MIT 2.008 Design and Manufacturing II

Spring 2025

Homework 2 – Cutting

Released: February 19, 2025 2:00PM

Learning Objectives

- *Calculation of key parameters of machined parts based on first order equations.*
- *Understanding how power requirements scale with the size of parts, material choice, and other cutting parameters.*
- *Familiarity with forces associated with cutting and ability to model these forces.*
- *Determine how key cutting parameters affect forces associated with cutting.*
- *Identification of key features of machined parts, and the steps necessary to produce a machined part.*

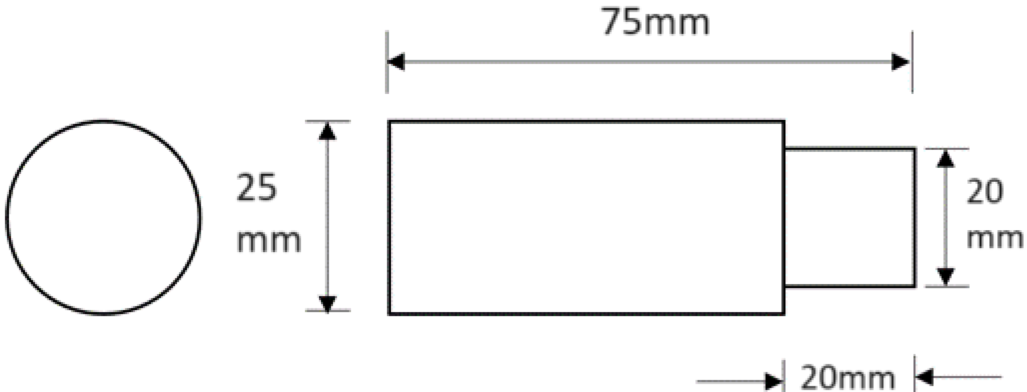
General Notes

- *For qualitative answers, we're not looking for long essays. Please answer using short (1-2 sentence per answer) bullet points.*
- *For quantitative answers, show your work as clearly as possible. When possible, keep answers in algebraic form until plugging in numbers at the very end; this way, it is much easier for graders to understand where you make mistakes and provide meaningful feedback.*

HOMEWORK TOTAL POINTS: 100 pts

Problem 1 – Turning (39 pts)

Consider the turning (orthogonal cutting) of a solid aluminum cylindrical alloy shaft from 25 mm to 20 mm diameter over 20 mm of its 75 mm length in a single pass—that is, with a depth of cut of 2.5 mm (per the image below). The spindle speed N is set at 1200 RPM and the feed *f* is 0.5 mm per revolution.



a) Please calculate the material removal rate (**MRR**) in mm^3/s.

b) How much **time** is required in order to complete this operation (again, in one pass)?

c) What is the power required to complete this turning operation? Refer to the Appendix for material properties.

d) What is the (average) cutting force applied to the shaft?

e) What are two actions one could take to reduce the power requirement while completing the same operation, with the same material, in the same amount of time? Note that we are looking for simple bullet points here, not detailed quantitative answers or equations.

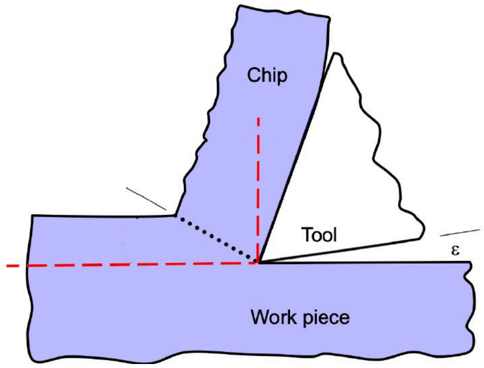
Action	**Brief Rationale**

f) What would be the power requirement if the cylinder diameter is doubled, but all other cutting parameters (including a single pass with the same depth of cut) are retained?

g) What would be the power requirement if the cylinder material is changed to titanium? Different materials often require changing cutting parameters - use a depth of cut of 2.5 mm, a feed of 0.15 mm/rev, and a cutting speed of 50 m/min. Refer to the Appendix for material properties.

<u>Problem 2 – Merchant's Diagram for Forces</u> (33 pts)

a) Below you can see the image of a tool cutting a workpiece, as shown in the lecture slides.



Fill out the table below to name each of the forces at work during this operation (limit yourself to the 6 forces indicated in Merchant's Diagram: **cutting, friction, tool normal, shear, shear normal, thrust**) as well as the plane in which they operate, **assuming the workpiece is horizontal**, as shown above. Just **circle or highlight the correct plane** for each row.

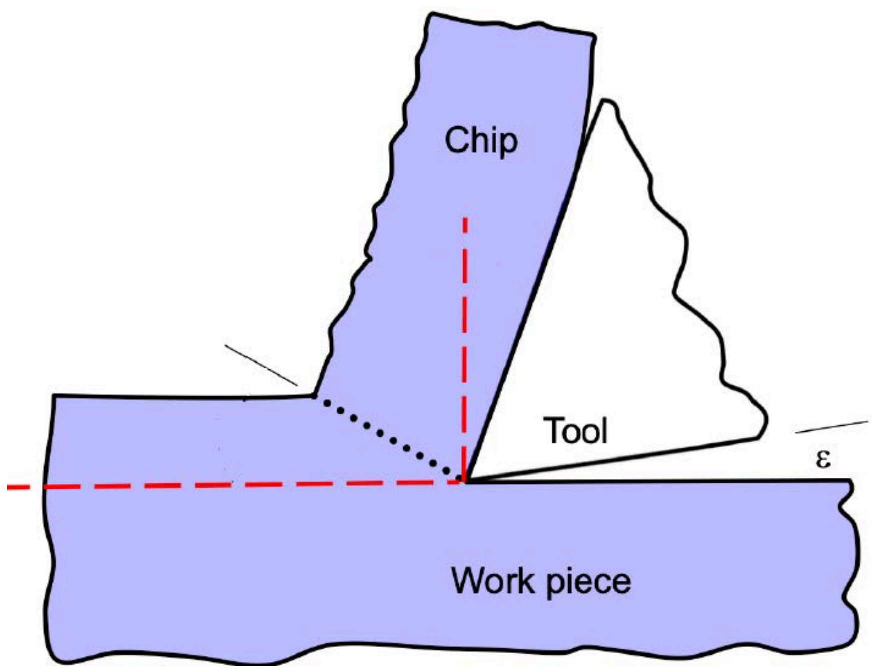
Interface between	Force	Plane (circle/highlight one)
Workpiece <-> Tool		Horizontal Vertical Tool-chip interface Tool-chip normal Shear plane Shear normal
Workpiece <-> Tool		Horizontal Vertical Tool-chip interface Tool-chip normal Shear plane Shear normal
Tool <-> Chip		Horizontal Vertical Tool-chip interface Tool-chip normal Shear plane Shear normal
Tool <-> Chip		Horizontal Vertical Tool-chip interface Tool-chip normal Shear plane Shear normal
Chip <-> Workpiece		Horizontal Vertical Tool-chip interface Tool-chip normal Shear plane Shear normal
Chip <-> Workpiece		Horizontal Vertical Tool-chip interface Tool-chip normal Shear plane Shear normal

b) Draw and complete Merchant's Diagram with respect to this operation. Your drawing should label, and indicate the direction of

- **Each of the 6 forces** from part a
- The **3 angles described in Merchant's** equation
- The **resultant force** vector

Directions of forces and angles should assume the following:

- Cutting force is acting on the tool
- The rake angle is positive, as the image implies
- Friction angle is less than the rake angle



c) Please **describe and explain** what happens to the following values as rake angle increases:

Value	**Increase or Decrease?**	**Brief Rationale**
Shear angle		
Chip thickness		
Energy dissipation via friction		
Chip temperature		
Likelihood of discontinuous or broken chips		

Problem 3 – Milling and Process Plans (28 pts)

For years Apple utilized milling to produce the housing of the iPhone. The housing of the iPhone 6 is shown in photographs below:

Figure 1: Back face (left) and main pocket (right) of iPhone 6 housing.

a) Assume that a 6 mm diameter end mill was used to machine the main pocket. According to the General Recommendations for Milling Operations Table in Kalpakjian and Schmid, *Manufacturing Engineering and Technology* (Table 24.2), the conditions for free machining aluminum alloys with an uncoated or coated cutting tool range as follows:

   Feed per tooth: 0.08-0.46 mm/tooth
   Surface speed: 300-3000 m/min

Calculate the spindle speed (also called rotational speed). Provide a conservative spindle speed using the low values and an aggressive spindle speed using the high values.

b) How do your calculated spindle speed values compare to the capability of the HAAS VF-2SS Mill in the LMP Shop? What surface speed can you achieve with the HAAS? See some specifications below.

SPINDLE	S.A.E	METRIC
Max Rating	30.0 hp	22.4 kW
Max Speed	12000 rpm	12000 rpm
Max Torque	90 ft-lbf @ 2000 rpm	122 Nm @ 2000 rpm
Drive System	Inline Direct-Drive	Inline Direct-Drive
Taper	CT or BT 40	CT or BT 40
Bearing Lubrication	Air / Oil Injection	Air / Oil Injection
Cooling	Liquid Cooled	Liquid Cooled

c) Consider all the machining operations needed to go from a block of metal to the finished machined part. **Sketch a possible process plan for machining the part below with a brief description of each operation.**

Note that this does not need to be a detailed sketch; we're simply trying to capture the major operations. Identify the fixture orientation (setup) as well as the type of tool. For simplicity, focus on the **main pocket,** the bottom features (**charging port slot**, **headphone jack hole**, **speaker holes**), the **left and right side slots**, the **overhanging internal features**, and the **radiused edges**.

Provide a sequence of operations which is most efficient for producing the housing (minimize re-fixturing, reduce possibility of defects), assuming you have access to the machines in LMP (the same ones you will use for your yo-yo project).

Note that you can ignore secondary operations such as the press fit threaded inserts and the plastic inserts. Also note that although different tool types are provided below, you do not need to differentiate between different flat/bull/ball head end mills in your plan (although you should specify whether you are using an end mill or a different type of cutter). You also don't need to assume that all of the provided tool types will be used.

Detailed photographs are available below.

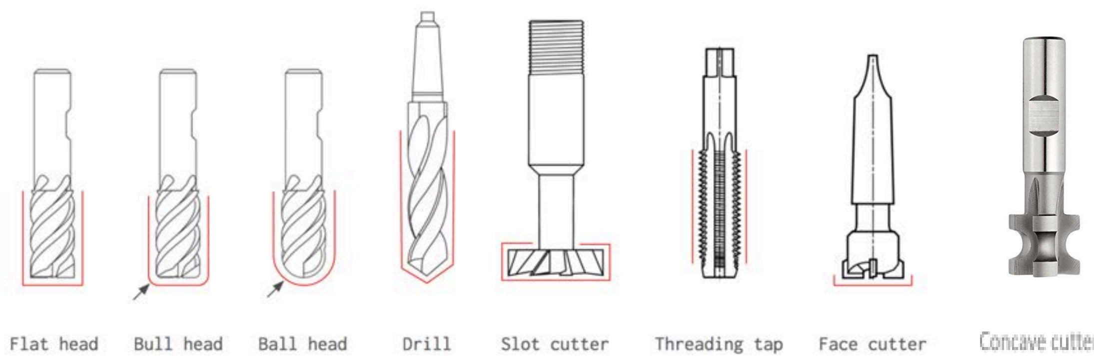


Figure 2: Include bottom holes and slot in the process plan.

Figure 3: Include right side button slots in the process plan.

Figure 4: Include left side button slots in the process plan.

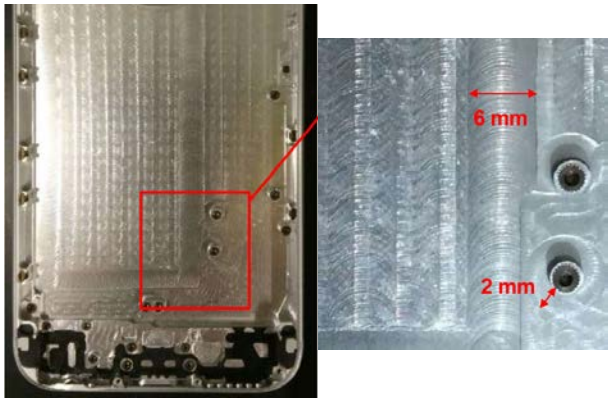


Figure 5: Pay close attention to tooling marks in the main pocket.

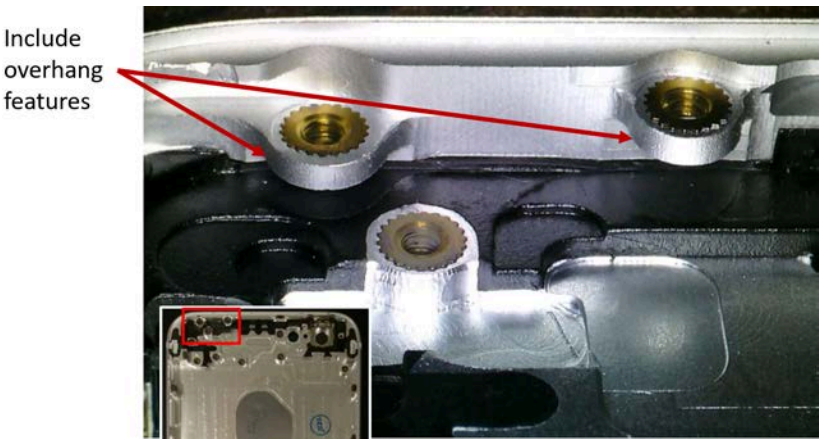


Figure 6: Include overhang features.

Figure 7: Include radiused edges in the process plan.

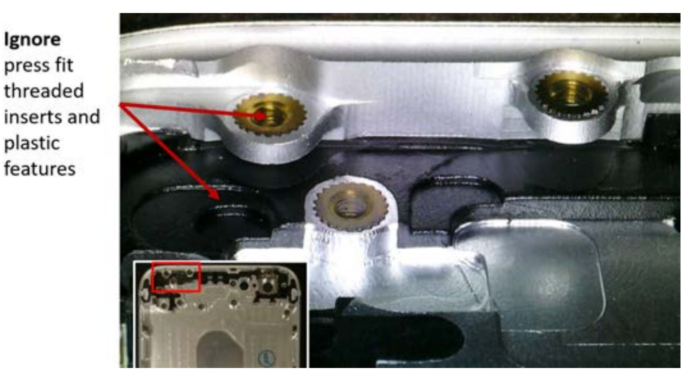


*Figure 8: **Ignore** press fit threaded inserts and plastic features.*

Description/ Feature	Tool Choice	Sketch of setup (orientation of the phone, fixture or how it is held, and direction of the tool)	Sketch of part after this step

(continue on the next page)

(continued)

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Appendix – Material Properties

TABLE 21.2

Approximate Range of Energy Requirements in Cutting Operations at the Drive Motor of the Machine Tool (for Dull Tools, Multiply by 1.25)

Material	Specific energy $W \cdot s/mm^3$
Aluminum alloys	0.4–1
Cast irons	1.1–5.4
Copper alloys	1.4–3.2
High-temperature alloys	3.2–8
Magnesium alloys	0.3–0.6
Nickel alloys	4.8–6.7
Refractory alloys	3–9
Stainless steels	2–5
Steels	2–9
Titanium alloys	2–5