2.007 Design and Manufacturing I
Spring 2009

2.007 – Design and Manufacturing I
Draft Exam on Gears, Springs, Mechanisms, and Drawing

This is a practice exam. On the real exam, you'll have 1.5 hours to answer about 7 questions. This exam is somewhat longer and would take about 2.5 hours by my reckoning. Point allocations (out of 100 total) are listed for each question based on what they'd be worth on the real exam. So, this practice exam adds up to about 160 points.

1. (10 points) Define the term "hysteresis." Explain its significance for sensors and for energy storage elements (e.g. rubber bands).

The wikipedia entry for hysteresis inluded the following material I find both accurate and relevant to the course:

"a system with hysteresis exhibits path-dependence"

"A simple way to understand it is in terms of a rubber band with weights attached to it. If the top of a rubber band is hung on a hook and small weights are attached to the bottom of the band one at a time, it will get longer. As more weights are *loaded* onto it, the band will continue to extend because the force the weights are exerting on the band is increasing. When each weight is taken off, or *unloaded*, it will get shorter as the force is reduced. As the weights are taken off, each weight that produced a specific length as it was loaded onto the band now produces a slightly longer length as it is unloaded. … In one sense the rubber band was harder to stretch when it was being loaded than when it was being unloaded. …In another sense more energy was required during the loading than the unloading; that energy must have gone somewhere, it was dissipated or "lost" as heat. Elastic hysteresis is more pronounced when the loading and unloading is done quickly than when it's done slowly…"

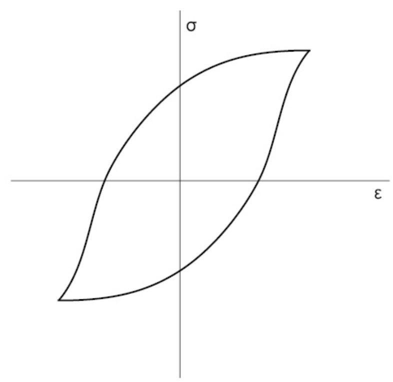


Figure by MIT OpenCourseWare. Please also see http://upload.wikimedia.org/wikipedia/commons/d/df/Elastic_Hysteresis.jpg

The Flexiforce sensors available to you in the contest "kit" exhibit a modest degree of hysteresis http://www.tekscan.com/pdfs/FlexiforceUserManual.pdf:

Hysteresis	<4.5% of full scale (conditioned sensor, 80% force applied)

2. (10 points) You fill a one liter container with air at 60 psi gauge pressure and plan to use it as a source of power for a machine. The air in the bottle is at thermal equilibrium with the air in the room at 20 degree Centigrade. Estimate the force applied if a valve is opened connecting the reservoir of air to a piston with a three inch internal diameter and a four inch throw.

First, consider the case that the air flow is minimal, for example if the actuator is used to apply a force at the beginning of its throw. If we assume the volume of the pneumatic lines is small compared to the one liter reservir, then 60 psi is applied to the face of the piston. The piston has a three inch diameter, about 7 square inches of area, and therefore 7in^2*60psi=420 pounds of force would be applied.

Now consider the more complicated situation in which the force is applied near the end of the stroke. The volume increase due to the 4 inch stroke is 7*4in^3 =0.46 liters. Going from 1.0 liter to 1.46 liters drops the pressure. If we assume the temperature is constant, the absolute pressure drops proportionally. Assuming adiabatic expansion, the pressure would drop even more. The gauge pressure can be computed by accounting for atmospheric pressure.

Assuming isothermal expansion

$$P_2 := (60 + 14.7)\cdot psi\cdot\frac{1\cdot liter}{1.46\,liter} - 14.7\cdot psi = 36.464\,psi$$

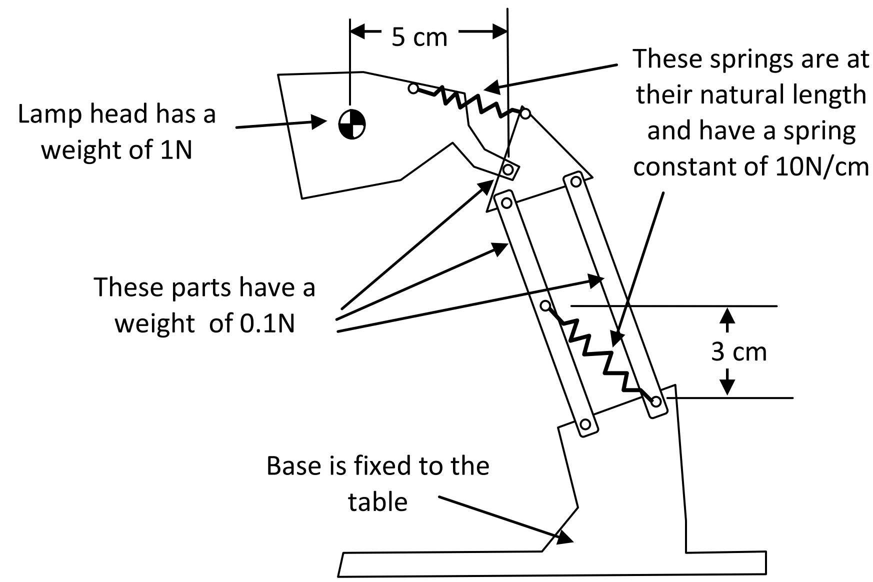
Assuming adiabatic expansion

$$P_2 := (60 + 14.7)\cdot psi\cdot\left(\frac{1\cdot liter}{1.46\,liter}\right)^{1.4} - 14.7\cdot psi = 29.277\,psi$$

I would say that adiabatic expansion more nearly describes the use of pneumatics in this biref event. So, the gauge pressure drops about in half and I will estimate **210 pounds** of force – a halving of my previous estimate assuming no volume change.

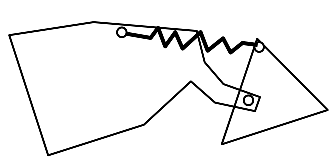
3. (20 points) Sketch the mechanism in a position that places it in static equilibrium. Assume the joints have negligable friction. The drawing is scaled properly in all dimensions so you can estimate any dimensions you need from the figure.

Briefly justify your solution with a couple equations, schematic diagrams, and/or a few sentences of explanation.



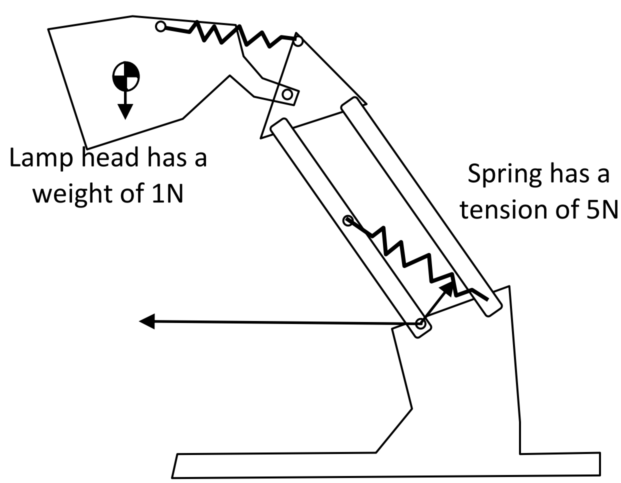
Because the lamp is on a parallelogram linkage we can take its two degrees of freedom in turn, fiurst the head and then the lower part. This is a subtle point. We know that whatever changes occur in the parallelogram part of the linkage, they will not cause any rotation that might affect the relative orientation of the weight vector and the spring tension. So, first we consider the head of the lamp.

The lamp head has 1N of weight. It acts at about 2.5 times the perpendicular distance from the pivot as compared to the spring. So the spring must apply about 2.5 N and extend about 0.25 cm to do this. The perpendicular distance of the lamp spring to the pivot is about 2cm, so around 1/8 of a radian or 7 degrees will extend the spring ¼ of a cm. The head will look very similar as before, roughly like this:



Based on the solution for the head, I make an initial guess that the lower part of the mechanism will also experience a rotation of 7 degrees. Similar to the other configuration, this causes about 0.25 cm of extension and 2.5 N of tension. As before, the lamp head has 1N of weight. But in this displaced 7 deg configuration, it acts at about 4 times the perpendicular distance from the pivot as compared to the spring. So the spring must apply about 4 N rather than the 2.5 N it would apply in this configuration. So I update my guess to 15 deg. Then the lamp will look roughly like sketched below. This would extend the spring about 0.5cm causing a tension of about 5N. The weight of the lamp is about 5 times the perpendiclar distance from the front pivot as the spring, so it should be nearly in equilibrium.

Here again I've made a simplifying assumption that may require more explanation. I treated the lower part of the mechanism as if the load of the lamp head were rigidly attached to the left arm of the parallelogram linkage. That is not quite true, but is close enough for the purposes of estimation +/- 20% in this problem. You can convince yourself of this by using virtual work. Imagine the lamp is in the position shown below and rotates by a small amount, say 5 degrees. What is the difference between the vertical displacement of the lamp head c.g. if the mechanism is a linkage as shown or if it is more simply a weldment including the left link, triqangle, and lamp head. I reckon the vertical motion of the weldment scenario is only about 20% higher than in the actual scenario. Close enough for this quick estimate where we have just about 10 minutes to work out a solution.



4. (20 points) The subproblems below refer to the page from a bearing catalog provided here.

A) (5 points) If gear PX32B-10 and PX32B-20 are mated together in a gear train, how far apart should the centers of their shafts be placed?

These gears have pitch diameters of .312 and .625. Sum them and divide by two – mount them 0.469 inches apart.

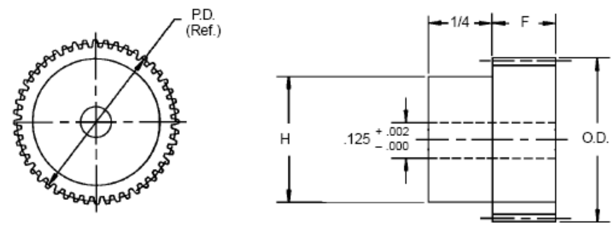
B) (5 points) If gear PX32B-10 and PX32B-20 are mated together in a gear train and a torque of 2 ft lbs is applied to PX32B-10, what is the torque on PX32B-20?

The ratio of the two torques is 2 (the same ratio as the ratio of the number of teeth) with the larger gear experiencing the larger torque. The answer is 4 ft lbs.

Spur Gears

24, 32, 48, and 64 Pitch 1/8" Bore AGMA Quality 4
Cold Rolled Steel and Brass 20° Pressure Angle

B 9



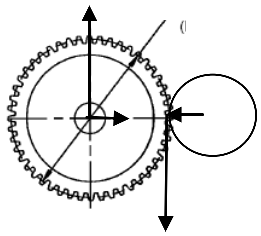
COLD ROLLED STEEL C12L14 OR C12L15 WITH SELENIUM	BRASS ALLOY 360					
STOCK NUMBER	STOCK NUMBER	NO OF. TEETH	PITCH DIA.	OUTSIDE DIA.	H	F
24 PITCH (.1309)						
PX24S-8	PX24B-8	8	.333	.416	.208	1/4
PX24S-9	PX24B-9	9	.375	.458	.250	
PX24S-10	PX24B-10	10	.417	.500	.291	
PX24S-12	PX24B-12	12	.500	.583	.375	
PX24S-16	PX24B-16	16	.666	.750	.542	
PX24S-18	PX24B-18	18	.750	.833	.625	
—	PX24B-22	22	.916	1.000	.792	
32 PITCH (.0981)						
PX32S-10	PX32B-10	10	.312	.375	.218	1/4
PX32S-11	PX32B-11	11	.344	.406	.250	
PX32S-12	PX32B-12	12	.375	.437	.281	
PX32S-14	PX32B-14	14	.438	.500	.343	
PX32S-15	PX32B-15	15	.469	.531	.375	
PX32S-16	PX32B-16	16	.500	.562	.406	
PX32S-18	PX32B-18	18	.563	.625	.468	
PX32S-20	PX32B-20	20	.625	.688	.532	
	PX32B-24	24	.750	.813	.656	
48 PITCH (.0654)						
PX48S-14	PX48B-14	14	.292	.333	.229	1/8
PX48S-15	PX48B-15	15	.312	.353	.250	
PX48S-16	PX48B-16	16	.333	.375	.271	
PX48S-18	PX48B-18	18	.375	.417	.312	
PX48S-24	PX48B-24	24	.500	.542	.437	
PX48S-32	PX48B-32	32	.666	.708	.604	
	PX48B-36	36	.750	.792	.687	
	PX48B-40	40	.833	.875	.770	
64 PITCH (.0490)						
PX64S-15	PX64B-15	15	.234	.265	.187	1/8
PX64S-16	PX64B-16	16	.250	.281	.203	
PX64S-18	PX64B-18	18	.281	.312	.234	
—	PX64B-24	24	.375	.406	.328	
—	PX64B-40	40	.625	.656	.578	
—	PX64B-48	48	.750	.781	.703	

Berg Manufacturing "The Mark of Quality" **1-800-232-BERG**

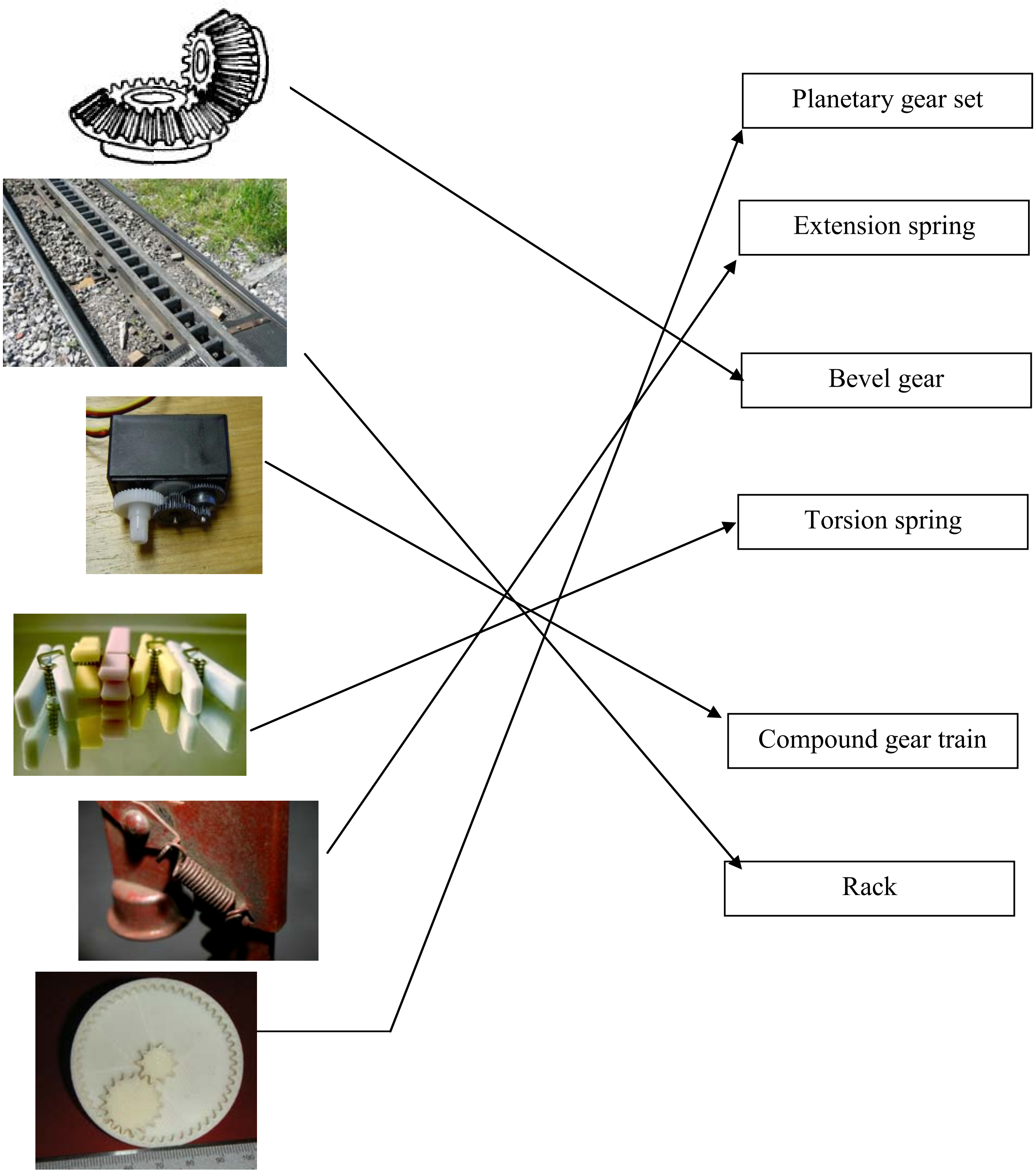
C) (10 points) If gear PX32B-10 and PX32B-20 are mated together in a gear train and a torque of 2 ft lbs is applied to PX32B-10, what is the direction and magnitude of the reaction force at the shaft where PX32B-20 is mounted? State any assumptions needed to arrive at your answer.

From (B) 4 ft lbs ia applied to PX32B-20. This is caused by a tangential force acting at the radius of 0.312 inches. Must be 154 lbs of tangential force. The gears have a pressure angle of 20 deg. The

separation force is therefore 154lb*tan (20deg)=56lbs. Both the tangential and separation forces are reacted at the bearing with the separation force acting toward the center of the other gear PX32B-10 and the tangential force acting perpendicular to that.



6. (10 points) Match the items below to the terms that describe them.



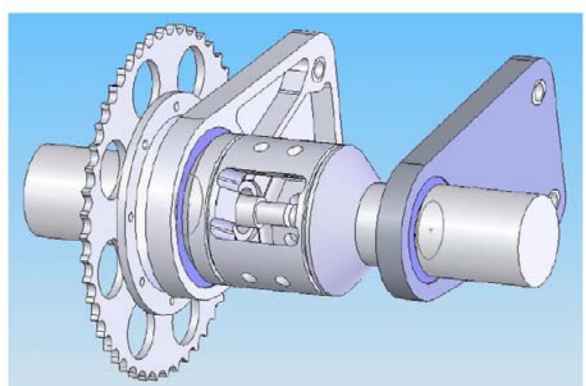
Images from melloveschallah, gregpc, and wizard23 on Flickr, and Wikimedia Commons, http://commons.wikimedia.org

7. (10 points) It is proposed to use the arrangement below to transmit torque from the drive shaft of an engine to the rear wheels of a small vehicle. Explain why this might be a good design for a small race car yet not a good choice for a typical family sedan.

This looks like a sprocket, so I guess the team decided to have a chain to transmit the engine's torque to the rear wheels. I like this idea because a passenger car would accomplish this function with a shaft, probably requiring a U joint to accommodate up and own motion and a differential to change the direction of the applied torque. The chain drive should be much lighter. In a race car, weight is at a premium, so this seems like a good choice. But a chain is also loud and has a shorter life in general. Also, the exposed chain may be OK for a race car where the debris on the road would be removed before a race and fair weather operation is ensured. In a passenger car, these factors would surely rule out a chain driven rear axle.

NOTE: What is that device in the middle. Can it allow the two wheels to rotate at different speeds during turns? I don't think I've shown enough details here for you to tell, but something would have to carry out that function.

FSAE section members: What would you add to this discussion?



8. (10 points) A circuit is arranged with a relays, a DC motor, and sources of voltage (+5V) Vdd shown below. A set of code is downloaded to a Basic Stamp Homework board is also given below. Describe what will happen when the code is run. (The specification sheet for the relays is shown on the next page for reference.)

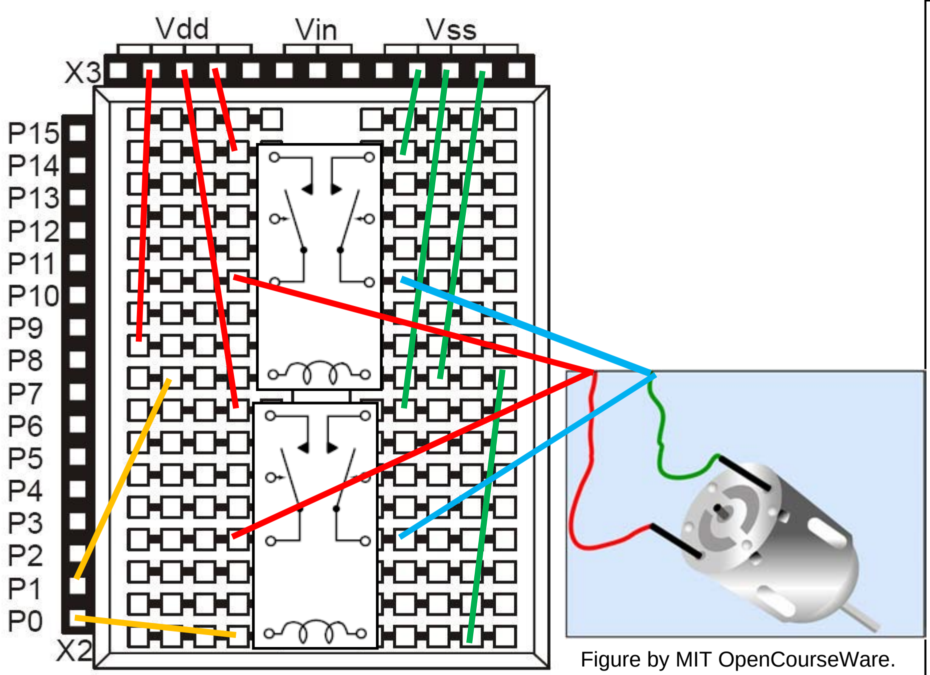


Figure by MIT OpenCourseWare.

```
' {$STAMP BS2}
' {$PBASIC 2.5}
i VAR nib
DO
FOR i=1 TO 10
LOW 0
HIGH 1
PAUSE 1000
LOW 1
HIGH 0
PAUSE 1000
NEXT
FOR i=1 TO 10
HIGH 0
HIGH 1
PAUSE 1000
LOW 1
LOW 0
PAUSE 1000
NEXT
LOOP
```

The wiring of the relays is similar to that needed for an H-bridge, but it doesn't connect the voltage supply in the opposite direction as it should. During the first FOR loop, the pins for the two directions are in opposite states (as needed for proper operation of an H bridge) and they toggle each second. If this were a proper H bridge, the motor would reverse directions going CW ten times and CCW ten times. Instead, this circuit just keeps going in the same direction as if it were connected continuously. During the second FOR loop, both pins are set to HIGH and all the relays in the bridge close. This would be just the same as before – on all the time. If this were a real H bridge, closing all the relays at one time would cause a short circuit condition.

Thought question: How would you change a small number of wires to get a proper H bridge?

9. (25 points) Give short answers to the subquestions below.

A) (5 points) What does it mean to say that a pair of mating gears exhibit “conjugate action”?

Conjugate action refers to the property that constant rate of rotation of the driving grear will lead to constant rate of rotation of the driven gear.

B) (5 points) Consider the statement “the involute curve is the only shape for gears that provides conjugate action.” Is this true or false? Justify your answer.

The involute curve is not the only gear profile that provides conjugate action. For example, epicycloidal and hypocycloidal gear tooth profiles also have the property and are widely used in positive displacement gear pumps. http://en.wikipedia.org/wiki/Gear_pump

C) (5 points) Describe, in your own words, the meaning of the term “pitch diameter”.

The pitch diameters of two mating gears are the diameters of two friction drive elements that would provide the same speed reduction as the meshing set of gears.

D) (5 points) Consider the statement “Gear teeth designed using an involute curve provide conjugate action even if the gears are mounted at a slightly greater distance greater than half the sum of the pitch diameters of the mating gears.” Is this true or false?

TRUE! This is a major benefit of the involute profile and a substantial reason for their popularity.

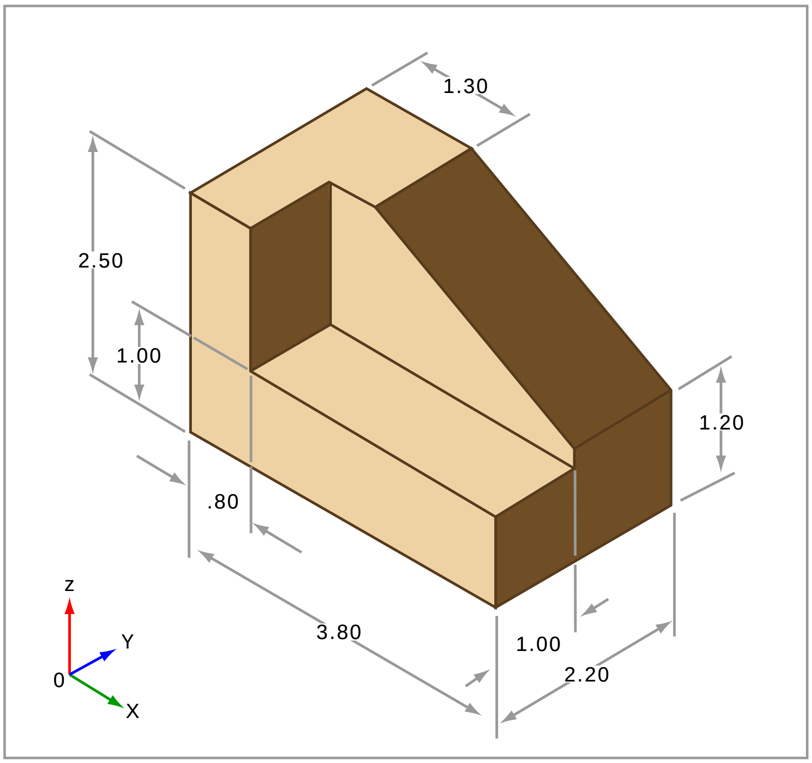
E) (5 points) Name and briefly describe two different ways that spur gears are manufactured and the differences in performance and cost of the resulting gears.

Molding and hobbing. Molding is inexpensive if you have high enough production volumes, but not all materials can be molded (mostly thermo-plastic gears are molded). Hobbing is common for steel gears and provides high accuracy and good surface finish.

10) (20 points)

A) (10 points) Make a three view drawing, complete with dimensions, of the part below. Show the dimensions on the view that best communicates each feature.

B) (10 points) Suggest a sequence of manufacturing steps to make the part. You can suggest and describe one or two small changes that would make the part easier to fabricate.



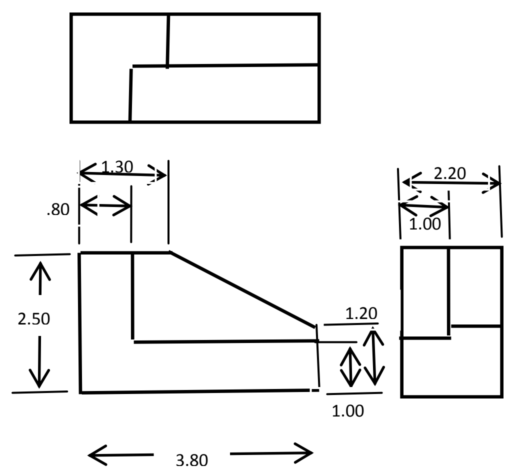


Figure by MIT OpenCourseWare.

Thought questions: Why isn't the angle dimensioned?

Does this use first or third angle projection?

11) (20 points) (Adapted from Shigley and Mischke, NOTE: The values of variables have been changed) A hydraulic cylinder has a diameter *D* = 4 inches, a wall thickness *t*= 1/2 inch, length *L* = 12 inches, and bracket thickness of *w* = ¾ inch. The brackets and cylinder are made of steel. Six 3/8 in SAE grade 7 coarse threaded bolts are used and tightened to 75% of proof load (120,000psi for SAE grade 7). By how much will the bolts increase in length when the cylinder changes from applying no load to applying a load of 4000 lbs (applied at the output on the right)?

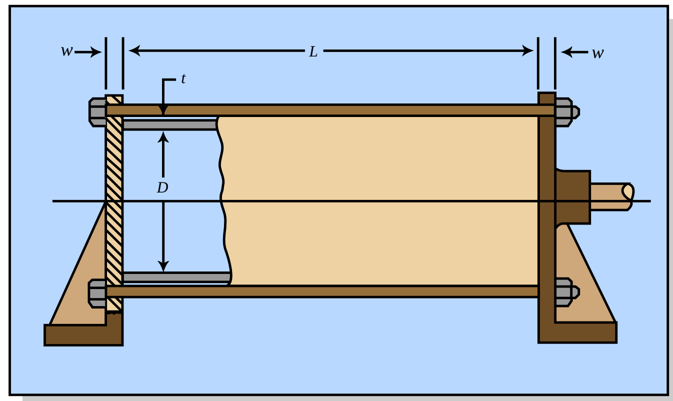


Figure by MIT OpenCourseWare.

This one is on the hard side. I didn't cover this much in lecture and I am not sure you got this in 2.001 either. But I wanted you to see this sort of analysis at some point. It is very important if you ever use bolts in a design that has to survive cycling loads. So here its is.

Each bolt is loaded to about 75% of proof load or 90,000psi. When the bolts are tightened to this load, the bolts stretch. Young's modulus of steel is about 30 10^6 psi, so the bolts stretch 0.3% of their length of 12 iches or 36 thousandths of an inch. Each bolt is about 0.1 sq inches in cross sectional area so at 90,00psi, each bolt squeezes the structure with 9,000 lbs force. There are six of them, so the structure is experiencing 54,000 pounds of compression when the hydraulic fluid is not under pressure. When the piston is loaded with 4,000 lbs, the machine has to carry this additional load. Some might think this load is carries by the bolts, so they need to stretch another but – maybe 4000/54000 or 7% of what they already stretched, maybe another 3 thousandths of an inch. But what actually happens is very different. The walls of the cylinder are 4 inches in diameter as ½ thick, so they have a cross sectional area of about 6 square inches. That's roughly ten times the cross sectional area of the bolts. The wall and bolts have basically the same Young's modulus so I guess the wall is 10 times as stiff as the bolts. If the bolts stretch, the wall also stretch the same amount. So, when the pressure in the fluid rises about ten times as much change in force occurs in the walls as in the bolts. Therefore the bolts stretch only about 0.3 thousandths of an inch. This helps a great deal as they are much less likely to fail due to fatigue if they see very little change in length as th structure is cycled. The bottom line lesson is that bolts should be tightened a lot. 75% of proof load sounds like a lot, but it's OK. In many applications, bolts are tightened right to their yield point.