Machining Techniques

Dimensions, Tolerance, and Measurement

Available Tools

Why Machine Stuff?

- Research is by definition "off-road"
  - frontier work into the unknown
- You can’t just buy all the parts
  - mounting adapter between laser and telescope
    - first-ever cryogenic image slicer
- Although there are some exceptions
  - optical work often uses “tinker toy” mounts, optical components, and lasers
  - cryogenics often use a standard array of parts
  - biology, chemistry tend to use standardized lab equipment
- Often you have to design and manufacture your own custom parts
  - learning about the capabilities will inform your design
  - otherwise designs may be impractical or expensive

Critical Information

- If you ask a machinist to make you a widget, they'll ask:
  - what are the dimensions?
  - what are the tolerances?
    - huge impact on time/cost
  - what is the material?
    - impacts ease of machining
  - how many do you want?
  - when do you need it/them?
  - what budget does this go on?
    - at $50 to $80 an hour, you'd best be prepared to pay!
- We'll focus on the first two items

Dimensions

- You want to make a part that looks like the one above
- How many dimensions need to be specified?
  - each linear dimension
  - each hole diameter (or thread type)
  - 2-d location of each hole
  - total: 22 numbers (7 linear, 5 holes, 10 hole positions)
Notes on previous drawing

- Some economy is used in dimensioning
  - repeated 0.129 diameter holes use 4x to denote 4 places
  - 4 → 1
  - connected center marks on holes allow single dimension
  - 8 → 4
- Numbers in parentheses are for reference (redundant)
- Dimension count:
  - 16 numbers on page
  - 6 linear plus 2 reference (don’t count)
  - 6 hole position, representing 10
  - 2 hole descriptors, representing 5
  - total information: 21 numbers (equal height of tabs implied)
- note: depth mark on 0.129 holes is senseless
  - artifact of the way it was made in SolidWorks

Standard views

- In American (ANSI) standard, each view relates to the others on the page such that:
  - pick the “main” view
  - a view presented on the right of the main view is what that part would look like if you looked at the part from the right side of the main view
  - a view above the main view is how the part looks from above the main view
  - etc.
- The examples on the right come from a good page:
  - http://pengatory.mit.edu/2.007/Resources/drawngifs/
- The international (ISO) standard is exactly opposite!!

Tolerances

- From the previous drawing, we see useful information in the title block
  - made from aluminum, only one, to be anodized (relevant for threads)
  - dimensions in inches; trust numbers, not drawing scale
  - XX values held to 0.010 inches
  - XXX values held to 0.002 inches
Another example

A closer look; #1
- New features:
  - radius spec.
  - angular spec.
  - counterbore spec.
  - detail (A) notation
- Note different tolerances, alloy specification

A closer look; #2
- New features:
  - depth spec. for tapped hole
  - countersink spec.
  - hidden lines (dashed)
Machining

- The primary tools in a machine shop:
  - lathe: for cylindrically symmetric parts
  - part rotator, tool on x-y stage
  - milling machine (or mill): rectangular parts, hole patterns
  - spindle rotates tool, part on x-y-z stage
  - drill press: for low precision or chasing pilot holes
  - like a mill, except no fine motion control, thus no side-cut capability (a matter of holding strength as well as motion)
  - bandsaw: for roughing out stock
  - circular band of a saw blade makes for a continuous "hack saw"
  - sandpaper, files, granite block
  - grinding wheel (make lathe tools, diamond pins)
  - measurement equipment

Lathe Capabilities

- Precision outer diameter
- Precision inner diameter
- Stepped and angled transitions
  - can drive tool at angle other than 90°
  - with numerical control, arbitrary profiles possible
- Facing off
  - flat, or even conical
- Threading (though complicated, advanced skill)
  - outer thread
  - inner thread
  - complete control over pitch, multi-thread, etc.
- Boring
  - usually with drill bit (possibly followed by reamer) in tail stock
  - but can use boring bar to make larger holes
lathe tools are usually shaped by the machinist using a grinding wheel

a “boring bar” lets you get deep inside a part for making an inner diameter (for holes larger than available drill bits & reamers)

The Milling Machine

Milling Machine Capabilities

- Surfacing/Shaping
  - fly cutting; facing edges
- Pockets
  - tightness of corners depends on diameter of bit
- Slots
- Hole Patterns
  - with table encoders, easily get to 0.001 inch (25 microns)
- With numerical control, arbitrary shapes/cutouts
  - gets around etch-a-sketch problem: can draw circles, etc.
- Simple and Complex Angles
- Boring (can use boring bar here, too)
Mill Bits

- square end-mills are the workhorse bits:
  - pockets
  - slots
  - edge trim
  - facing

- ball-end mills make rounded pockets or spherical pockets; also fillets

- corner-rounders form rounded corners!

- conical end-mill for chamfers

Drills and Reamers

- standard "jobber" drill: will flex/walk, follow pilot

- stub drill for less walk/greater rigidity

- center drill establishes hole position with no walk

- reamers (straight or spiral)
  - finish off hole (last several thousandths)
  - precise hole diameter
  - for insertion of dowel pins, bearings, etc.
  - plunge while spinning, extract still

- countersink: for screw heads & deburring hole

Drilling Practices

- Drills come in fractional inches, metric, and a standard wire gauge index
  - wire gauge index is most common in U.S.: most finely graded
  - see [http://www.carbidedepot.com/formulas-drillsiz.htm](http://www.carbidedepot.com/formulas-drillsiz.htm)

- Drills walk when pushed into unbroken surface
  - must use a punch to establish a conical defect for drill to find
  - or use a center drill (no walk) to get the hole started
  - stub drills better than jobber, but not as good as center drill

- Use pilot hole for larger holes
  - especially if precision important: use several steps so drills primarily working on walls

Taps and Dies: making threads

- Taps thread holes, after pre-drilling to the specified diameter
- Taper tap for most applications
- Plug tap for getting more thread in bottomed hole
  - preferably after plug already run
- Bottom tap for getting as many threads as possible in bottomed hole
  - preferably after plug already run
- Dies for outside thread: seldom used
  - buy your screws & threaded rod!
• Final part outer dimensions are 1.550x0.755x0.100
  - so find 1/8-inch aluminum stock and cut on bandsaw to something
    bigger than 1.625x0.8125 (1 5/8 by 13/16)
  - de-burr edges with file or belt sander
• Establish outer dimensions
  - get 0.755 dimension
    • put in mill table vice on parallels, part sticking about 0.1 inches above
      jaws
• Procedure, cont.
  – get 0.100 dimension
    • center in jaw, with guaranteed > 0.030 above jaw: machining
      into vice is very bad. NEVER let the tool touch the jaw!
    • use large-ish end-mill or even fly-cutter to take down surface by
      0.010; take out and de-burr
    • flip part to remove other side (skin) by an additional 0.015,
      measuring before final cut (in place, if possible)
• Establish hole pattern
  – leaving in place, establish coordinate origin
    • use edge-finder to get edge positions, resetting encoders to
      zero at edge-finder jump
    • remember to account for 0.100 edge-finder radius (need to re-zero
      at 0.100 in appropriate direction)
  – center drill each hole position
    • use small center drill, in collet if possible (rather than chuck)
    • at each coordinate pair, run in center drill as far as you can
      without exceeding final hole size
• Procedure, cont.
  – drill holes
    • use #30 drill on four holes
    • use #20 drill for 8-32 pre-tap
      – see http://www.3-lexus.net/public/aco/3dsaptdril.html
    – take part out and de-burr holes (with countersink in hand)
• Cut two notches out
  – place part in vice so that the tab that will remain is completely free of vice jaws
    • use edge-finder to establish left-right origin
    • measure end-mill diameter carefully (maximum extent of teeth)
    • work out x-positions corresponding to full cut on both sides
    • bring up knee to touch material, set to zero
    • with end-mill off to side, bring up knee 0.400 inches (usu. 4.00
      turns of crank)
Procedure, cont.

- begin swiping 0.020 at a time off of edges until you are 0.005 from designated stopping points
- move end-mill to side so that final travel will be against blade direction for best finish (climb cut)
- bring up knee by final 0.005
- go final 0.005 in x-direction for final cut
- make final cut, then walk away in x to finish bottom cut
- end-mills cannot be plunged unless material at center of end-mill is already cleared out: they aren’t drills

- Tap 8-32 hole with taper tap
- Final de-burr, final measurement check
- Clean part, check fit to mating piece(s)

Measurement Tools

- General Purpose Caliper
- Micrometer
  - reading a micrometer:
- Dial Indicator
- Depth Micrometers
- Cleaning is a very important part of measurement

Intro to SolidWorks

SolidWorks Overview

- SolidWorks is a totally fantastic design package that allows:
  - full 3-D “virtual” construction/machining
  - excellent visualization: rendering and rotation
  - feedback on when enough dimensions are established
  - parameters such as volume, mass, etc.
  - conversion from 3-D to 2-D machine drawings
  - assembly of individual parts into full assemblies
  - warnings on interferences between parts in assemblies

- Typical sequence:
  - 2-D sketch in some reference plane, with dimensions
  - extrude sketch into 3-D
  - sketches on surface, followed by extrude or cut, etc.
Our Exposure to SolidWorks

- Computers in lab have SolidWorks on them
- Pick a machining piece you want to model
  - or find/dream-up your own, but be careful to pick appropriate difficulty level
  - if it’s your own creation, you must describe its purpose
- Measure relevant dimensions of piece to model
- Go through SW online tutorials until you have enough knowledge to make your 3-D model
- Make 3-D model, and turn this into 2-D machine drawing
  - with dimensions in “design” units and appropriate tolerances

Assignments

- Reading from Chapter 1:
  - (black = 3rd ed.; red = 4th)
    - sec. 1.1 except 1.1.8, sec. 1.1 except 1.1.8
    - sec. 1.2: secs 1.2, 1.3
    - secs, 1.3.4–1.3.8; secs 1.4.1–1.4.4, 1.4.8
    - sec. 1.4: sec 1.5
- SolidWorks Tutorial & part emulation, including:
  - 3-D part, matching measurements
  - 2-D drawing a machinist would enjoy
  - description of part function, if not a pre-made part
  - brief write-up including difficulties overcome, estimated mass (from SolidWorks model), and a brief description of how one would make the part—roughly at level of second indentation (dash) in lecture detail of the example part
  - see website for (definitive) lab instructions/details