Week 5 - CNC milling and routing

PREP WORK

1. Ensure the CNC machine is operational
2. Ensure that all tools necessary for working with the CNC machine are available - wrenches, double-sided tape, ShopVac
3. Ensure that a variety of end mills are available for demonstration and use
4. Ensure the CNC host interface machine and software is operational
5. Prepare or gather simple and appropriate 2D and 3D CAD designs for demonstration
6. Prepare or gather pre-made examples to demonstrate:
    a. Effects of different toolpath passes
    b. End mill shapes and sizes
    c. 2D vs 2.5D vs 3D designs
7. Gather scrap materials for experimentation (foam, wood, wax, metals)
8. Gather personal ShapeOko for demonstration

Outline

1. *Discussion of Curiosity Handbook work since last class session*
2. Show-and-tell and conceptual introduction to machine
3. In-depth tour of CNC machine and features
4. Discussion of materials compatibility and safety
5. Discussion of end mills - flutes, sizes, end shapes, length, material, collets
6. Discussion of toolpaths - roughing, smoothing, finishing
7. Overview of advanced topics - two-sided milling, rotary cutting, 3D contact scanning
8. *Guided demonstration of entire project workflow*

Show-and-tell and conceptual introduction to machine

1. Demonstration and discussion of pre-made pieces
2. What is a CNC milling machine? = a machine that uses sharp bits and a rotary tool to carve designs into and out of blocks of material
3. What can a CNC milling machine do? = can carve both 2D and 3D designs in many different kinds of materials. This one can even do 3D contact scanning!
4. Why use a CNC milling machine instead of a …
    a. *Laser cutter* = does not burn edges, can handle thicker material, and can use a wider variety of materials
    b. *3D printer* = capable of much smoother surface finish, can create certain designs faster (with smart machine use), can create objects out of many more kinds of materials (including ABS!)
5. What can't a CNC milling machine do? = it cannot reach underneath overhanging features without special tools

In-depth tour of the CNC machine

1. Machine features and specifications
    a. *Model name* = Roland Modela MDX-40A
    b. *Spindle*
        i. Very low runout (wobble) drill.
        ii. User-controllable speed from 4,500 to 15,000 RPM
    c. *Table / work surface / bed*
        i. Dimensions = 12 x 12”
        ii. Meant to hold spoil board, **not** your work piece
    d. *Z axis travel / stroke / plunge depth*
        i. Up to 4 ⅛” to bed
        ii. Remember to account for spoil board thickness!
    e. *Host machine and CAM software interfaces*
        i. VPanel = remote control of all machine functions
        ii. SRP Player = CAM processor provided by manufacturer, good enough for 2D projects and even basic 2D design
        iii. VCarve Pro = commercial alternative to SRP Player. Better for 3D projects.
2. Fundamental concepts
    a. *Subtractive manufacturing (SRP)*
        i. Contrast with additive manufacturing (3D printing)
    b. *Drill vs mill vs router*
        i. Drill = vertical cutting

   ii. Mill = smaller machine where bed and tool moves. Good for cutting fine features in small blocks of material (foam, wood, metal). Capable of cutting very small sheets of wood and plastic, but not as useful.
   iii. Router = larger machine where bed and material stays in one spot and tool moves around. Good for cutting large sheets of wood and plastic, but capable of doing 3D contouring.

c. *Tools = drill bits vs end mills*
   i. Tool = generic name for the piece that comes in contact with material
   ii. Drill bits = sharp on the tip, not on the sides. Meant to carve vertically.
   iii. End mills = sharp on the sides, usually not on the tip. Meant to carve horizontally
   iv. "Drill bit" and "end mill" are sometimes used interchangeably in conversation, but very different definitions.

d. *Toolpaths and passes*
   i. Toolpath = the path that the tool follows to create your object
   ii. Pass = one execution of a toolpath

Discussion of materials compatibility and safety

1. Known good and safe materials
   a. *Foams* = insulation foam, styrofoam, high-density urethane foam
   b. *Plastics* = acetal, Delrin, acrylic, PVC, ABS, HDPE
   c. *Wax* = machining wax
   d. *Metals (non-ferrous)* = aluminum, copper, brass
2. Properties and conditions to avoid
   a. *Dust* = fine dust created by some materials can be dangerous without proper protective equipment. Avoid asbestos, glass, elemental metals (mercury, lead), toxic pigments or anything else that is dangerous in dust form.
   b. *Structural integrity* = some materials may fall apart, splinter, crack or chip dangerously when put under stress.
   c. *Hardness* = nothing harder than brass. May cause end mill to break, and machine may halt itself if it detects excessive resistance to movement.
   d. *Excessive friction* = hard materials or inappropriate cutting speeds can result in lots of friction, which generates heat in both your material and the end mill. Heat from friction can cause:
      i. Melting = especially in materials like wax
      ii. Fire = especially in dry woods, especially as fine saw dust builds up (think of rubbing sticks together to create campfire).
      iii. Tool wear and breakage = cutting edges of end mills become duller, and will break sooner than normal

<u>**Discussion of end mills**</u>

1. <u>Cutting diameter</u>
    a. Common diameters are ¼", ⅛", 1/16", 1/32" and 1/64"
    b. Use the largest diameter for rough cuts, then progressively smaller diameters until desired surface smoothness is achieved.
2. <u>Shank diameter</u>
    a. *Shank* = the end of the tool that is grabbed by the machine (collet)
    b. Common diameters for desktop-sized machines include ¼" and ⅛"
3. <u>End shapes</u>
    a. Ball = rounded tip, good for cutting curved surfaces
    b. Straight = straight tip, good for cutting flat surfaces and making perfect pockets
4. <u>Flutes</u> = sharp edges used for cutting. More flutes mean more cuts per revolution, but most projects never need more or less than 2.
5. <u>Cut direction</u> = what side the helical spirals are sharpened on
    a. *Upcut* (most common) = carries chips upward and away from cuts, but can rip softer materials like wood and soft plastics leaving unattractive "fuzz". Leaves the bottom side of a piece smooth.
    b. *Downcut* = pushes chips downward, which can build up inside of pockets and holes. Good for woods and soft plastics. Leaves a smooth surface on the top side of piece
    c. *Compression* = half upcut, half downcut. Combines properties from both
6. <u>Length</u> = normal length or extended length
7. <u>Collets</u> = socket used to securely hold end mills

<u>**Discussion of toolpaths**</u>

1. Multiple passes with multiple end mills are often necessary
2. The number and types of passes varies based on the design and the size of the material.
3. In general, you should have at least two passes:
    a. *Roughing* = use the largest end mill you can (¼" or ⅛") to remove large areas of material, leaving less work for the more delicate end mills to do
    b. *Smoothing* = use a smaller end mill to remove more material, but not all.
    c. *Finishing (optional)* = use smallest end mill to create finest features (not always necessary if smoothing pass is good enough).

Guided demonstration of entire project workflow

1. Execute a basic design with students watching, asking questions such as:
   a. Are there any problems with the design chosen?
   b. What end mill should I use? Why?
   c. How many passes should I do?
   d. What material would be good (or not) to use? Why?

Overview of advanced topics

1. Two-sided milling = mill one side of a piece of material, then flip it over and mill the other side. Generally it's necessary to create a frame or jig around the design in software, with small tabs holding your piece. Some software can generate all this automatically.
2. Rotary milling = special attachment that allows workpiece to rotate about X axis so that features can be milled all the way around the piece.
3. 3D contact scanning = scans surface of an object by touching it with a tiny needle. Potentially extremely high quality, but requires huge amount of time and computing resources.