AUTODESK UNIVERSITY 2015

CP11498

Prototype Machining for Product Designers with Fusion 360®

Andrew Grevstad - Tormach Inc., Madison, WI

Curt Chan - Autodesk

Learning Objectives

- List advantages of CNC machining for prototyping
- Describe CAD/CAM workflow for designing and machining parts
- Understand essential CNC milling concepts
- Create simple tool paths using Autodesk Fusion 360® (live demo)
- Prepare a basic machining project in Autodesk Fusion 360® (live demo)

Description

This class presents several real-world examples using Autodesk's Fusion 360 software as a platform for making things using a Tormach PCNC milling machine. We will look in depth at case studies in rapid prototyping, mass customization, tool making, and specialty manufacturing.

Your AU Experts

Andrew Grevstad *has worked as an engineer in the machine tool industry since 2003. Currently he is a senior applications engineer at Tormach Inc., in Madison, Wisconsin. Tormach designs affordable, easy-to-use CNC (computer numerical control) mills, CNC lathes, and other tools for product development, prototyping, and specialty manufacturing of precision-machined components. Mr. Grevstad received a bachelor's degree from Michigan Technological University and a master's degree from University of Wisconsin-Madison.*

Introduction

New advances in affordable and approachable hardware and design software have opened CNC machining technology to new applications outside of traditional manufacturing. Increasingly, product designers are using tools like Tormach PCNC mills and Autodesk Fusion 360® to reduce outsourcing, compress design cycles, create functional prototypes, test market products, and transition to short-run production.

The Advantages of In-House CNC Machining for Prototyping and Product Design

CNC machining has a number of advantages over other rapid prototyping methods. These include:

- The ability to create functional prototypes with real world materials like metals, engineering plastics, composites, and other materials that cannot be reproduced by additive methods.
- The ease of which a CNC machined prototyped part can be scaled up to test-run, small-run, and specialty production with minimal additional development costs
- The ability to compress design timelines and reduce costs by enabling rapid design iteration and design variations through the entire design cycle.
- The ability to be adapted to personalized and customized manufacturing where small design variations can be easily accommodated

Functional Prototypes with Real World Materials
CNC machining inherently uses "Real World" materials. While 3D printing methods have become an indispensable tool for product designers interested foremost in "form", the suitability of these 3D-printed materials for evaluating "function" is limited, especially if the component is designed for mechanical or thermal loading. The engineering properties of 3D printed plastic parts are different than parts produced by machining, injection molding, extrusion or other production-ready methods.

FIGURE 1: THIS AUTONOMOUS UNDERWATER VEHICLE PROPULSION ASSEMBLY DESIGNED AND MANUFACTURED BY RAUCH ENGINEERING USES A CNC MACHINED PROPELLER AND MOTOR HOUSING IN COMBINATION WITH 3D PRINTED COWLING.

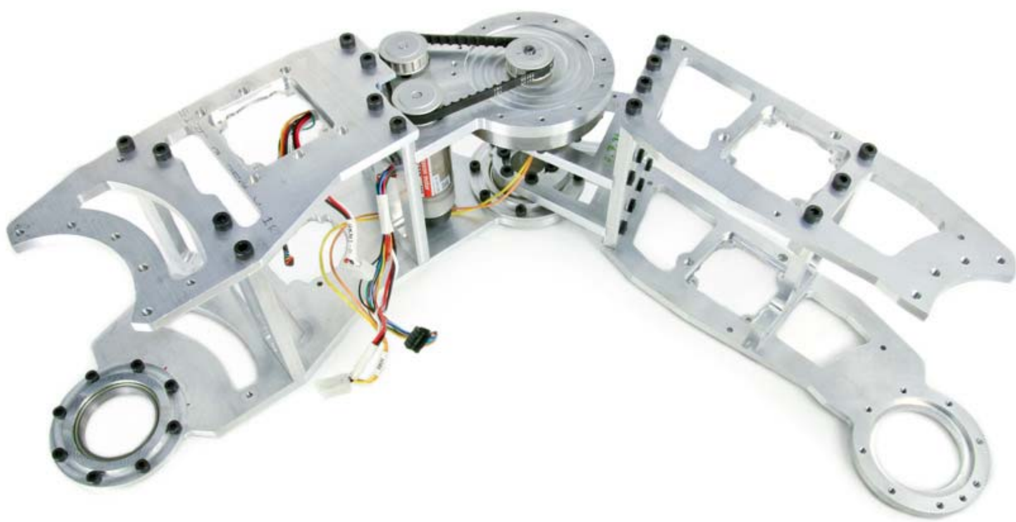

FIGURE 2: RESEARCHERS AT DREXEL AUTONOMOUS SYSTEMS LABORATORY (DASL) USE A PCNC 1100 TO MACHINE STRUCTURAL COMPONENTS SUCH AS THIS LEG ASSEMBLY FOR THE HUBO+ AUTONOMOUS HUMANOID.

ASTM and ISO material design standards are well-established for homogenous materials but are still evolving for additive manufacturing techniques where material strength and other properties are directionally dependent and can vary significantly with changes to manufacturing specifics including layer thickness, layer orientation, nozzle temperature, filament or powder diameter, etc. This makes CNC machining especially compelling for safety-critical components designed for use in a diverse group of industries including medical implant, aerospace, automotive, and industrial process control applications.

FIGURE 3: A MICROFLUIDIC DEVICE MACHINED ON TORMACH PCNC 770. PHOTO CREDIT: EDMOND YOUNG, UNIVERSITY OF TORONTO

From Prototype to Production: Scaling Up and Test-Marketing
CNC machining techniques can be readily scaled from single prototype to production with very little additional development costs. This is especially attractive for niche or specialty products when it is not economically feasible to invest in specialized tooling or in a test marketing scenario where the demand for an unproven product is uncertain.

FIGURE 4: WITH A COMBINATION OF SHORT-RUN CNC MACHINED INJECTION MOLDS AND MACHINED RIGID PLASTIC PARTS, MARSHMALLOW FUN CLUB WAS ABLE TEST MARKET THEIR "MARSHMALLOW BLASTER" AT THE NY TOY FAIR BEFORE ORDERING EXPENSIVE PRODUCTION TOOLING FOR MASS PRODUCTION

Faster Design, Better Design: Rapid Design Iteration

Product designers that rely on outsourcing prototype CNC machining can be subject to significant lead times and delays from contract machine shops or expenses incurred from rapid prototyping services. With an in-house CNC machining capability, product designers can rapidly iterate on designs. The design process is much more responsive: designers can create functional prototypes much earlier in the design cycle and more readily adapt to late stage design changes. This can have many advantages, including reducing time-to-market, shrinking overall product development costs and improving product quality.

FIGURE 5: PRODUCT DESIGNER EDWARD SCOTT CREATED OVER 25 DIFFERENT PROTOTYPE MOLDS USING A TORMACH PCNC 1100 TO PROVE OUT HIS CONCEPT FOR THE "CRUSH CUP" BEFORE INVESTING IN PRODUCTION TOOLING.

Customization and Personalization
CNC machine techniques are readily adapted to create customized variations of products to suit unique applications where a one-size-fits all philosophy does not work. Parametric CAD/CAM design tools like Autodesk Fusion 360® have made this workflow very easy the tool path can automatically adjust to a design change in the CAD model so that expanding a design to a family of related parts takes less effort.

FIGURE 6: INDIVIDJUAL EYEWARE USES A TORMACH PCNC 770 TO CREATE PERSONALIZED SUNGLASSES FOR HARD-TO-FIT CUSTOMERS.

FIGURE 7: EISERTECH USES A TORMACH PCNC 1100 TO MANUFACTURE SPACERS AND SCREWS FOR SPINAL IMPLANT SURGERY USING MEDICAL GRADE PLASTIC AND TITANIUM.

Designing for machining: An overview for Product Designers

Design for Manufacturing (DFM)

Each part should be critically evaluated for its suitability for manufacturing by CNC machining. Often, a few small but thoughtful decisions in the beginning of the design process can greatly reduce manufacturing complexity with respect to tooling and workholding. Here are four interrelated questions that should be asked prior to finalizing the part design:

1. **What is the minimum feature resolution?** The diameter and form of the cutting tool will determine the smallest feature that it can produce. One area to look at in particular are fillets and the inside corner radius of a pocket or void. These features will often dictate the diameter of the smallest end mill needed to produce the feature.
2. **What are the important dimensional tolerances and how will I machine these features?** For example, clearance holes do not require the same tolerance as a bearing pocket or piston bore. There are a number of ways that a CNC machine can be programmed to make a hole, but not all methods will produce the same hole tolerance.
3. **What tools will I use?**
   - Strive for a minimum of tool changes
   - Use the largest reasonable cutter
   - Use multipurpose tools when possible
   - Use the shortest tool overhang possible
4. **How will I secure this part during machining?** Workholding is one of the most important considerations when designing any machined process. While there is no single “right” approach, ask yourself the following questions before designing your setup:
   - Is it simple? Good workholding techniques should minimize the number of setups.
   - Is it rigid? Good workholding techniques resists vibration and movement.
   - Is it repeatable?

Workholding Fundamentals

Workholding technique is learned and improved over a lifetime. Good workholding design should strive for simplicity, rigidity, and repeatability. While the variations can be endless, there are several common techniques that can be adapted to the majority of part geometries:

- *Flip and Deck* – for small parts, especially those that have opposed parallel edges
- *Picture Frame* – for odd shaped and complex parts
- *Fixture Plate* – for large parts and thin parts
- *Collet Fixtures* – for round parts and parts that must be machined on end

Flip and Deck

A machinist vise is the most versatile workholding tool. Many small parts can be machined effectively in a machinist vise using the “Flip and Deck” method where the majority of the part is machined from one side followed by a second operation where the remaining features are machined from the other side.

FIGURE 8: THE LONG PARALLEL EDGES OF THIS CAMERA ADAPTOR IS A NATURAL FIT FOR A “FLIP AND DECK” WORKHOLDING STRATEGY USING A MACHINIST VICE.

Picture Frame

Picture frame machining is an effective way to mill complicated shapes while eliminating the need to design purpose built fixtures. With this technique, the majority of the perimeter is machined away, leaving only several small *tabs* to hold the part in place. The tabs can then be removed by hand using a bandsaw, pedestal grinder, and/or deburring tool; or in a separate CNC finishing operation. The CAM module in Autodesk Fusion 360® includes a tab design feature to aid in their creation.

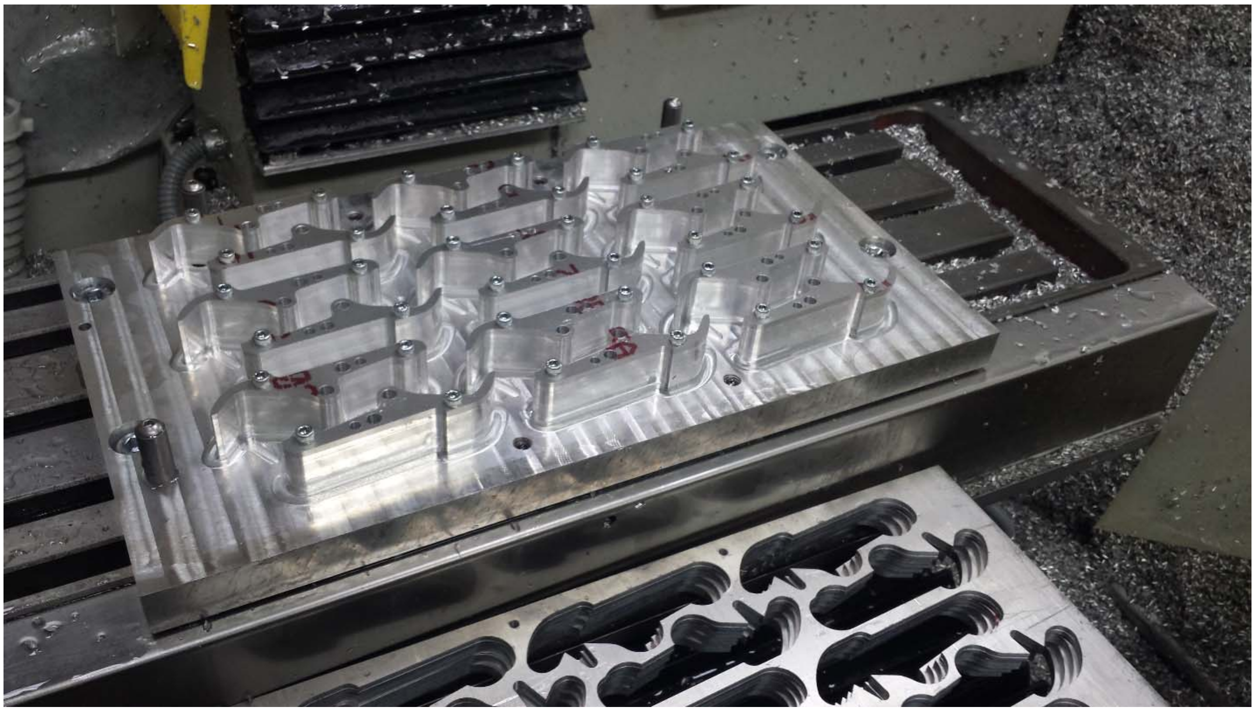

FIGURE 9: THESE PARTS ARE MACHINED BY FIRST USING A "PICTURE FRAME" WORKHOLDING TECHNIQUE TO ROUGH MILL THE PERIMETER PROFILE BEFORE A SECOND FINISHING MILLING OPERATION ON A FIXTURE PLATE.

Fixture Plate and Fasteners or Hold-downs

Large and/or thin parts need support from the bottom to counteract deflection and sagging. A dedicated fixture plate can be designed to securely hold the part in place. When designing a fixture plate, several questions should be addressed:

- Can existing holes in the part be used as fastening locations?
- If not, where can fastening locations be added that do not interfere with part function and are inconspicuous?
- Hold down clamps get in the way of perimeter cutting operations. Low profile Cam-lock clamps (Mitee-Bite™ and similar) can reduce interference but the machining process may still need to be designed so that the clamps can be repositioned during a programmed pause in the machining sequence.

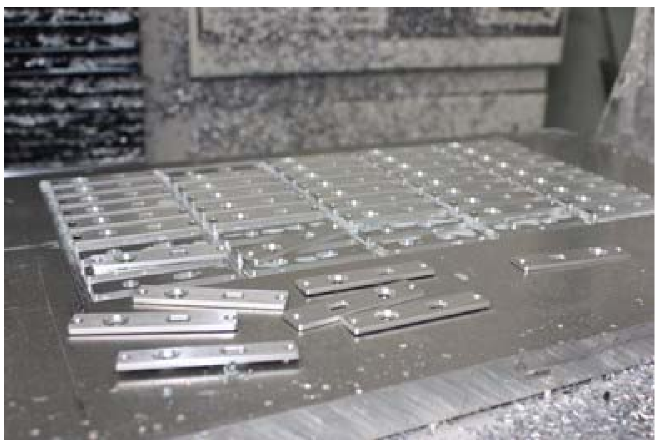

FIGURE 10: THE THIN PLATE DESIGN OF THIS ELECTRONICS PANEL IS SUPPORTED FROM THE BOTTOM USING A FIXTURE PLATE. THE SAME HOLES USED FOR FINAL ASSEMBLY ARE ALSO USED TO HOLD DOWN THE PARTS ON A FIXTURE PLATE.

Collet Fixtures for Round Parts

Collet fixtures are an easy way to hold round parts on end. Hexagonal and square collets are also used available. V-blocks, V-jaws, and adjustable chucks can also be useful for holding round parts.

FIGURE 11: A COLLET FIXTURE IS USEFUL FOR SECURING ROUND PARTS LIKE THIS TRUMPET MOUTHPIECE FOR MACHINING

Basic Tool Path Strategies

The following strategies are commonly used when designing a CNC machined part:

Roughing and Finishing

Precision machining often benefits from a two-staged machining approach, known as *Roughing* and *Finishing*.

A roughing operation is designed to maximize material removal efficiency. After completion of the roughing sequence, a small amount of material is left to be removed in the final finishing operation. A finishing operation has two primary goals:

- Improving geometric part tolerance
- Improving surface finish

Roughing and finishing can be done with the same tool or with different tools.

Facing / Decking

Facing or Decking describes using a tool to mill a part to final thickness. This technique is often used when a machinist vise is used for workholding as it can be easily incorporated when both the top and bottom need to machined.

Spot-Drill-Tap

The spot-drill-tap sequence is perhaps the most common CNC workflow sequence. A Spot Drill is a larger diameter drill that is used to accurately “spot” the hole by creating a pilot divot to guide the subsequent twist drill. This is necessary as a point of a twist drill will have a tendency to skate as it bites into the workpiece; this can result in an inaccurate hole location and/or an out-of-round hole diameter. If necessary, one or more finishing operations can follow the primary drilling operations such as:

- Tapping
- Thread milling
- Boring
- Chamfering / Countersinking
- End milling

3D Contouring

3D contouring is a finishing strategy that is time consuming because of the machining time needed to achieve acceptable results. It is most often used in toolmaking applications, for example, stamping and forming dies, plastic injection molds, and patterns and forms for composite layup and resin or metal casting.

The most universal 3D contouring strategy uses a *Ball End Mill* to machine the surface in a rastering tool path. Surface finish is correlated to the stepover between raster passes. Reducing the stepover will improve surface finish but increase machining time.

CAD/CAM Workflow Cheat Sheet for Designers

1. Evaluate Design for Machining (DFM)
    a. Workholding?
    b. Which tools to use?
2. Figure out the machining sequence
    a. How many operations
    b. How many strategies
3. Set up the project in CAM
    a. Orientation
    b. Work Offsets
    c. How much modeling is needed
4. Design toolpaths
    a. Get the geometry right first, then fill in the details (feeds/speeds/depths of cut/width of cut)
5. Simulate
    a. Look for obvious problems