Quiz 1

2.008 Design and Manufacturing II

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- There are four questions with 40, 30, 20, 10 points, respectively.

- Closed book.
- Subparts of each question have approximately equal points, if not marked.
- You are given 75 minutes.
- If you need more space, use the back of each page. (I doubt you need more space, since most answers would be short.)

- **Make sure you write down your name below.**

- Good luck!!

Name: Solution

Problem 1: (40 points)

A 6 inch long, 1.5 inch diameter 304 stainless steel rod is going to be machined at the lathe into the geometry below. (Fig. 1-1)

$\phi 1.5$

$\phi 1.46$

$\phi\ 3.0$
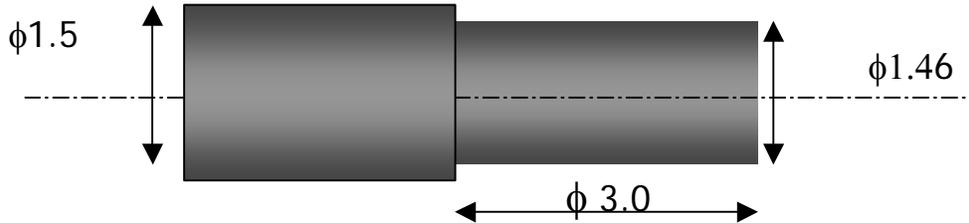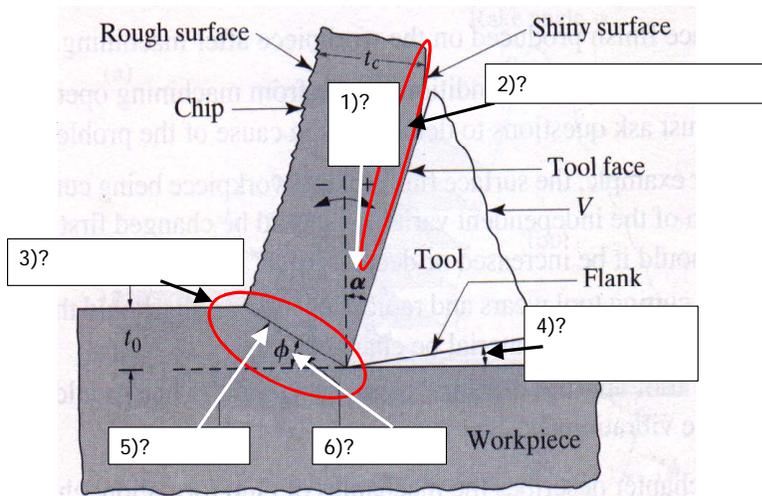
Fig. 1-1 The finished steel rod.

a) Since you don't know how to set the machining (turning) parameters, you decide to find them out by recalling the cutting physics lecture. First step is to name the diagram below assuming the job above is in the orthogonal cutting condition.

Name the "?'s" in Fig. 1-2. (3 points)

Rough surface   Shiny surface   1) Rake Angle

t_c 2)?

Chip → 1)?   2) Secondary shear zone

Tool face

V   3) Primary shear zone

3)?   Tool

Flank   4) relief or clearance angle

t_0 α 4)?

ϕ 5) shear plane

5)?   6)?   Workpiece   6) shear angle

Fig. 1-2 Orthogonal cutting

b) In order to set the proper feed, speed, depth of cut, you need to find out the cutting force, power, etc. From the cutting force FBD in Fig 1-3-a), Merchant made a diagram to find out the shear plane and related parameters. (Fig. 1-3-b)

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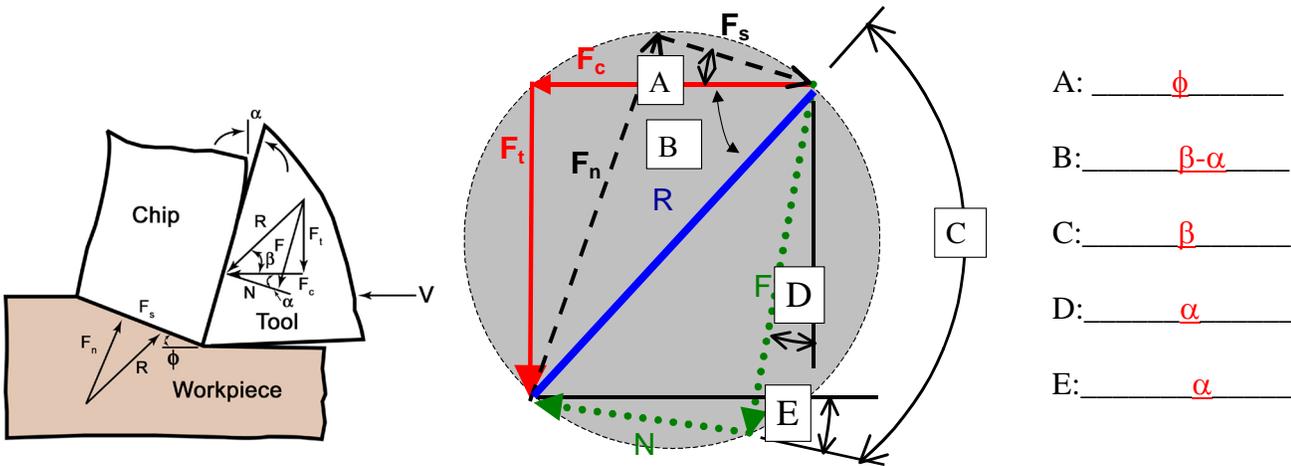*Get the angles A, B, C, D, E in terms of α, β, φ. (2 points)*

A: _____φ_____

B: _____β-α_____

C: _____β_____

D: _____α_____

E: _____α_____

Fig 1-3   a) FBD of cutting   b) Merchant's diagram

c)   From the diagram in Fig. 1-3-b), Merchant derived the relationship among α, β, φ .

Write down the relationship among α, β, φ?(5 points)(You don't need to derive it.)

$$\phi = 45° + α/2 - β/2$$

What was his assumption of locating the shear plane in deriving the above equation? (5 points)

The shear plane adjusts its location to minimize the cutting force or maximize the shear stress.

The tool given is HSS material with a rake angle of 10 ^{o}. The friction coefficient between the tool and the material given is 0.5. What is the shear angle, φ? (5 points)

The angle, β can be found from the relationship,

$$μ = \tan(β)$$

That means that

$$β = \arctan(0.5) = 26.6°$$

From the problem statement,

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rake angle = 10° = α

Therefore, from Merchant's relationship,

$\phi = 45° + 10°/2 - 26.6°/2 = 36.7°$

d) Now you set the turning parameters as below. Rotational speed, N=400 rpm, Tool travel speed along the work piece length, 12 inch/min, and the machining is going to be done by one pass. (15 points + 5 bonus points)

If the specific energy of the steel given is 1.47 hp. min/in³, what is the cutting force? (10 points) (1 hp=396,000 in lbf/min)

w = width of cut = $(D_i - D_f)/2 = .02$

tool speed (along length) = 12 in./min.

N = spindle speed = 400 rev./min.

f = feed rate = (12 in./min)/(400 rev/min.) = .03 in./rev.
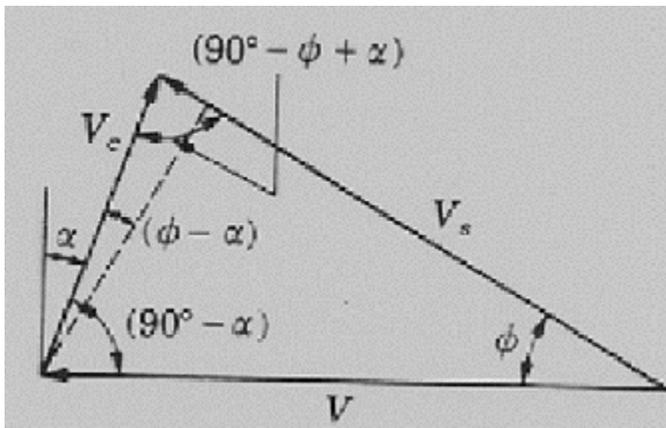
V = $(D_i + D_f)/2 * \pi * N$ = (1.5+1.46)/2 * π * 400 = 1860 in./min.

MRR = V * f * w = 1860 * 0.03 * 0.02 = 1.116 in³/min.

P = MRR * specific energy = 1.116 * 1.47 = 1.64 hp

Fc = cutting force = P/V = 1.64 * 396,000/1860 = 349.2 lbf.

Calculate the chip thickness and its speed? (5 points + 5 bonus points when you solve this.)

cutting velocity diagram, where V_c = chip velocity, V_s = shear velocity and V = cutting velocity

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From the law of sines,
$$V_c/\sin(\phi) = V_s/\cos(\alpha) = V/\cos(\phi - \alpha)$$

Therefor Vc= V* $\sin(\phi)/\cos(\phi - \alpha)$
From c) $\phi = 36.7°$, $\alpha = 10°$
From d)   V= 1860 in/min

Chip speed, Vc=1244 in/min

From the continuity (mass conservation).

$$V*t = V_c*t_c$$

Rearranging the equation above and substituting from the law of sines,

$$t_c = V/V_c * t = t * \cos(\phi - \alpha)/ \sin(\phi)$$

From d), f = 0.03 inch, and is the thickness of the material before the cut in the equation above.
$$t_c = 0.045 \text{ in.}$$

Note that here t represents the thickness of the material before it is cut and the chip is 50% thicker than t.

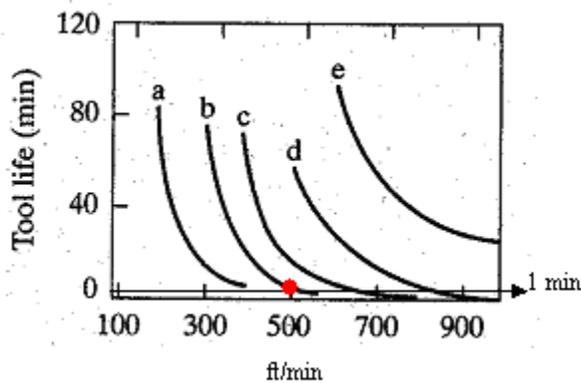e) The life of the HSS tool material has been tested as curve b in Fig. 1-4.

Fig. 1-4 Tool life measurement curve.

From the Taylor's Tool life equation below,

$$V \cdot T^n = C$$

predict the tool life of yours with the cutting conditions set in problem d). Assume the power index n = 0.2 in the tool life equation. (7 points)

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Look at the relationship when T = 1 min. This makes V = C. If you trace along the 1 min. line in Figure 1-4, you'll see that V = 500 = C at the red mark. Now you can predict the life of the tool with n = 0.2 and V = 1860 in./min. as you found above.

First converting V to have units of ft./min.

1860/12 = 155 ft./min.

Now solving for T,

$T^{0.2}$ = 500/155

T = 350 min.

If you use the same HSS tool for machining of softer materials, like aluminum, is the tool life curve moving to the left of curve b (such as a) or to the right (such as curve e)?(3 points)

Machining a softer material would push the life curve to the right, towards point e.

Problem 2: (30 points)

From the injection molding lecture, you learned that the design for injection molding includes the following points.

- Use uniform wall thicknesses throughout the part. This will minimize sink marks, warpage, and improve general performance of the molded part.

- Use generous radius at all corners and enough draft angles for the sides.

- Use the least wall thickness to ensure rapid cooling, short cycle times, and minimum shot weight.

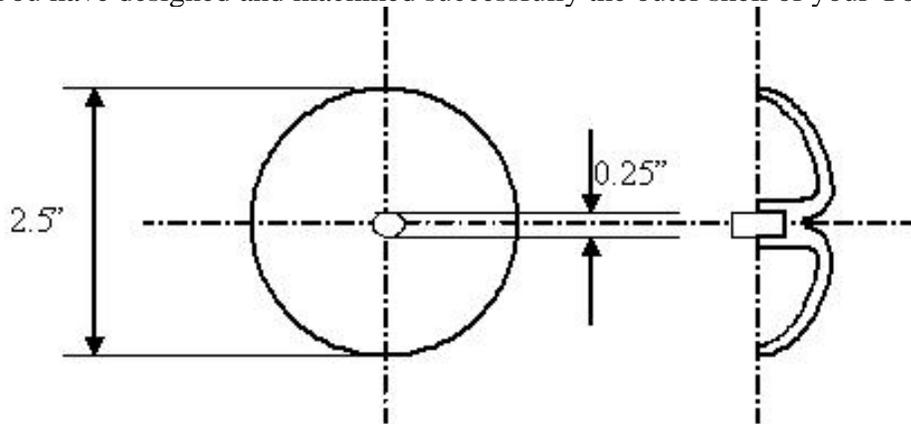You have designed and machined successfully the outer shell of your Yo-Yo as below.

Fig. 2-1 Yo-Yo outer shell design for injection molding

Now you are running the injection molding machine at the shop with the mold for the above part. Material supplied is PP (polypropylene), and the molding machine parameters were set already by someone whom you don't think reliable.

a) You first ran the machine for 50 shots. All the shots produced had a lot of flashes.

What would be the first guess on the cause of this trouble and the possible remedy of it? (5 points)

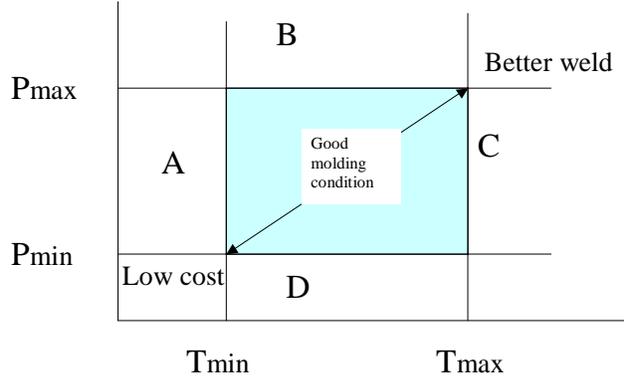The injection pressure may be too high. To prevent flashes, the pressure may be reduced.

Fig. 2-2 Injection molding process window

b) You changed the settings randomly, but didn't know exactly which knob is for which parameter. Therefore, you have observed different kind of defects for different combinations of the melt temperature and the injection pressure.

What kind of defect do you see for each region (A, B, C, D) of the process window? (5 points)
(The question in (a) will be repeated, but answer them shortly.)

A: poor quality

B: flash

C: burn, degradation

D: short shot

c) After settling down the process conditioning, the cycle time of the part is measured as 1 minute. It is composed of mold filling (10%), part cooling (70%), ejecting and mold closing, and etc. (20%). This cycle time cannot justify the selling price at the market. So, you need to reduce the thickness of the part further (30%) and to increase the injection speed 100%.

Explain why you need to increase the speed of injection? (3 points)

With thinner walls the flow path ratio (L/t) may become too high and result a short shot. In order to prevent a short shot, the injection speed needs to be increased to fill the cavity before the melt freezes.

Estimate the new cycle time. (7 points) Assume the thickness change uniformly over the whole part.

The filling time will be reduced to one half due to the increased filling speed:

60 sec • 0.1 • 0.7• 0.5 = 2.1 sec

The cooling time depends on the thickness squared:

60 sec • 0.7 • 0.7^2 = 20.6 sec
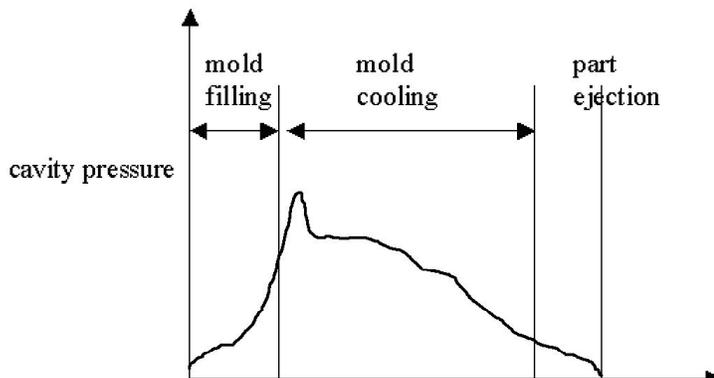
The time for ejecting, mold closing, etc. will remain the same:

60 sec • 0.2 = 12 sec

New cycle time: t = 3 + 20.6 + 12 sec = 34.7 sec, which is quite close to the economic production rate.

d) During one process cycle of injection molding, draw the cavity pressure history on the figure below, during one cycle of injection molding . (5 points)

| mold filling | mold cooling | part ejection |

cavity pressure

Cavity pressure during a cycle of molding

Explain the sudden increase of the pressure after the mold cavity is completely filled and why it is needed. (5 points)

The pressure peak after the mold is filled is due to the packing pressure which is applied in order to compensate the differential shrinkage between the metal mold and the plastic part.

Problem 3: (20 points)

The first high volume production of a pressure sensor began in 1974 at National Semiconductor, and the volume of the market has grown to 45 million units in 1998. Nearly all pressure sensors are produced using bulk micromachining technology. The technology is available through the KOH bulk micromachining of the silicon wafer, and the MAP sensor and disposable blood pressure sensor are the two largest applications. Fig 3. shows the bulk micromachined silicon bonded on top of pyrex with a back side hole. The membrane deflection is measured by four piezoresistors forming a Wheatstone bridge to get the pressure from the back side hole.
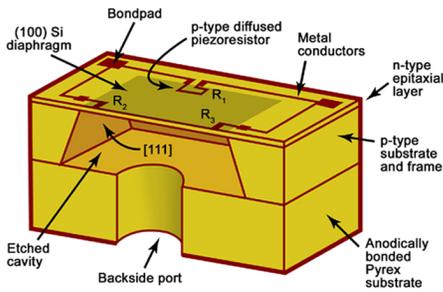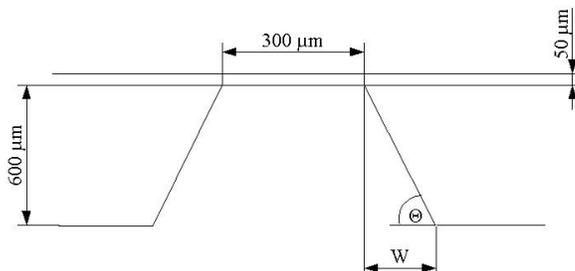

Figure 3

a) In order to make the membrane, the bottom of the wafer is coated with silicon nitride firstly and then etched to form a square opening. As KOH etching proceeds, the exposed {100} planes of p-type silicon etch rapidly while the {111} planes etch slowly, which makes angle θ with the plane of the wafer.

What is the angle θ? (3 points)

θ = 54.7°

b) The KOH solution etches the (100) silicon at 1.4 µm/min and stops when it reaches the top layer of n-type silicon. The remaining n-type silicon forms the membrane. The thickness of the wafer is 650 micron and the top 50 µm layer of the wafer is n-type silicon.
If the membrane size is 300 µm by 300 µm, what should be the size of the silicon nitride opening and how long does it take to KOH etch a membrane? (7 points)
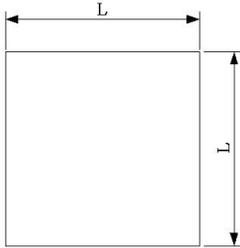

From the figure we get:

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w = 600/tan(54.7°)
L = 300 + 2 • w = 300 + 2 • 600/tan(54.7°) = 1149.6 µm

Where L is the length of one side of the silicon nitride opening according to the following figure:

The etching time can be calculated according to the following equation:

t = 600/1.4 = 428.6 min

If you can develop a surface micromachined pressure sensor of the same membrane size and sensing circuitry, what would be the most outstanding benefit you can get in comparison to the bulk micromachined sensors? (5 points)

You saw from above that the size of the back side opening is much bigger than the size of the top membrane (15 times larger). A surface micromachined device will be much more compact, and therefore more products can be produced per one wafer.

c) In order to bulk micromachine silicon wafer as described above, you need to select a p-type (100) silicon from the stock of many different wafers.

Which wafer is the right one among the four types below? (5 points)

Answer: __d_____ (among a, b, c, d)

Primary flat
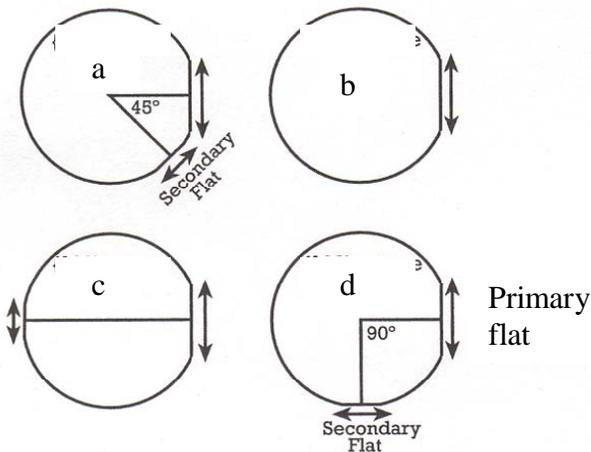
Problem 4.

Design for manufacturing or design for assembly is one of the core themes, which 2.008 is trying to deliver to you. (10 points)

Describe one clear example of DFM or DFA you have seen around you. An illustration of the example and adequate explanation will make the answer. (10 points.) Do not over describe your answer. Less than a half page is the maximum length.

Literally, most of the industrial products around us are well designed for manufacturing. Why? Otherwise, they cannot survive and stay at the market. I wish you well consider this aspect of design in your Yo-Yo project.