common machines. These can be driven by a skilled operator, or by numerical control:
 - Milling machine (aka “mill” or “Bridgeport”)
 - Lathe
 - Drill press

Other processes are used as needed:

- Near net shape forming (Rolling, casting, extruding, stamping)
- Surfacing (bead blasting, grinding, lapping)
- Welding, brazing
- EDM (Electrical discharge machining)
- Precision cutting (Laser, abrasive water jet)

Different materials have very different limitations –
Get to know the guys in the shop

Rules of thumb for machined parts

± 1 mm for coarse dimensions that are not important
(0.040 inches or “forty thousandths”)

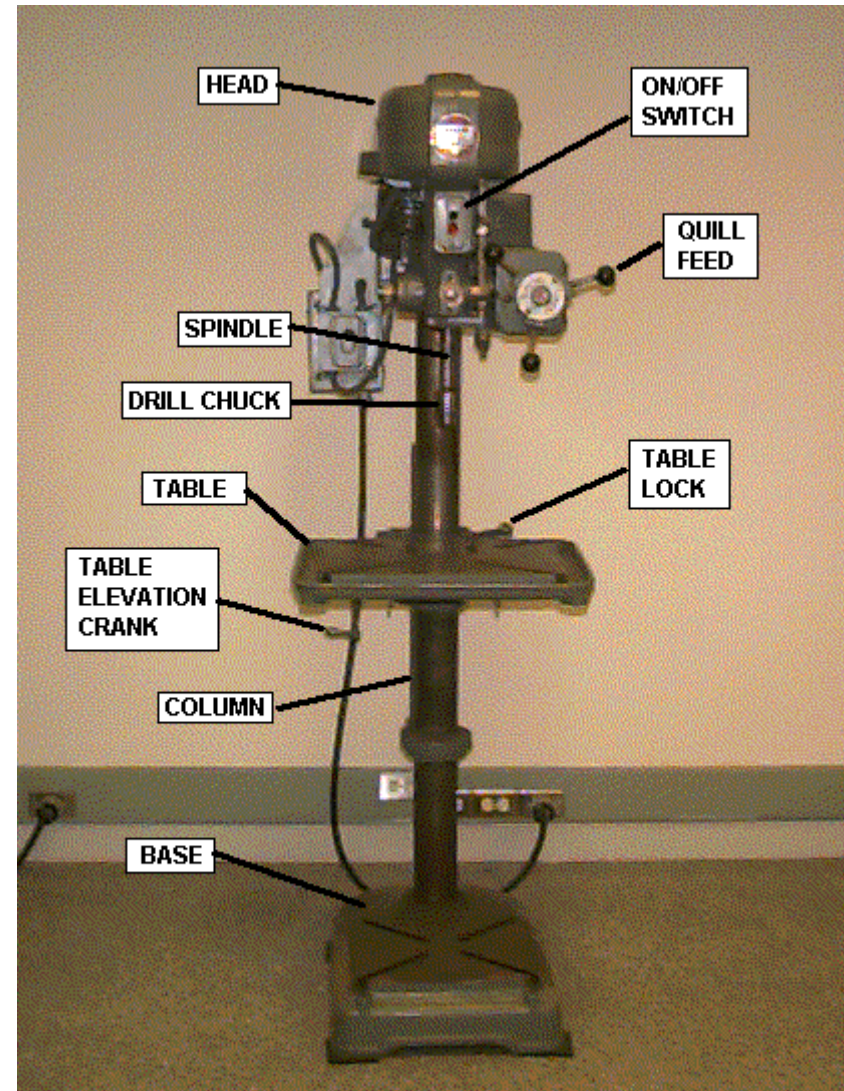
± 0.25 mm for typical machining without difficulty
(0.010 inches or “ten thousandths”)

± 0.025 mm precision machining, readily accessible
(0.001” inches or “one thousandths” or “1 mil”)

$< \pm 0.002$ mm high-precision, requires special tooling
(0.0001” or “one ten-thousandths” or “one tenth” or
“one hundred millionths”)

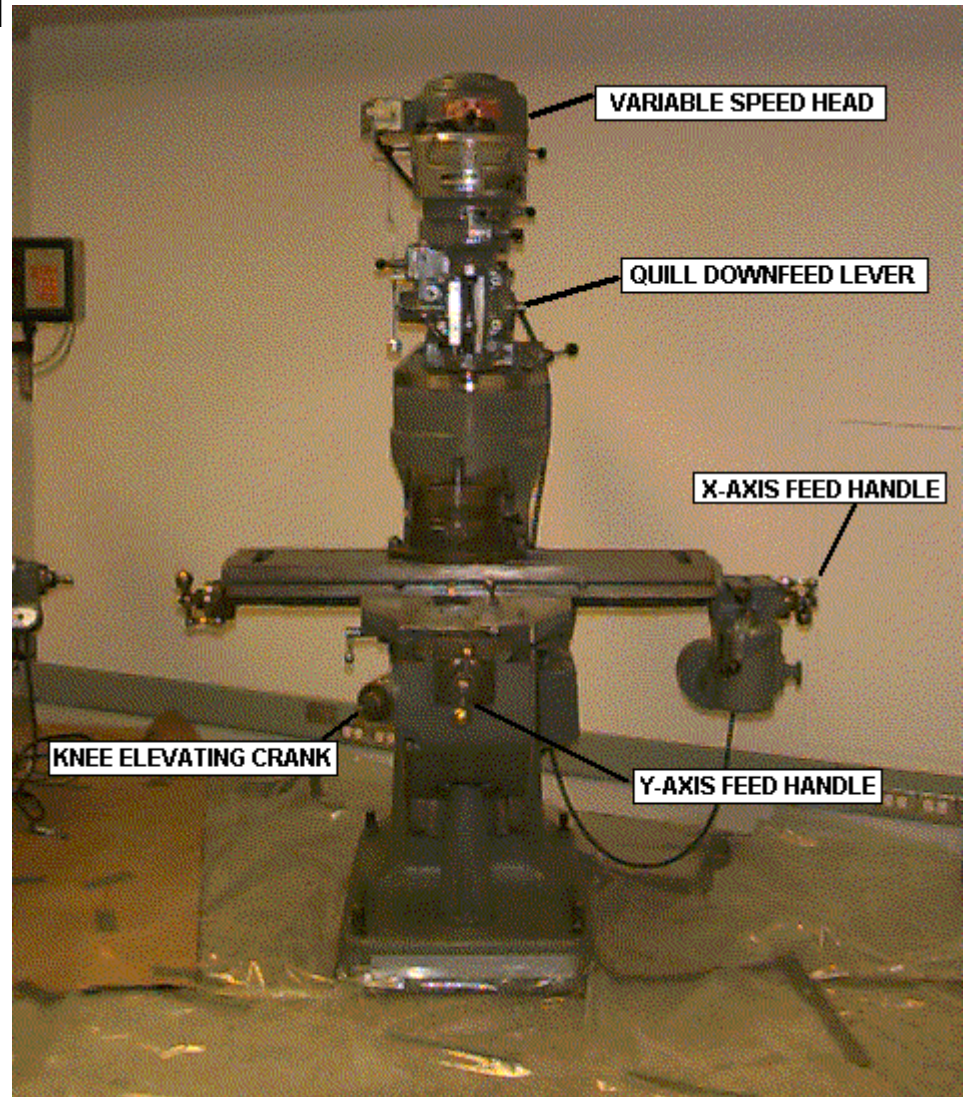
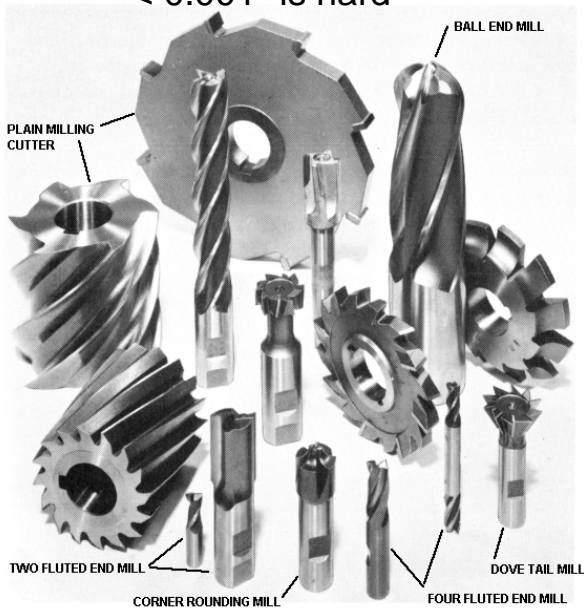
Drill Press

- Clamp part to table, drill holes one at a time
- Drilling, reaming and tapping
- Use center drill to locate holes to $<0.005''$.
- Holes drilled to $0.002''$ diam, reamed to $<0.001''$ diam



Milling machine

- Part is moved under rotating cutting tool
- Limitations:
 - Deformation of part to clamping
 - Backlash, stage limitations
 - Registration accuracy
 - Machine dynamics
 - Tool wear
- Accuracy
 - 0.005" accuracy is easy
 - < 0.001" is hard

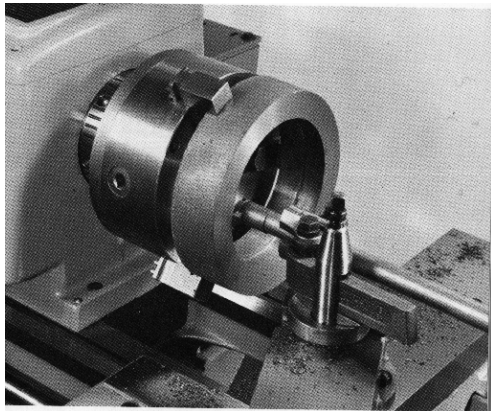


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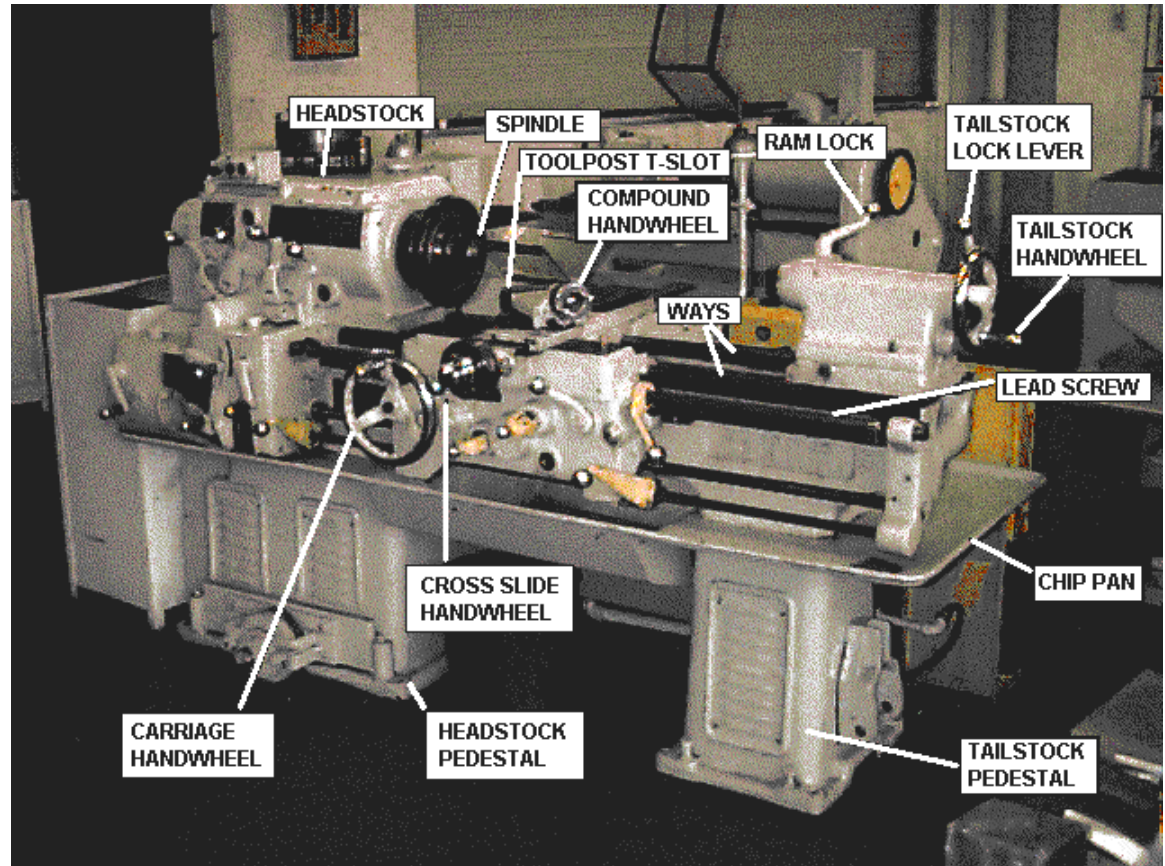
<http://www-me.mit.edu/Lectures/MachineTools/mill/intro.html>

Lathe

- Part is rotated under tool
- Limitations:
 - Deformation of part to clamping
 - Backlash, stage limitations
 - Registration accuracy
 - Machine dynamics
 - Tool wear
- Accuracy
 - 0.005" accuracy is easy
 - < 0.001" is hard



Boring!



<http://www-me.mit.edu/Lectures/MachineTools/lathe/intro.html>

Numerically Controlled (NC) machines

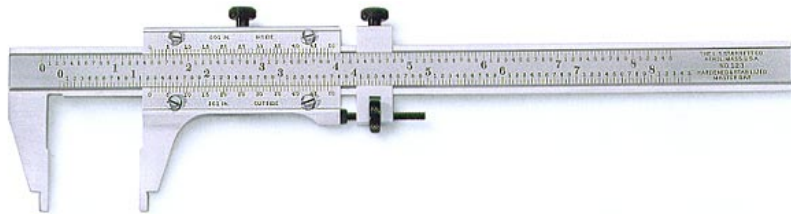
- Very flexible, can make complex parts efficiently
- Accuracy 0.002" is common, <0.0001" is possible
- NC Mill, lathe, EDM
- Make complex parts, straight from the CAD output
- Well maintained machines produce excellent performance



Common tools for measuring length

- Plastic ruler: Good for quick, rough measurements. Most practical measurements in the lab will be made with the ruler. Be careful -- the end of the ruler usually does not coincide with the 0 mark
- Steel rule: Allows much more accuracy, costs more.
- Tape measure: Good for quick measurements over wide distance variations. High quality surveying tapes can be used for measuring over dozens of meters to sub-millimeter accuracy.
- Calipers: These are common, inexpensive, fairly accurate, and versatile. Use them for measuring outside dimensions, inside dimensions, and depth.
- Height gage: Usually used on a flat granite table. Measures height from ~1 to 30 inches
- Micrometer: This is a fine pitch screw with accurate marks. Use the vernier for highest accuracy.
- Outside micrometers: A frame holding a micrometer for measuring outside dimensions. These can be purchased for measuring up to about 10 inches.
- Inside micrometers: Holds a micrometer for measuring inside dimensions. These are made with extensions that can be put together for measuring up to 20 feet.
- Gage blocks: Highly accurate for defining length standards for 0.1 – 4 inches. Special length standards can be purchased for much longer distances.
- Indicator: Can be digital or dial. Often used for measuring motion, such as runout on a spindle
- Depth gage: Uses a micrometer or indicator to measure depth.
- Telescoping gages: Measures small gaps, calibrate with outside micrometer

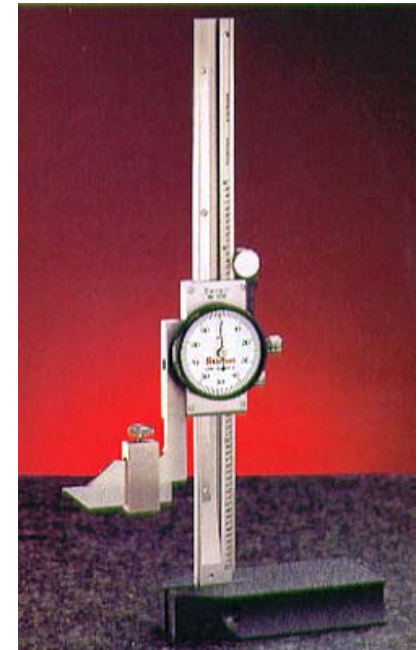
Calipers



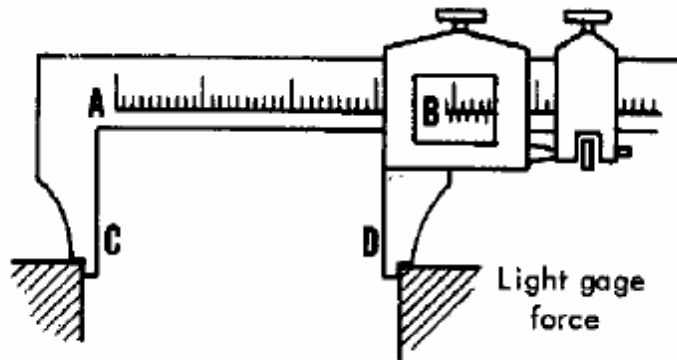
depth



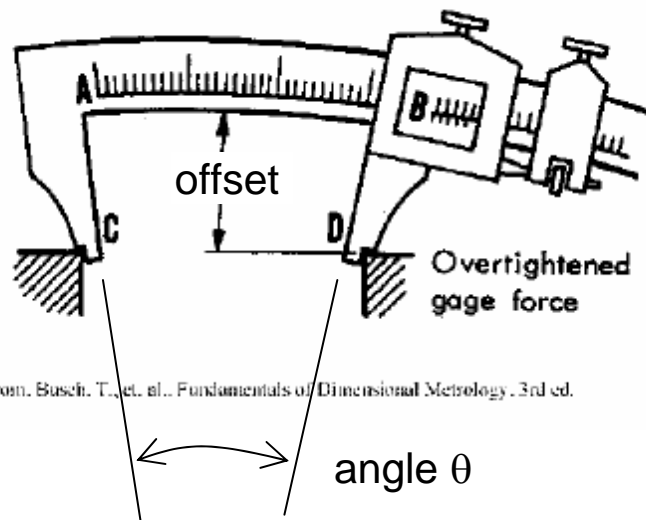
height



Abbe offset error



from: Busch, T., et. al., Fundamentals of Dimensional Metrology, 3rd ed.



from: Busch, T., et. al., Fundamentals of Dimensional Metrology, 3rd ed.

Offset = 0



$$\text{Error} = \text{offset} * \text{angle}$$

Micrometers



outside

inside

depth



Indicators



Gage blocks, standards

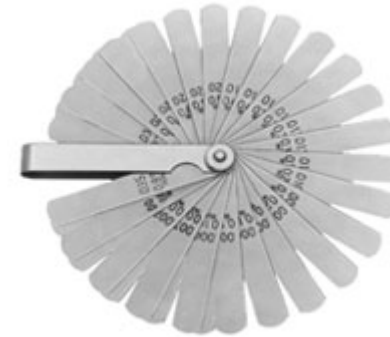
Gage blocks



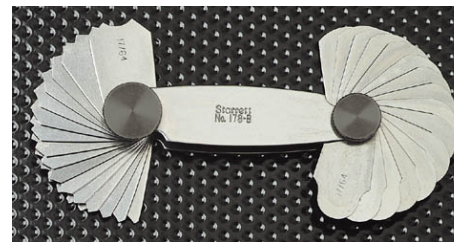
Length standards



Thickness (feeler) gage



Fillet/radius gage



Step gage



Create accurate datum features

- Flat mirror for angle
- Tooling ball for 3D position at a point
- Plug gauge (cylinder) for 2D position



Quality control for mechanical parts

- CMM
Coordinate Measuring Machine
 - Measure relative to datum surfaces, compare with computer model of part for QC
 - 10 μm accuracy is common
 - 0.5 μm accuracy is available
- Comparator
 - Uses imaging system
 - $\sim 1 \mu\text{m}$ resolution
 - $\sim 0.1\%$ accuracy
- Portable systems:
 - Romer arm
 - Laser tracker

