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”)

< ± 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

http://www-me.mit.edu/Lectures/MachineTools/drill/intro.html
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

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

\[ \text{Error} = \text{offset} \times \text{angle} \]

Offset = 0
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
  – ~1 µm resolution
  – ~0.1% accuracy

• Portable systems:
  – Romer arm
  – Laser tracker