MECH 392, An Introduction to Manufacturing Processes

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Introduction

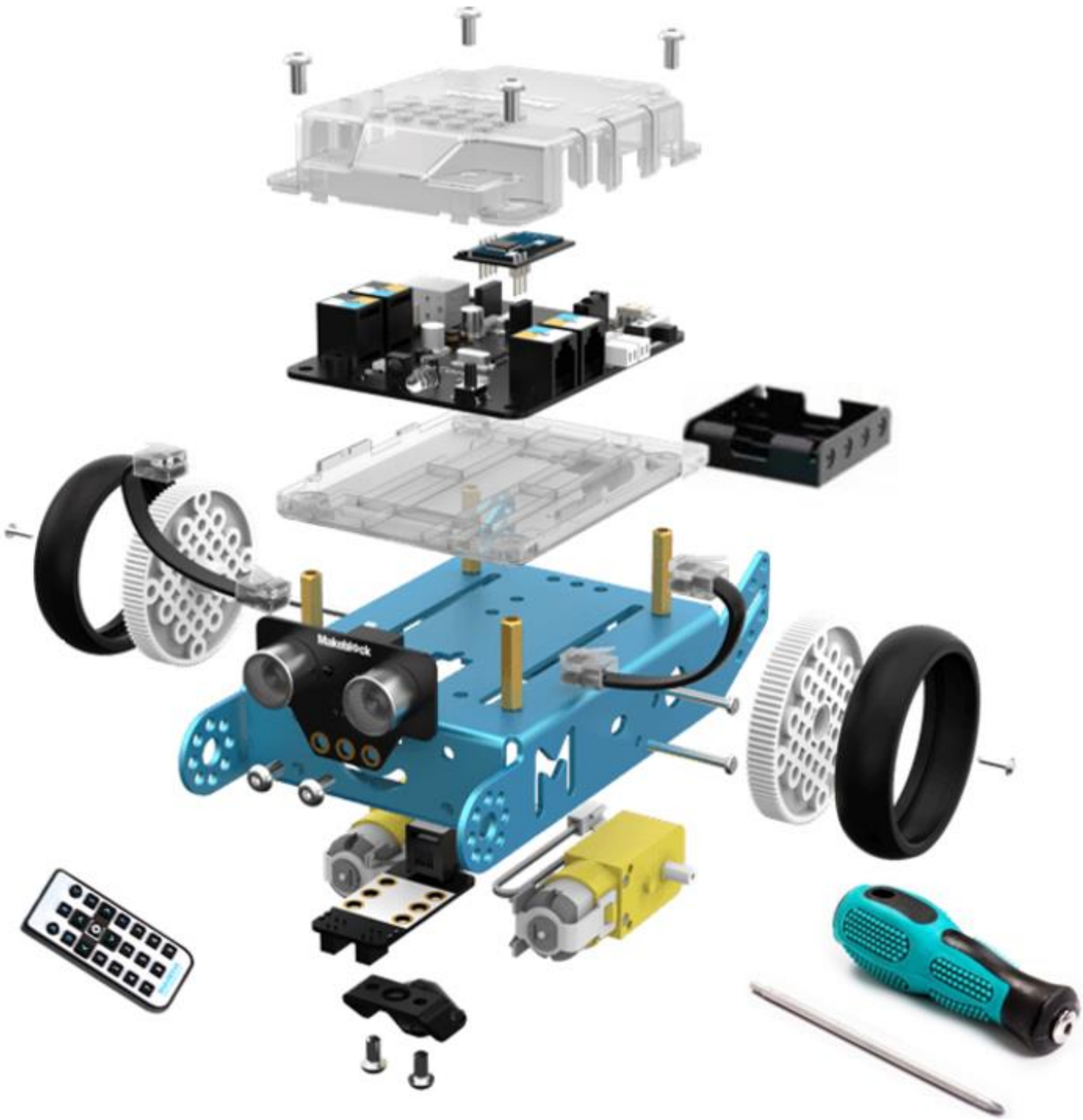
The application of physical and chemical processes to change the geometry, properties, and appearance of a material to make a functional part is called manufacturing. It also includes an assembly of multiple parts to make products.

The main objective of this course is to learn the fundamentals and applications of a wide range of manufacturing processes through examples and video demonstration. After completion of this course you will also gain a perspective on the future of manufacturing and how it will be shaped by advanced technologies.

There is a spectrum of manufacturing processes, such as machining, molding, casting, sheet metal forming, thermoforming, and additive manufacturing. Most products require the integration of multiple processes.

Example) The MakeBlock mBot unboxing:


images from: www.robotshop.com



images from: www.robotshop.com

Process Selection:

The 4 Main Attributes of each manufacturing process: Cost, Rate, Quality, and Flexibility

Cost: How much is the cost of making one unit of a product?

Rate: How long does it take to produce one unit?

Quality: size, surface, consistency, function, life and durability, …

Flexibility: What it takes to produce another product with a different shape? For example, what it takes to mold or machine a different geometry or shape?

Attribute / **Process**	**Cost**	**Rate**	**Quality**	**Flexibility**
Machining				
Sheet Metal Forming				
Thermoforming				
Injection molding				
Casting				
3D Printing				

Course Modules:

1. Machining
2. Sheet Metal Forming
3. Injection Molding
4. Thermoforming
5. Casting
6. Additive Manufacturing
7. Quality and Monitoring

For the course syllabus, objectives, requirements, projects and other details please check Canvas.

Quick Review (Stress & Strain)

Module 1. Machining

Machining consists of the removal of material and modification of the surfaces of a workpiece. It involves relative motion between a workpiece and a tool that remove material locally. Machining operations include milling, drilling, boring, turning, facing, tapping, threading, and cut-off.
In this module we focus only on turning and milling process.

Turning:

Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, is fixed while the workpiece rotates. Turning can be done manually or automatically, in a form of lathe.

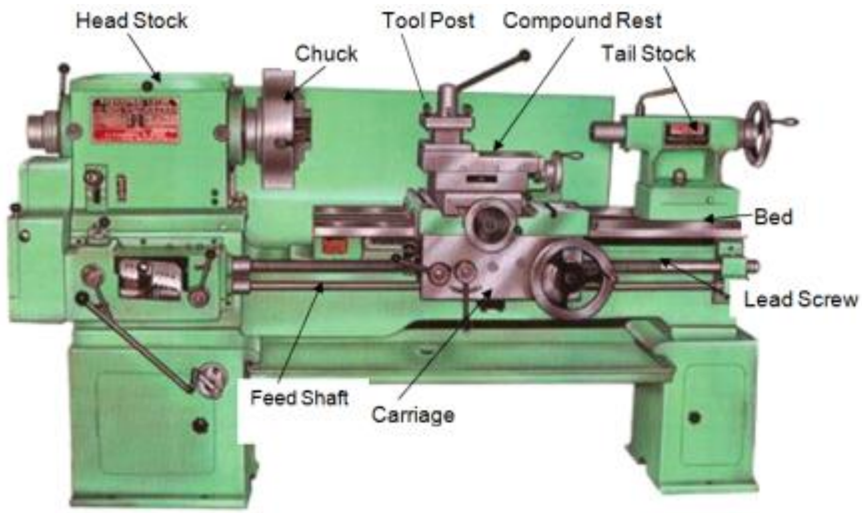
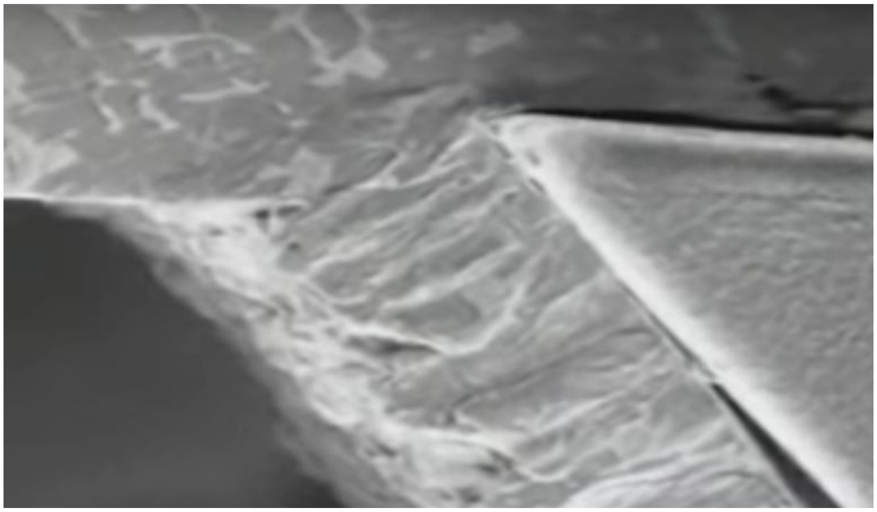
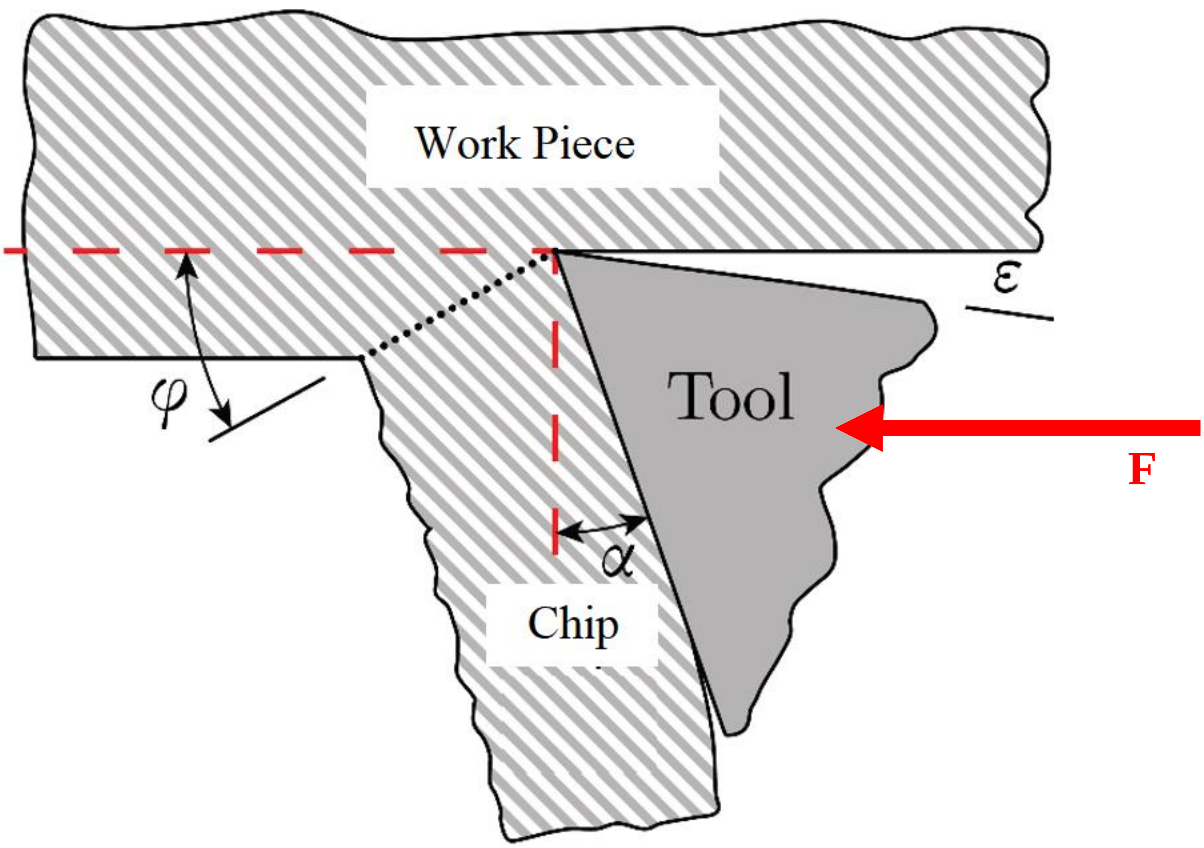


Image Source: https://esskaylathemachine.wordpress.com/category/lathe-machine-manufacturers/

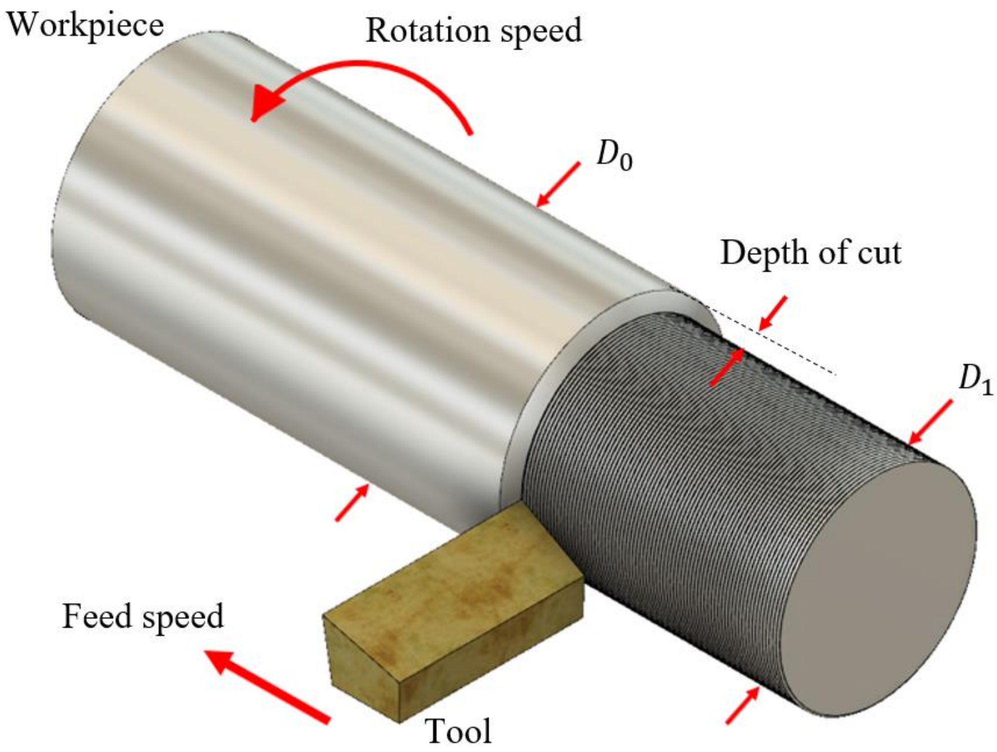
The mechanism of material removal:



*(**video in class**), image from https://www.youtube.com/watch?v=mRuSYQ5Npek*



Material Removal Rate (MRR):



Example 1) On a lathe the operator is machining an Aluminum rod. The initial diameter of the rod is 2.0cm, and he set up the tool for a depth of cut 0.2cm. If the rotation speed is N= 500 RPM, and the tool axial velocity is 0.4 mm/min, what is the material removal rate?

Experimental Test:

There are many parameters influence the work piece deformation and wear of the tool, such as the interaction forces between tool and workpiece, friction, vibrations, and heating. In the following video, the operator changes different parameters and measures the cutting forces.

(video Cutting with Wax, source: https://www.youtube.com/watch?v=MMEWrUXujFo&feature=youtu.be)

1- Feed increase
2- Smaller Rake angle
3- Spindle rpm increase
4- Depth of cut increase
5- Smaller diameter of stock

Merchant's Relation:

Shearing Stress during machining and the chip formation can be calculated by:

$\tau = G(\cot(\emptyset) + \tan(\emptyset - \alpha))$

G: Shear Module of Elasticity

$\boldsymbol{G = \frac{E}{2(1-\nu)}}$ **,** whereas E is module of elasticity, and ν is the Poisson ratio of the material.

$\emptyset$ is called shear angle and can be calculated by Merchant's formula:

$\emptyset = \frac{\pi}{4} - \frac{\beta}{2} + \frac{\alpha}{2}$

β friction angle

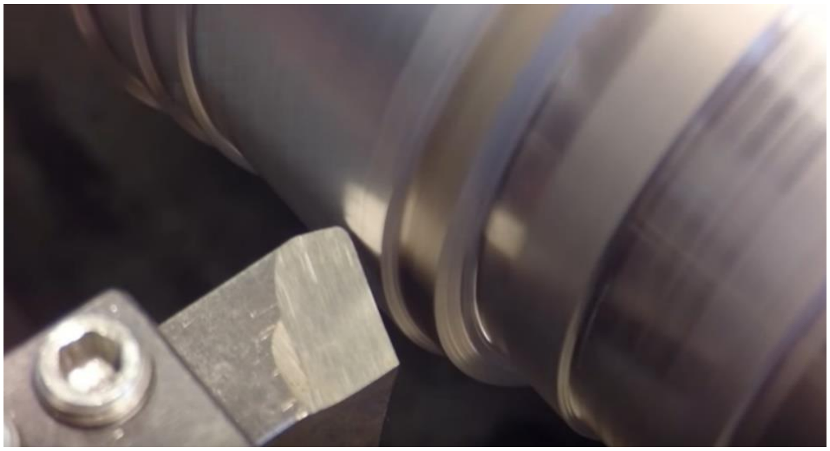
If Rake angle decrease or friction angle increase $\longrightarrow$

It is proved experimentally that smaller shear angle results in:

1. Chip thickness increase
2. Energy dissipation via shear increase
3. Heat generation and temperature increase

Cutting Tools:

Cutting tool may be made of HSS (High Speed Steel) or Carbide



(video in class, source: https://www.youtube.com/watch?v=y0HVyg3a6ls&feature=youtu.be)

The hardness of tool must be higher than the workpiece material. For example, if we cut a steel material with hardness: 32 Rockwell; then we can use HSS or Carbide.

Usual hardness of HSS for tools: 64 Rockwell

Usual hardness of Carbide for tools: 77 Rockwell

Observation from the demo (above video):

Limitation on RPM based on the tool; with HSS he could not go up to higher speed (the tool failed). But the carbide could cut at higher speeds. Eventually he had to stop due to power requirement limitations.

In this experiment we noticed the RPM affect the material removal rate (MRR), the power requirement, the chip characteristics, heat generation, tool wear, and surface quality.

As the tool cuts the part, the part rubs back on the tool, wearing down the side of the tool. It also creates friction and generates heat. Tool wear is caused due to high temperature and high cutting forces. Using a coolant allows the tool to retain its hardness. Carbide tools have a higher hardness than high speed steel tools, and therefore have higher tool life. Ceramic tools have higher hardness than carbide tools.

Heat generation during cutting may change the mechanical properties of the tool material and it results in tool wear. Carbide can withstand (retain its mechanical properties) higher temperature than HSS. Now a days with advanced coating technologies, cutting at higher speeds is possible. There is a spectrum of carbide tools with different layers of coating.

TiN coating:

TiCN coating:

Al_2O_3 coating:

High tool temperature, high material removal rate and insufficient tool hardness may all cause tool wear and poor surface quality.

If the workpiece is not properly supported, it may deflect and chatter against the tool due to cutting forces and vibrations, resulting in poor surface quality.

Power Requirement:

Specific cutting energy (SCE) is the amount of energy required to cut a given volume of work material ($W.Sec/mm^3$) and varies with material properties. The table below indicates values of SCE for some metals, it should be noted that values vary somewhat in different sources:

Material	**SCE (W.s/mm$^{3)}$**
Magnesium alloys	0.3
Zinc alloys	0.35
Leaded brass	0.7
Aluminium alloys	0.6-1
Stainless steels	1.4
Steel 1020	1.5
Steel 1040	1.8
Steel 1330	2.5
Cast irons	0.8-1.6
Copper	2
Titanium	3

The cutting force is determined by the shear strength of the material and the cutting area. Hence the material strength and rake angle influence the required cutting power. The required power for machining a workpiece with a material removal rate of MRR can be calculated by:

$$Required\ Power \quad P = MRR \times SCE$$

Example 2) Calculate the required power in Example 1? Aluminum specific cutting energy:

Required time for removing volume material V can be computed by:

Example 3) What is the minimum time it would take to machine 250 mm^3 of aluminum if your machine could provide 0.4 kW of power?

Example 4) Consider differences in machining two metals, an alloy of Steel (with module of elasticity 200GPa, and thermal conductivity of 50 W/m.K) and an alloy of Copper(with module of elasticity 115GPa, and thermal conductivity of 400 W/m.K). Compare machining of these two materials?

Milling:

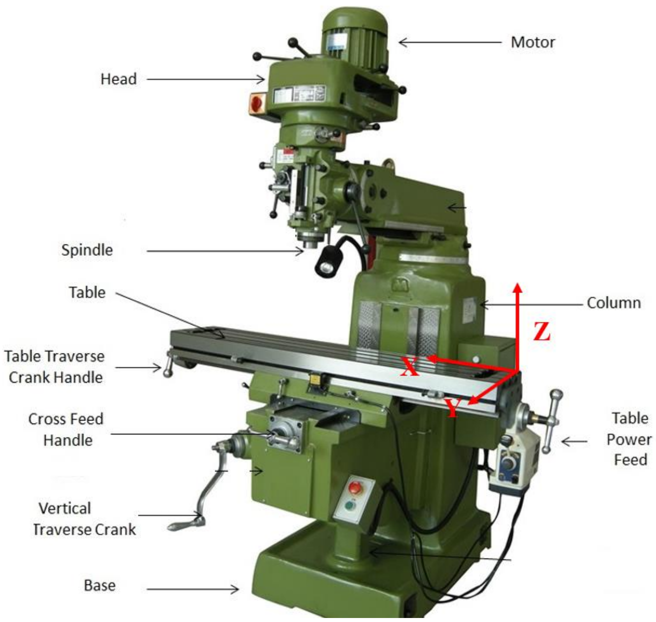
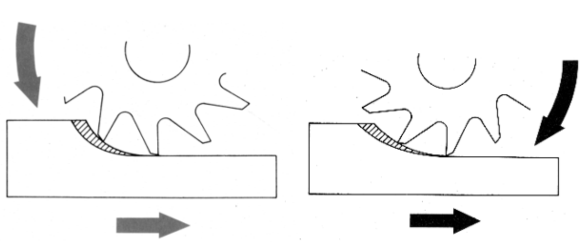


Image from *https://www.lvcnc.com/difference-between-cnc-mill-and-manual-mill.html*

(Video demo in class, source: https://www.youtube.com/watch?v=k2JRYjSGNBo)

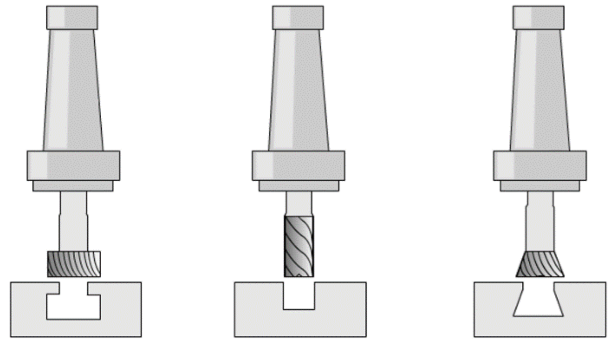
Two modes of milling: Climb vs. Counter/Conventional Milling



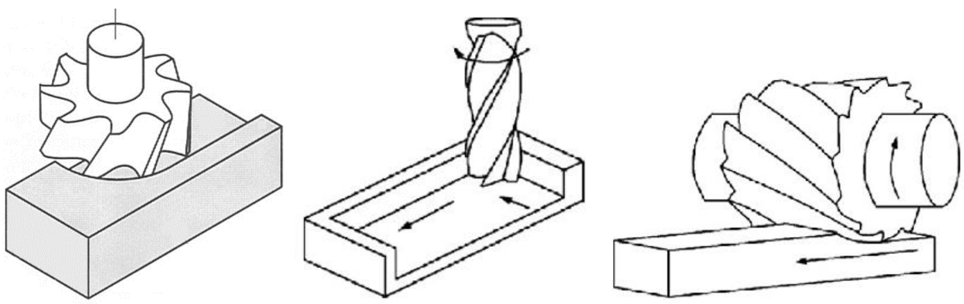
Climb cutting
(Direction of cutter rotation same as feed direction)

Counter cutting
(Direction of cutter rotation) oppose to feed direction

Types of milling operations:

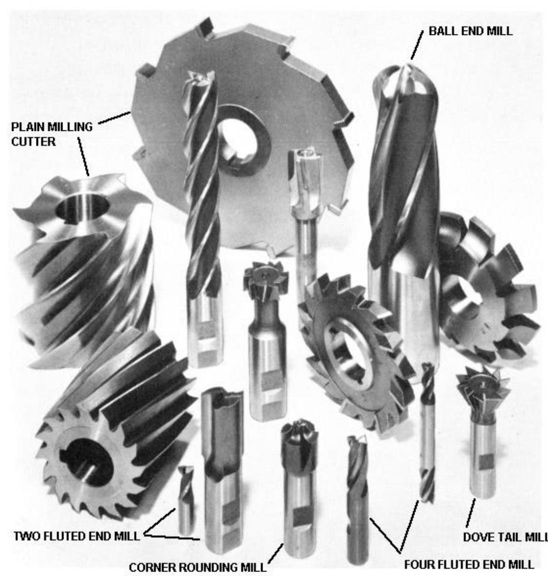


- Face milling
- Shoulder/side (end milling)
- Contour milling (complex surface curvature)
- Cutting slots and grooves
- Holes and taps



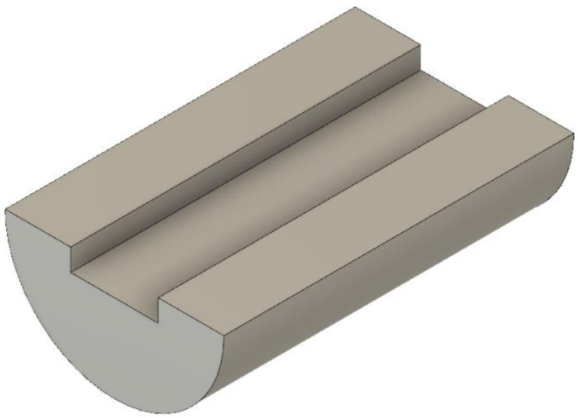
Types of tools:

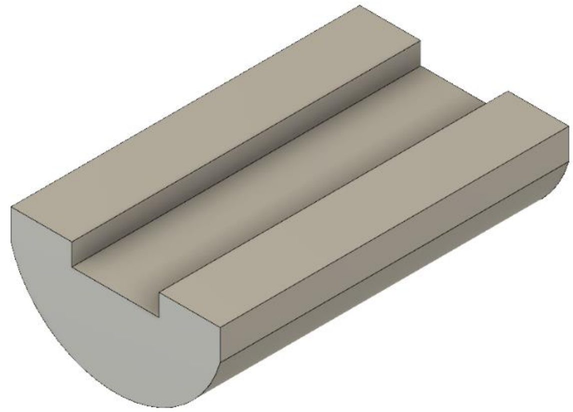
- Face mill
- End mill
- Peripheral/Side mill
- T-slot, Slot, Dovetail-slot mill

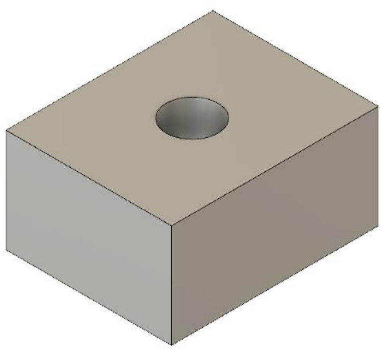


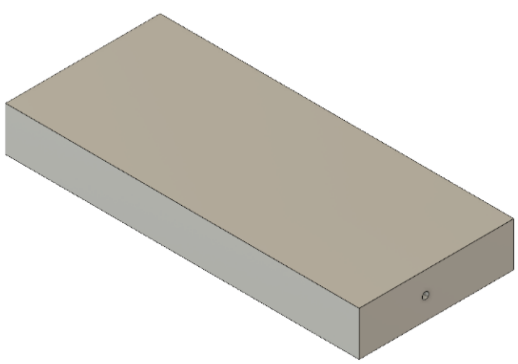
Example 5) In milling, what is the feed per tooth (in millimeters), f, if the tool velocity, v = 25 mm/s, the rotational speed, N = 1000 RPM, and the number of teeth, n = 4?

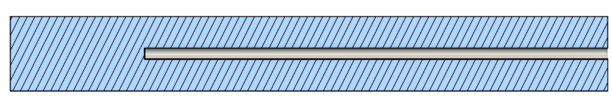
Design for Machining: *(in class discussion)*

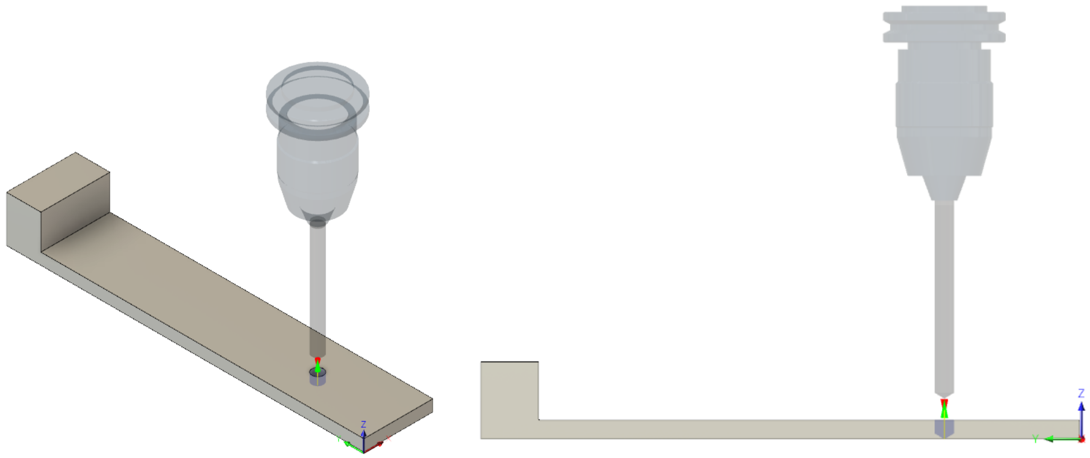


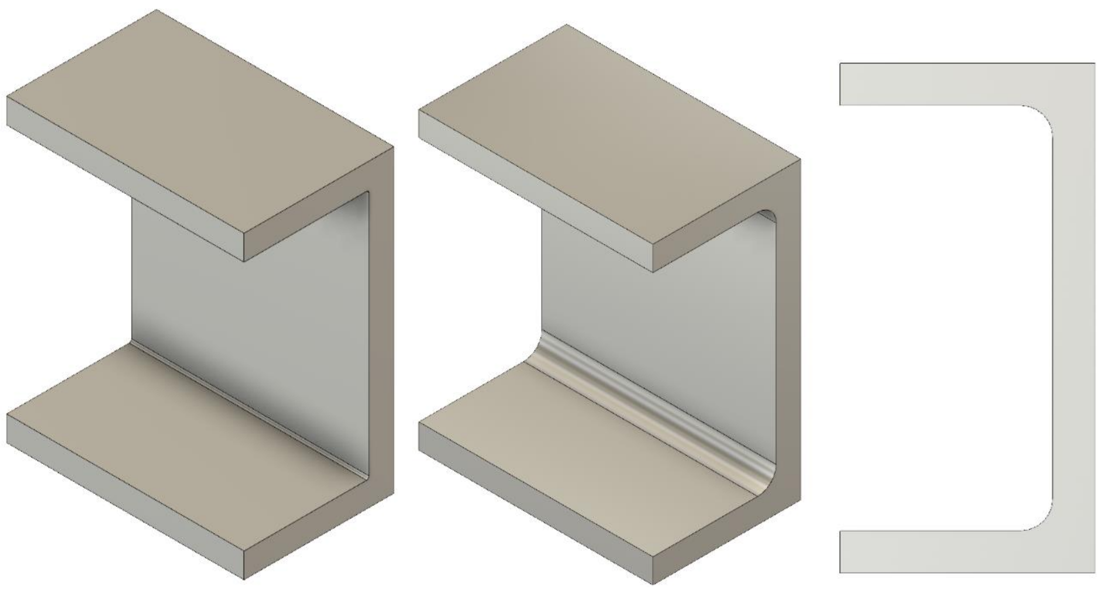




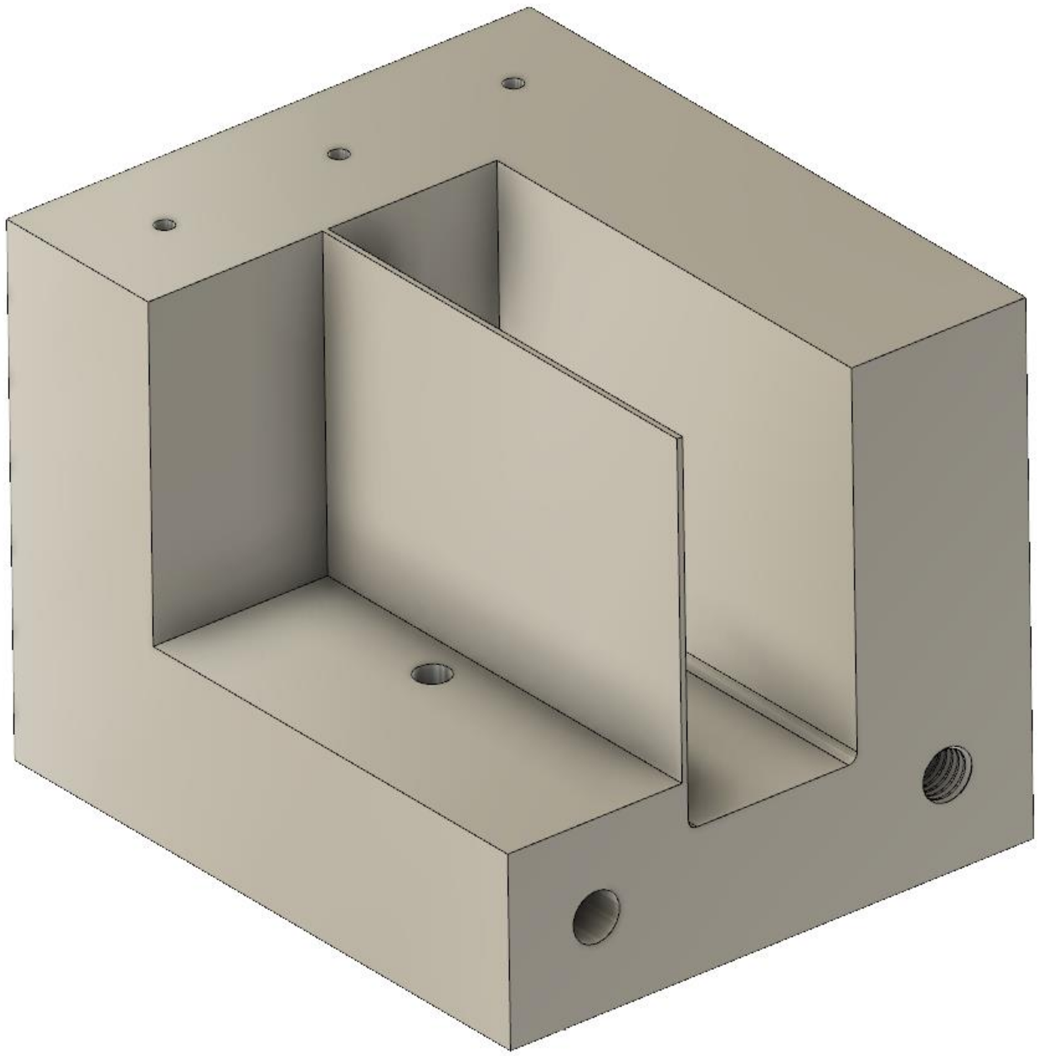




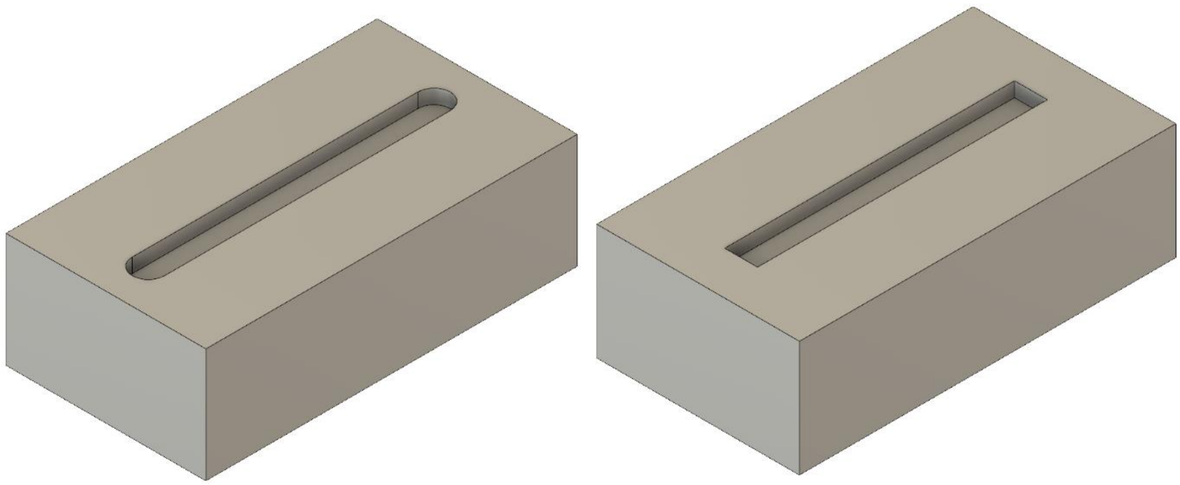




Example 6) What is wrong with machining this part?



Example 7) You want to mill a pocket that is wide and narrow. Which of the following shapes should you pick from a Design for Machining perspective?



Example 8) We need to make a thermoform mold that needs 0.05 inch-diameter holes to draw vacuum. Which of the following designs is optimized for manufacturability?