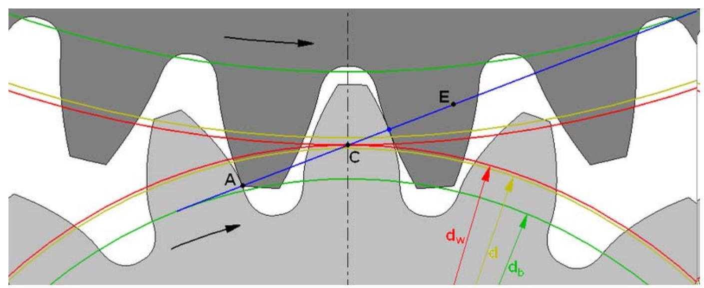
2.007 Design and Manufacturing I
Spring 2009

2.007 –Design and Manufacturing I

Gears: Terminology, Geometry, Gear Trains, Strength



Presented by Dan Frey on 17 MAR 2009

Images from Wikimedia Commons, http://commons.wikimedia.org

Today’s Agenda

- Distribute homework #3
- Gears
  - – Applications
  - – Types
  - – Terminology / nomenclature
  - – Congugate action
  - – Involute curve
  - – Analysis & design

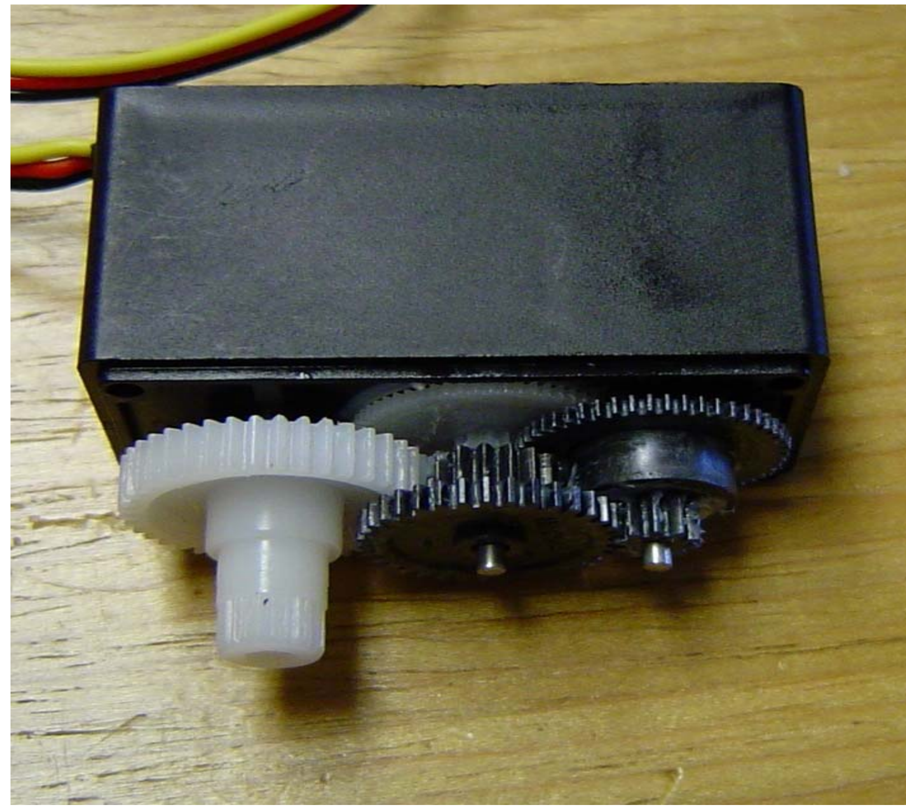
Applications of Gears

Images removed due to copyright restrictions. Please see
http://mossmotors.com/Graphics/Products/Schematics/SPM-027.gif
http://www.nmm.ac.uk/collections/displayRepro.cfm?reproID=A6263

Sobel, Dava, *Longitude*

Spur Gears

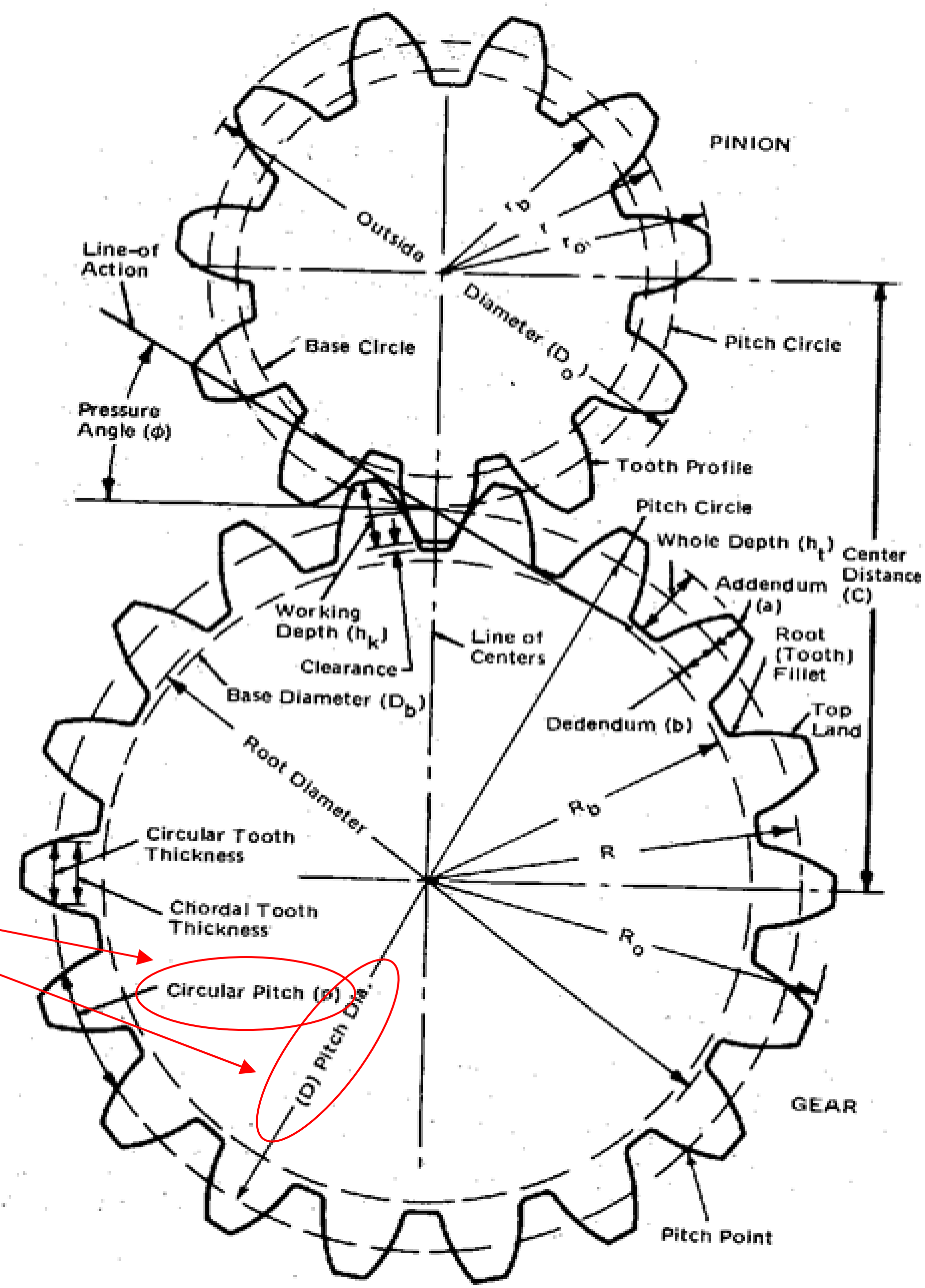
- Transmit motion between parallel shafts
- Teeth are parallel to the axis of rotation
- This is the simplest kind of gear we'll consider and most of today is dedicated to them



Gear Terminology

Diametral pitch (teeth per inch)
# of teeth on a gear with a
1 inch pitch diameter

Easily confused



Source: Fig. 1.1 in "Gears." *Design and Application of Small Standardized components Data Book 757*. Stock Drive Products, 1983. Accessed September 18, 2009. Courtesy of Stock Drive Products/Sterling Instrument.

Other Types of Gears

Image courtesy of perlmonger on Flickr.

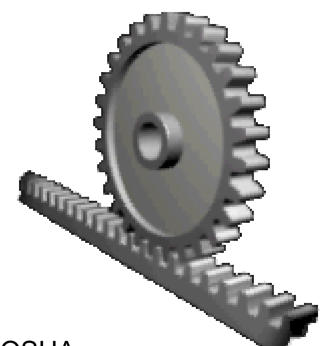
Bevel

Helical

Images from Wikimedia Commons, http://commons.wikimedia.org

Worm

Rack



Courtesy OSHA.

Early Gears

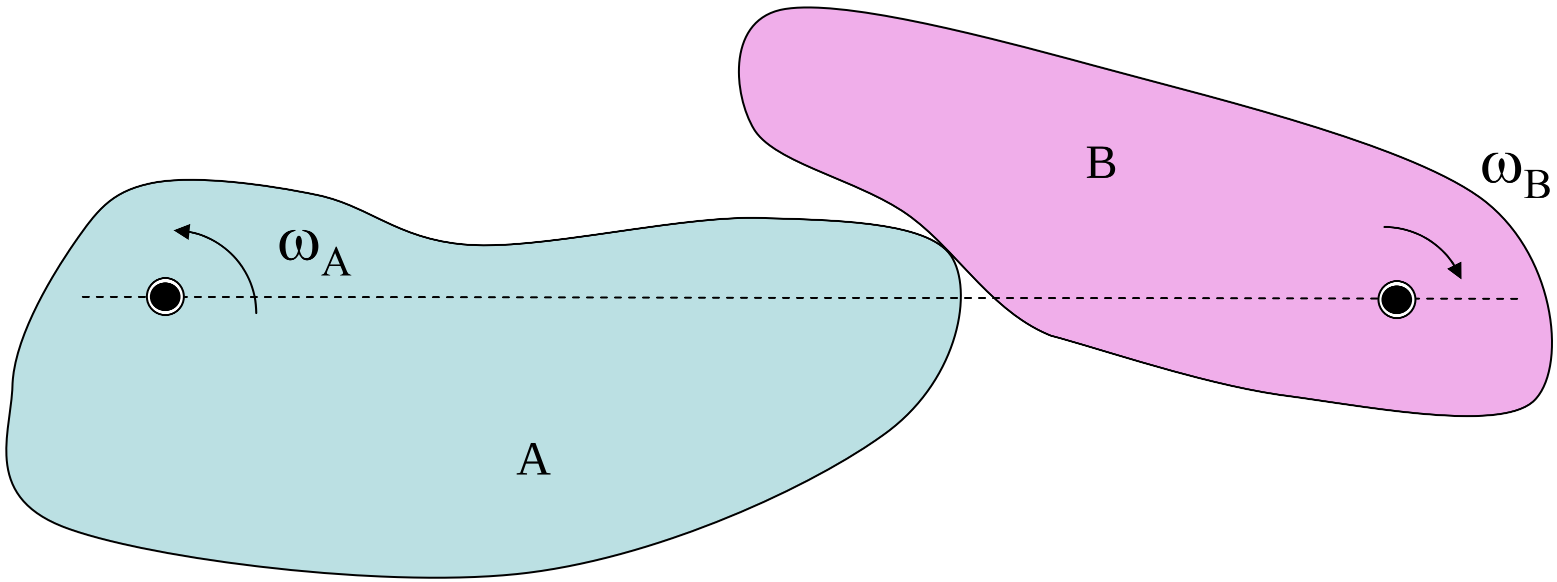
Drawings of waterwheels and gears removed due to copyright restrictions.

Roman watermills at Barbegal
300AD

Application for powering textile machinery
18^{th} century

Conjugate Action

NOTE: As discussed in class, the rotation of the driven body B can be inferred. The key is that the two bodies stay in contact even after a small increment of rotation. For this reason, the "gear ratio" is a function of the orientation of the line normal to the point of contact.



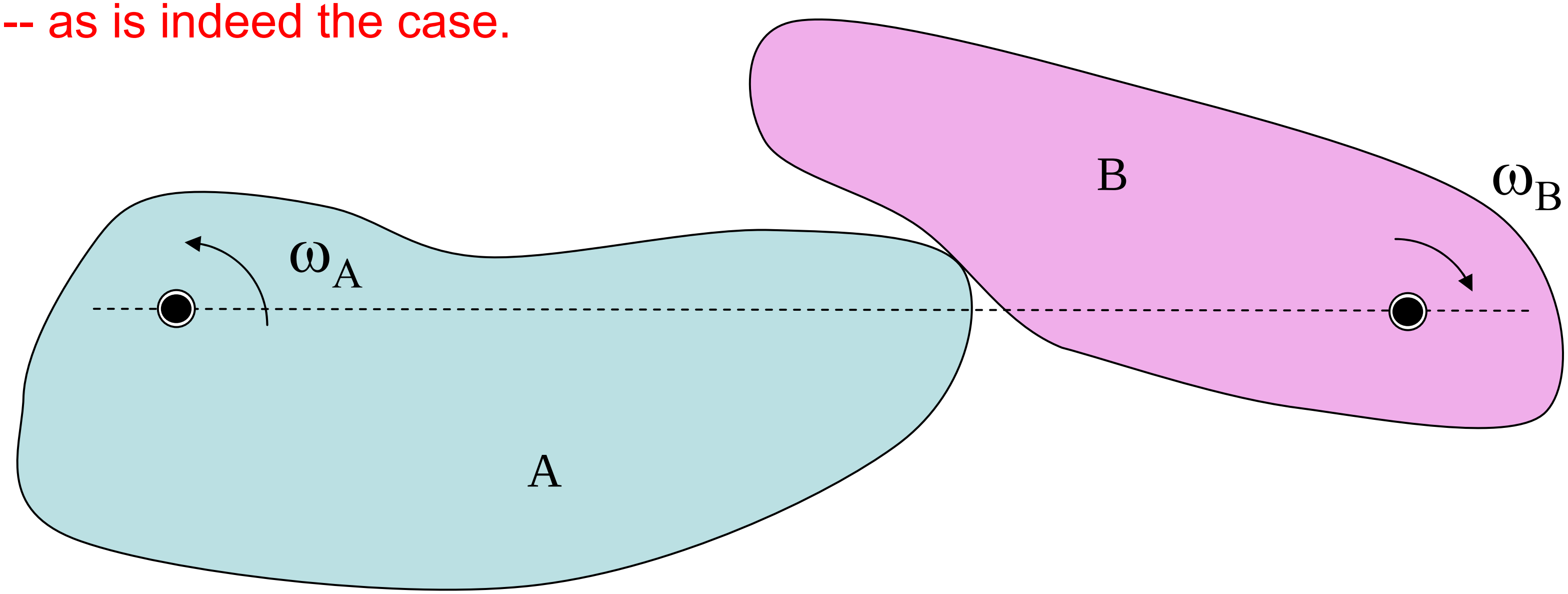
Let's say ω_A is a known. How can we determine ω_B?

Let's say ω_A is a constant with time. Can we synthesize a shape of body B so that ω_B is also constant with time?

Yes, generally one can synthesize a shape B for any shape A to attain conjugate action. An analog of a "rack cutting" procedure would generally do it.

Pitch Point

Line of action, also called **'Pressure line'**. The line along which the force between two meshing gear teeth is directed. It has the same direction as the force vector. In general, the line of action changes from moment to moment during the period of engagement of a pair of teeth. For involute gears, however, the tooth-to-tooth force is always directed along the same line -- that is, the line of action is constant. this implies that for involute gears the path of contact is also a straight line, coincident with the line of action -- as is indeed the case.



What is the line of action?

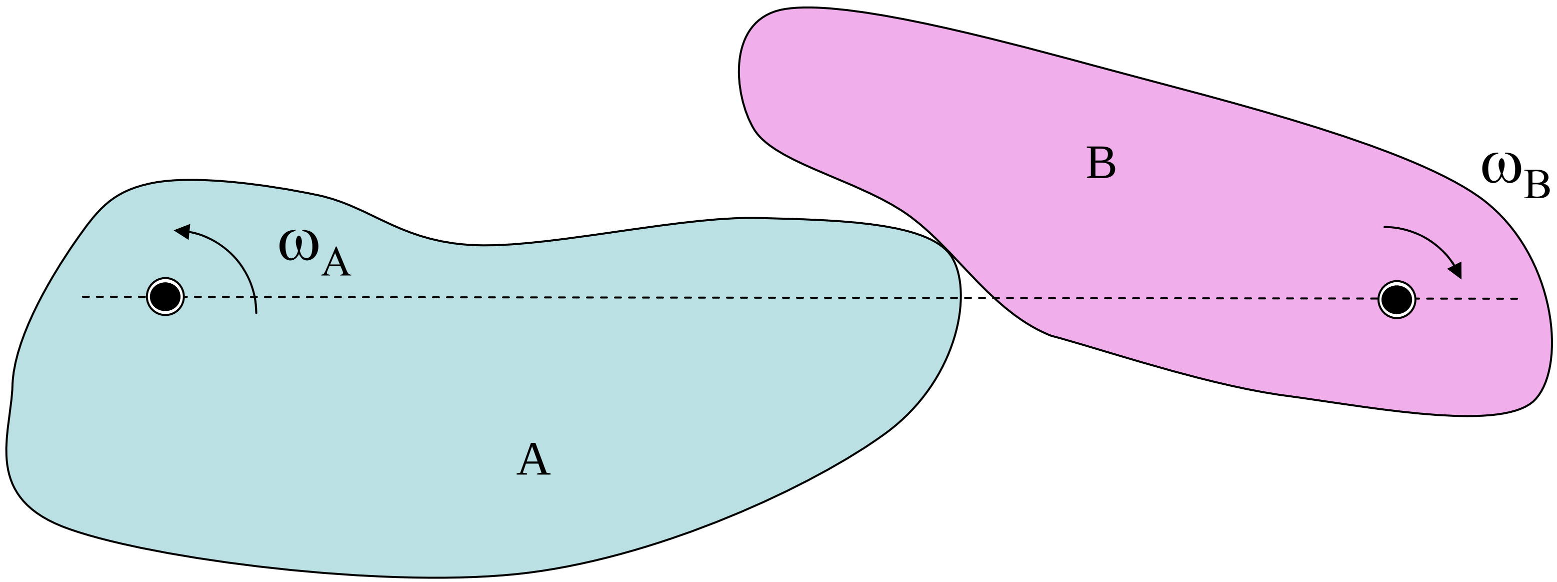
What is the pitch point?

What are the relationships among these?

Pitch point (p). The point where the line of action crosses a line joining the two gear axes.

http://en.wikipedia.org/wiki/Gear

Sliding and Rolling



When one body is driving another, do the surfaces slide, roll, or both?

Generally both rolling and sliding are going on at the same time.

What is the relationship to the pitch circles?

But at the pitch point where the pitch circles touch, there is purely rolling.

How could you determine this?

Draw the velocity vectors at the pitch point.

Rack Cutting

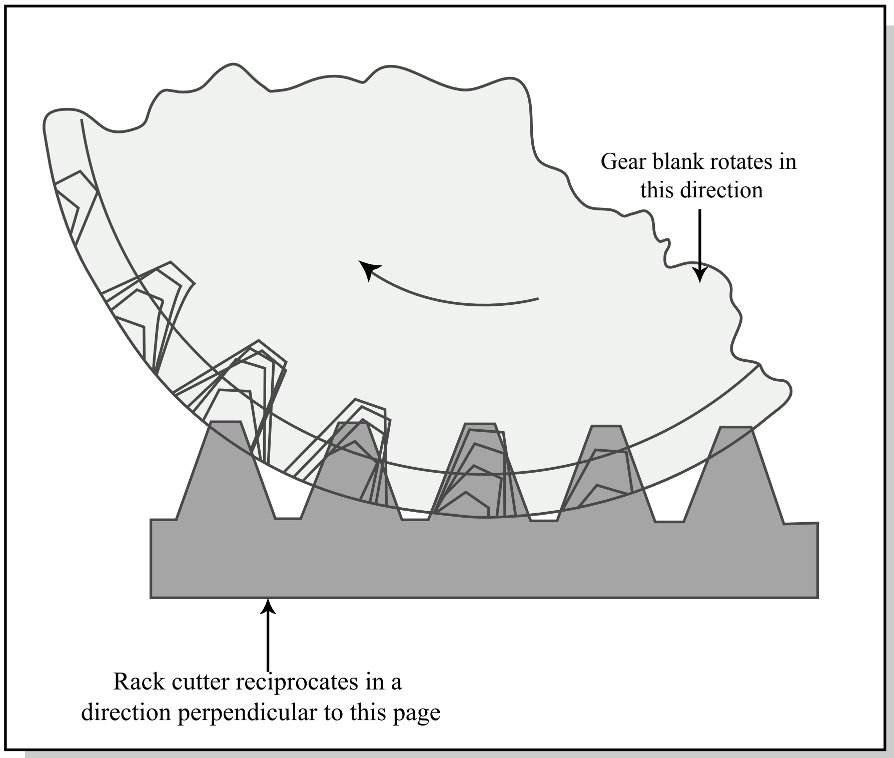
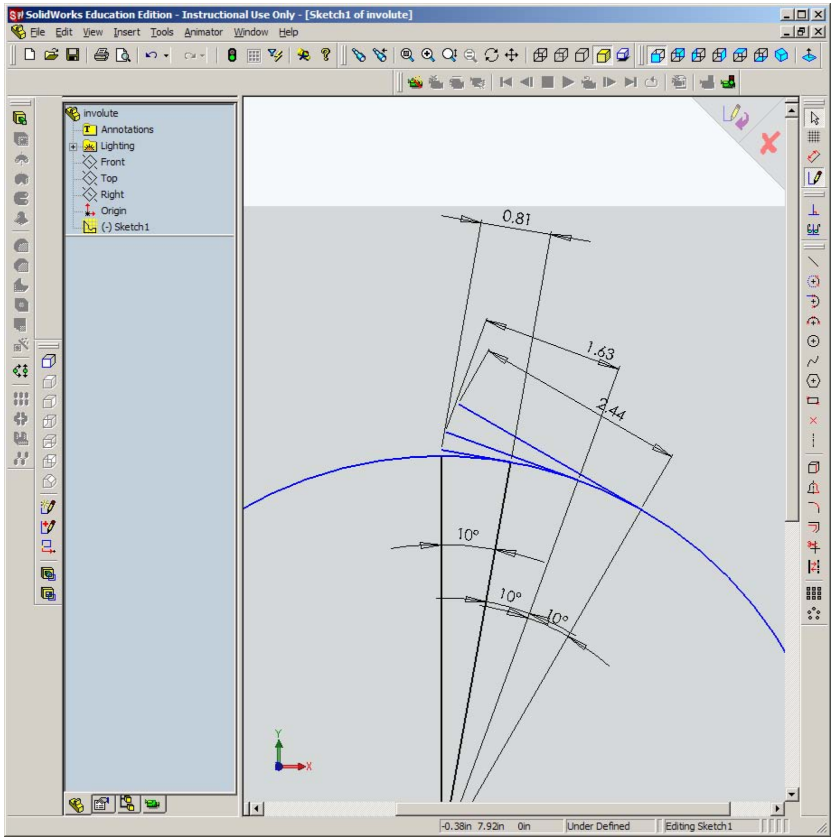


Figure by MIT OpenCourseWare.

- A way to get the relative motion you want
- Pick one shape as you wish
- Enforce the motion you want
- Cut away everything that interferes

Involute Profile

- How it is constructed
  - Demo
- Properties
  - Conjugate action
  - Allows design of whole sets of compatible gears
  - Conjugate action not sensitive to center distance variations



More Gear Terminology

From
Shigley and Mischke

Image removed due to copyright restrictions. Please see
http://commons.wikimedia.org/wiki/File:Gear_words.png

This geometry is not an involute.

Pressure Line

- Where the teeth contact, the surface normal defines a pressure line
- The force transmitted acts along this line
- The pressure line always includes the point of tangency between the pitch circles
- With the involute gear profile, the pressure line is constant

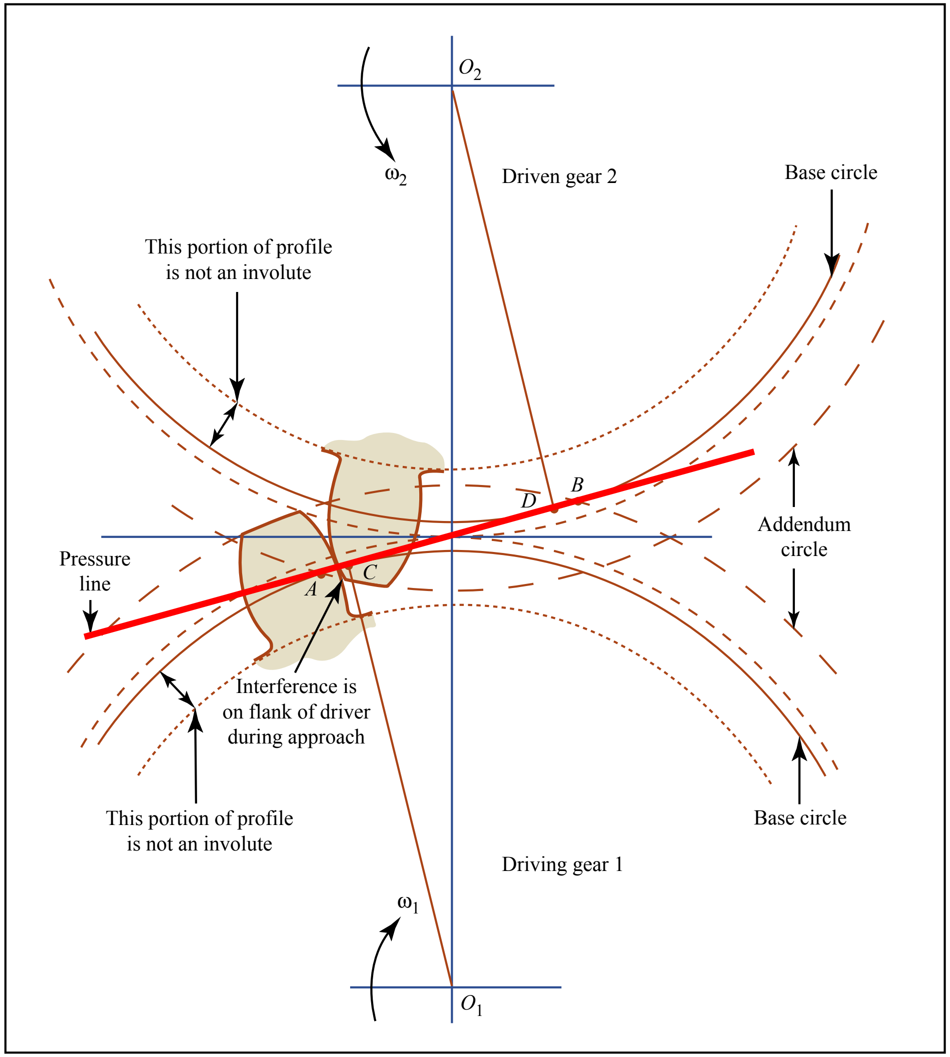
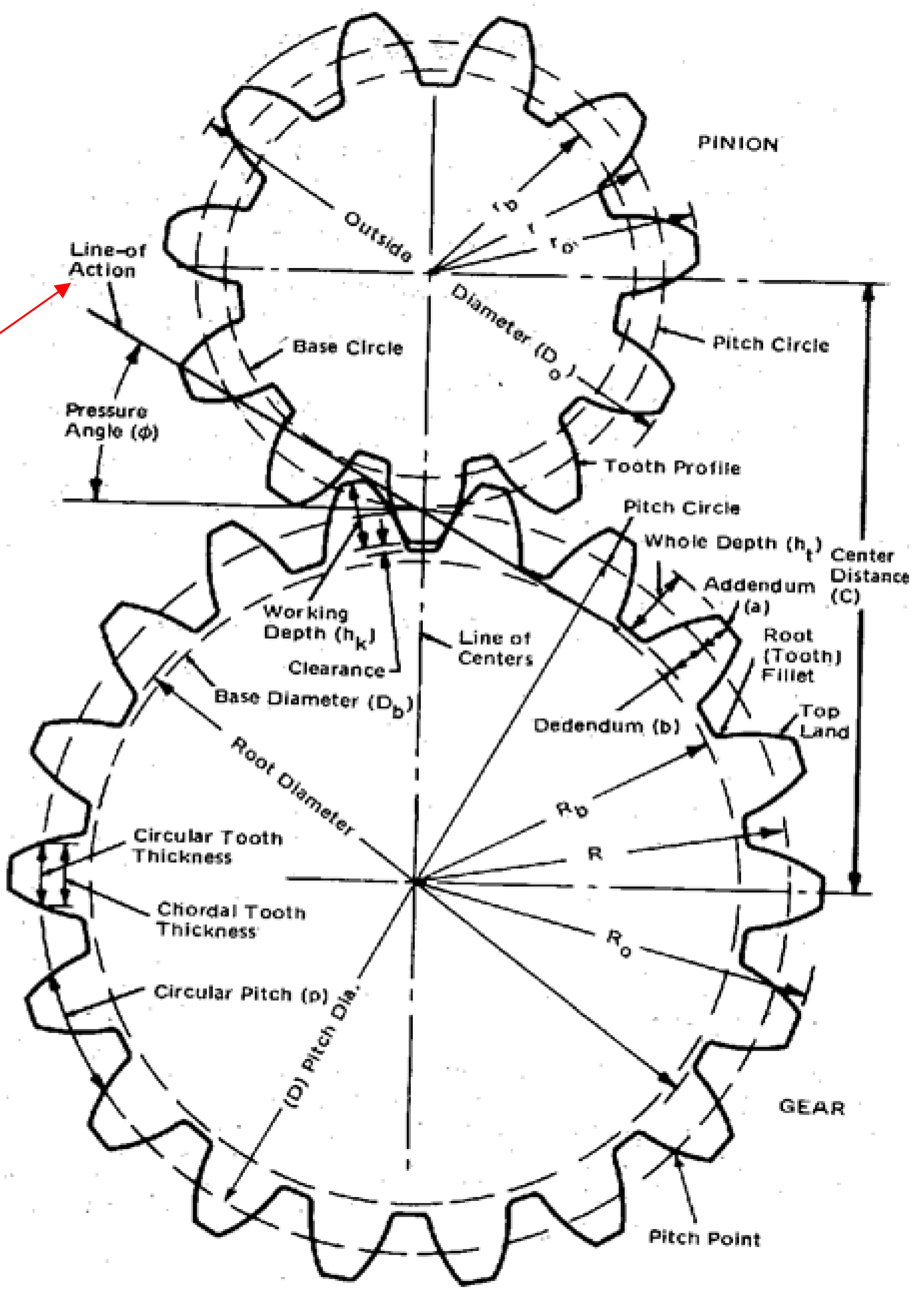


Figure by MIT OpenCourseWare.

From Shigley and Mischke

Gear Terminology

"Line of action" & "pressure line" & "generating line" are all synonymous



Source: Fig. 1.1 in "Gears." *Design and Application of Small Standardized components Data Book 757*. Stock Drive Products, 1983. Accessed September 18, 2009. Courtesy of Stock Drive Products/Sterling Instrument.

Pressure Angle

- The pressure line acts at some angle to the tangent of the pitch circles
- This angle can be chosen by the designer
- It affects
  - Separation forces
  - Tooth shape

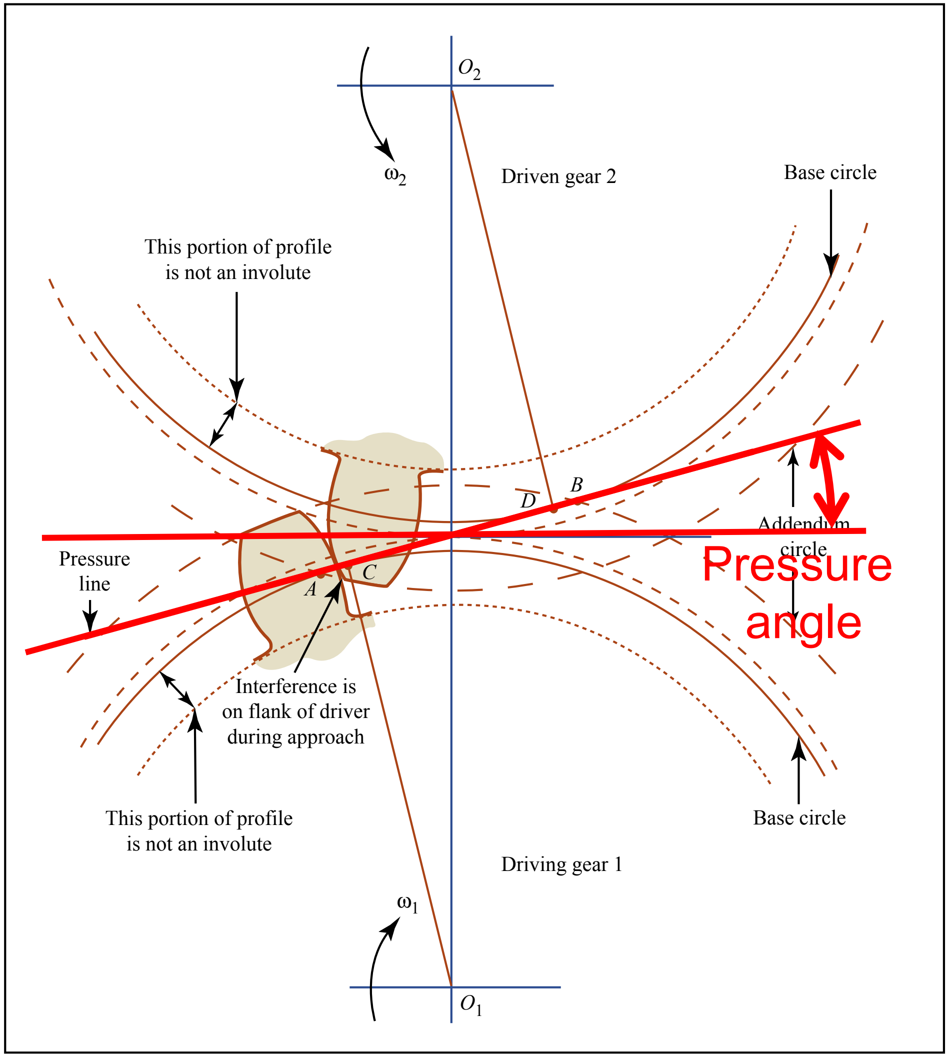


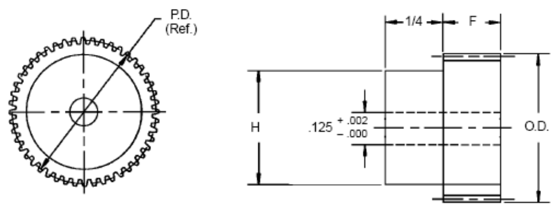
Figure by MIT OpenCourseWare.

From Shigley and Mischke

Concept Question

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	
PX24S-9	PX24B-9	9	.375	.458	.250	
PX24S-10	PX24B-10	10	.417	.500	.291	
PX24S-12	PX24B-12	12	.500	.583	.375	1/4
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	
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	1/4
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	
PX48S-15	PX48B-15	15	.312	.353	.250	
PX48S-16	PX48B-16	16	.333	.375	.271	
PX48S-18	PX48B-18	18	.375	.417	.312	1/8
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	
PX64S-16	PX64B-16	16	.250	.281	.203	
PX64S-18	PX64B-18	18	.281	.312	.234	1/8
—	PX64B-24	24	.375	.406	.328	
—	PX64B-40	40	.625	.656	.578	
—	PX64B-48	48	.750	.781	.703	

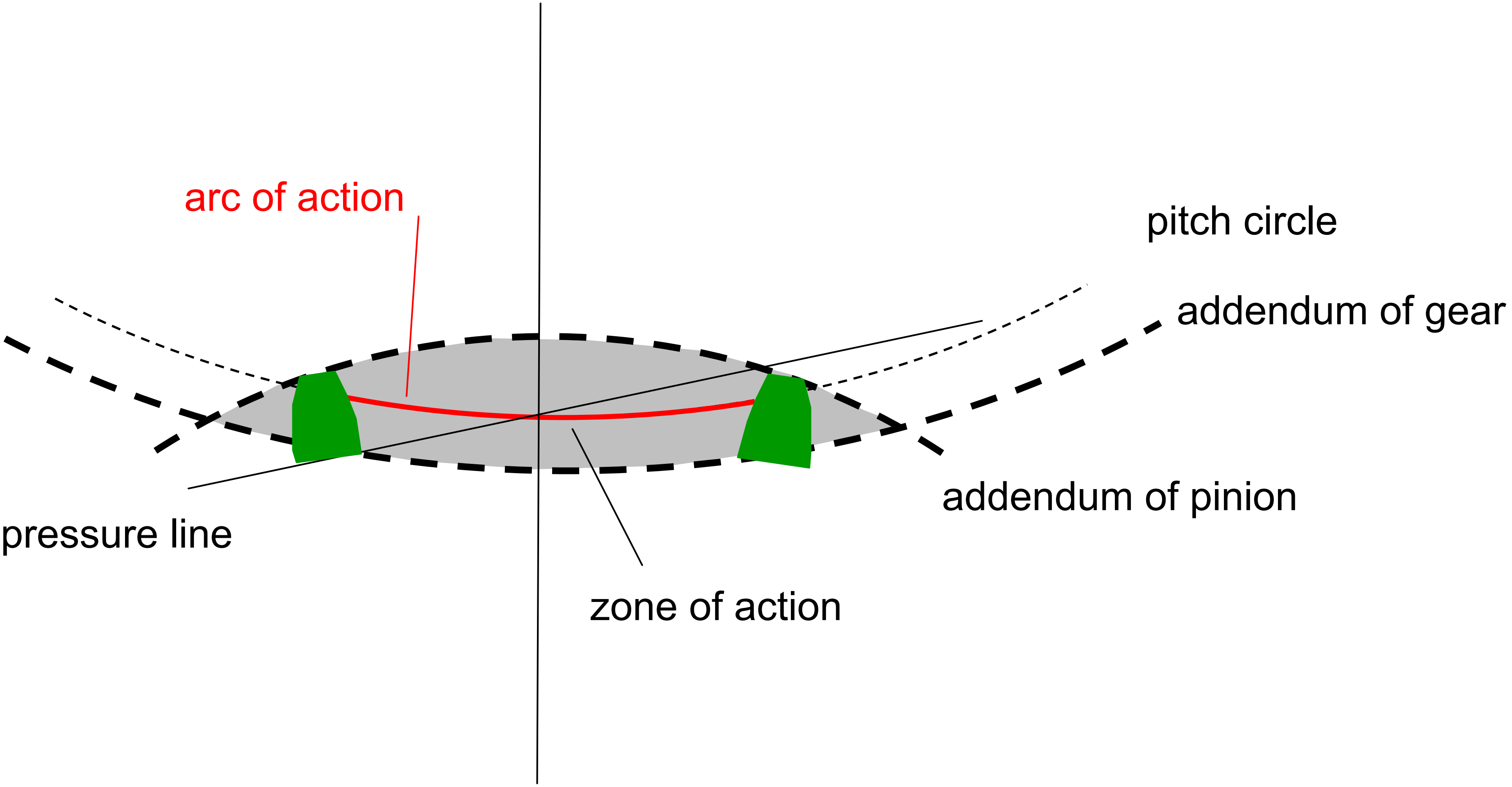
Berg Manufacturing "The Mark of Quality" **1-800-232-BERG**

A pair of gears are mated. One is driven at a set torque, the other is regulated at a set speed. The gears are the ones circled. What is the ratio of the separation forces and the total force on the bearing?

1. << 0.3
2. About 0.3
3. About 0.5
4. >> 0.5

Answer = 1: The key thing is pressure angle which is 20 deg. The ratio of separation and total force is sin 20 deg.

Contact Ratio



contact ratio = length of arc of action / pitch = average number of teeth engaged

Interference

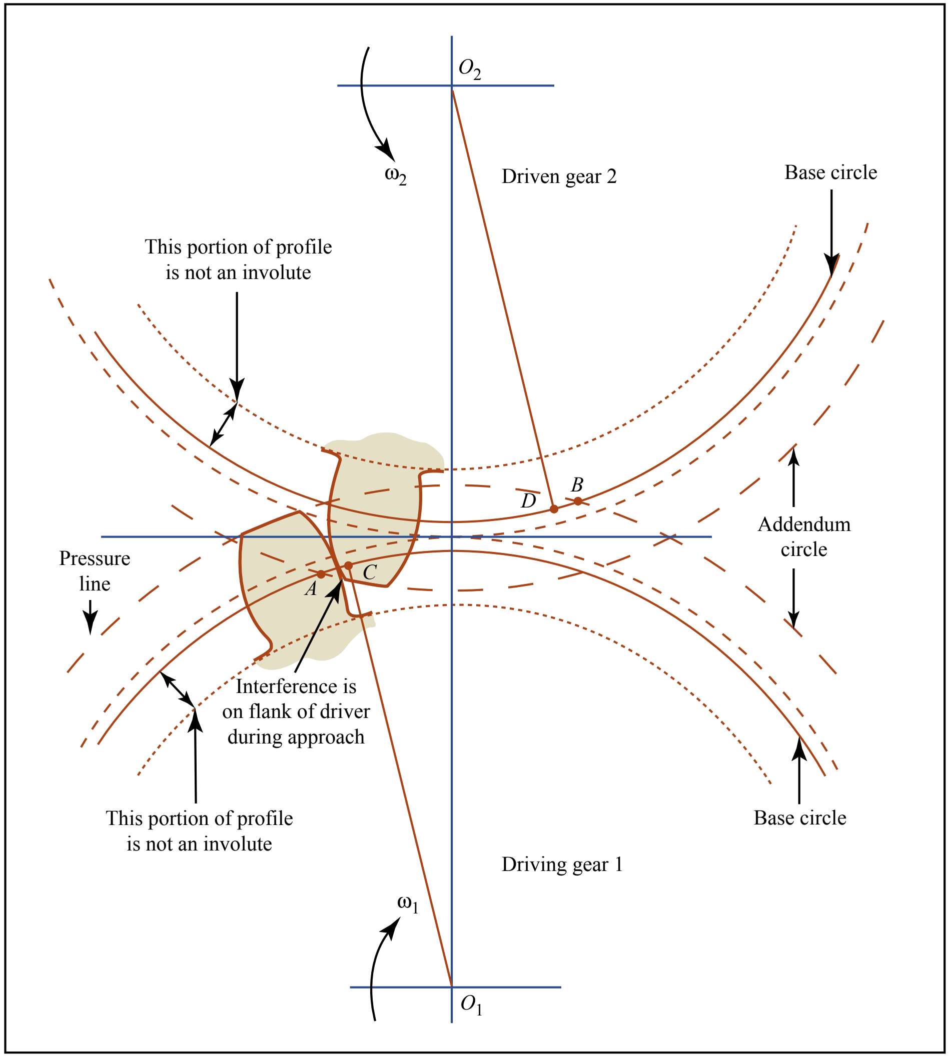
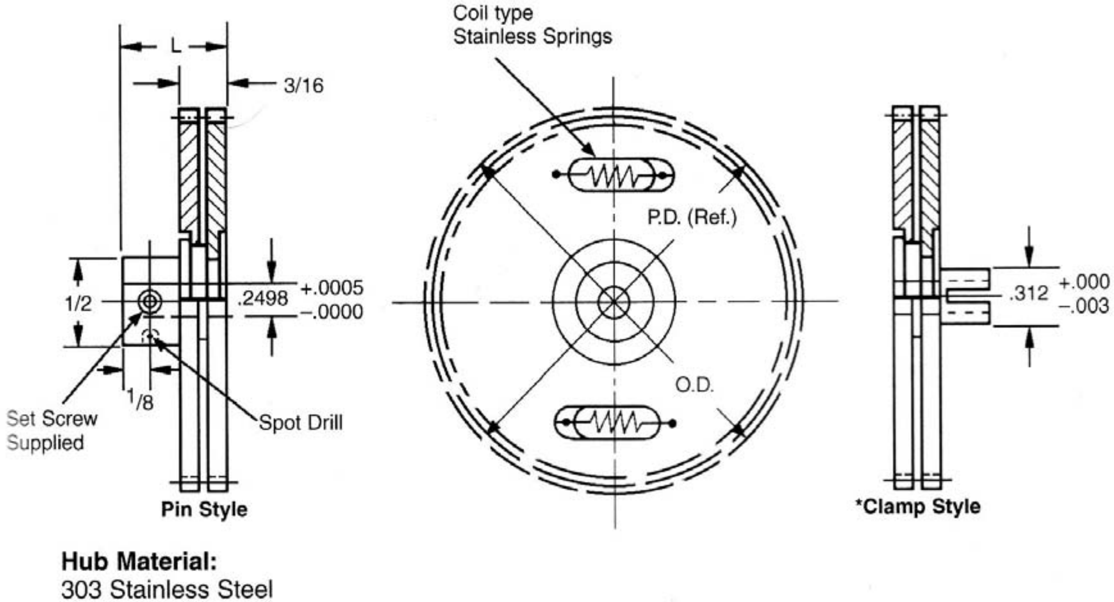


Figure by MIT OpenCourseWare.

From Shigley and Mischke

Backlash



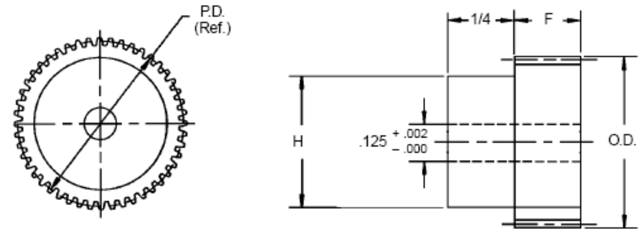
L
3/16
Coil type
Stainless Springs
P.D. (Ref.)
1/2
.2498
+.0005
−.0000
.312
+.000
−.003
O.D.
1/8
Set Screw
Supplied
Spot Drill
Pin Style
*Clamp Style
Hub Material:
303 Stainless Steel

Gear Selection

- Pitch
- Face width
- Material
- Pressure angle
- # of teeth
- Hub style, bore, etc.

Spur Gears

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



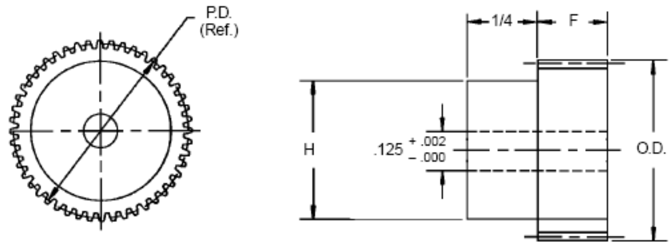
B 9

COLD ROLLED STEEL C12L14 OR C12L15 WITH SELENIUM — STOCK NUMBER	BRASS ALLOY 360 — 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**

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**

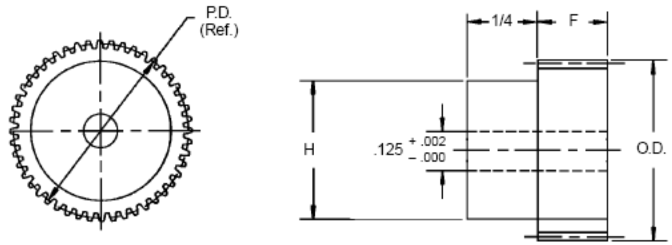
You call up the number 1-800-232-BERG and ask that, for a special application, you want a 48 pitch spur gear, but with a pitch dia of 0.32 inches. They will probably say:

1. OK, no problem
2. OK, but it will cost a lot
3. No, this is not technically possible

I'd say "3". A 48 pitch gear of 1 inch pitch dia has 48 teeth. The requested gear has 0.32*48=15.4 teeth. Integer s are better for the number of teeth.

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**

You call up the number 1-800-232-BERG and ask that, for a special application, you want a 48 pitch spur gear, but with a pitch dia of half the smallest one in the catalog. They will probably say:

1. OK, no problem
2. OK, but it will cost a lot
3. OK, but it will be weak
4. No, this is not technically possible

I'd say both "2" and "3". A 48 pitch gear is listed with 14 teeth. Half the dia will give a pinion with 7 teeth. It will be hard to make it and tricky to avoid lots of undercut.

Ways Gears Fail

Exceed endurance limit in bending

Exceed static yield stress in bending

"stripping"

Image courtesy of deltaMike at Flickr.

Exceed endurance limit in contact stress

Images removed due to copyright restrictions. Please see
http://materials.open.ac.uk/mem/mem_mf6.htm
http://www.hghouston.com/x/39_gearpit.html

"pitting"

Stress in Gears

Image removed due to copyright restrictions. Please see p. 1 in
http://courses.washington.edu/mengr356/daly/Gear_stress.pdf

A Beam in Bending

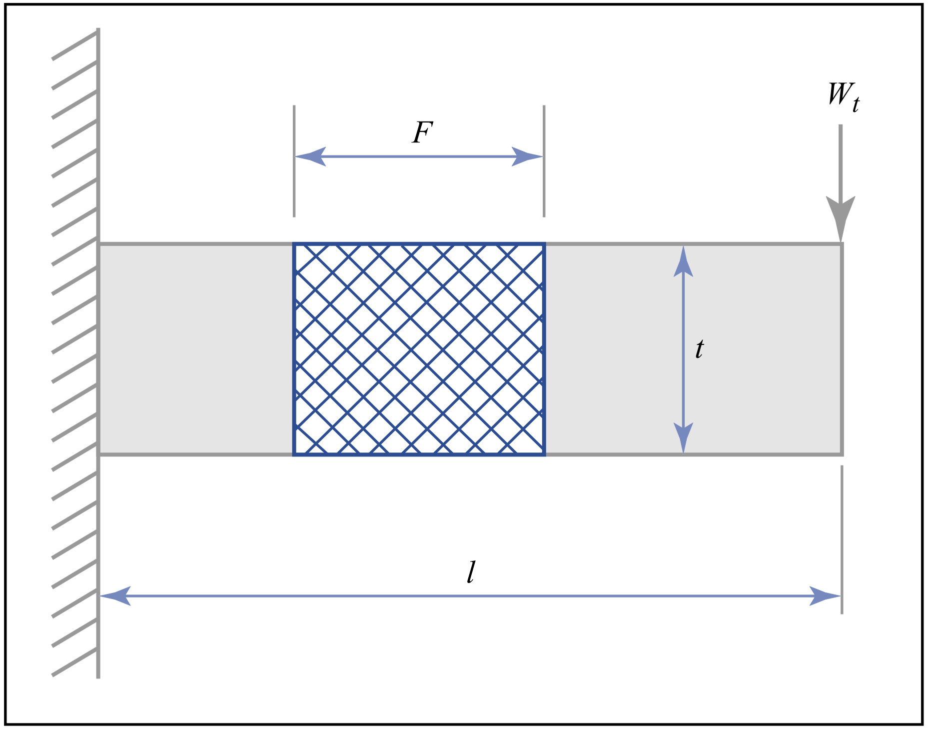


Figure by MIT OpenCourseWare.

$$\sigma = \frac{M}{I/c} = \frac{6W_t l}{Ft^2}$$

Concept Question

- In selecting a gear of one inch pitch diameter, we are choosing between 48 and 24 pitch gear teeth. The effect on torque that can be transmitted before <u>bending</u> failure of the teeth is

1. Around a factor of 10
2. Around a factor of 4
3. Around a factor of 2
4. Less than a factor of 2

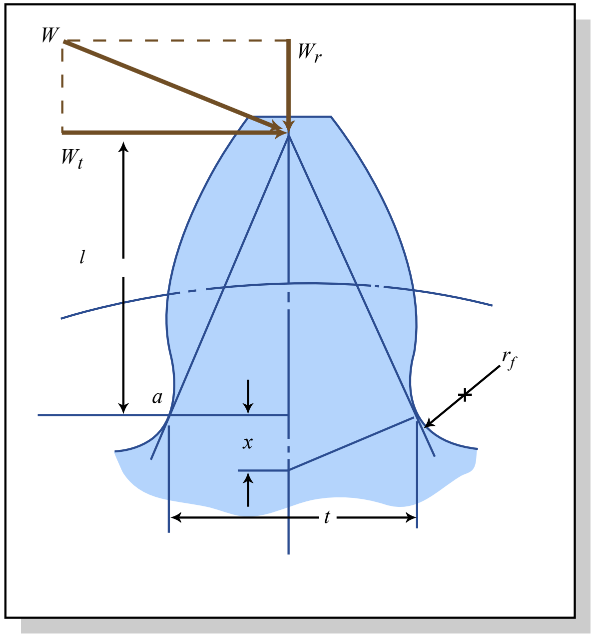


Figure by MIT OpenCourseWare.

Answ= 3: Model the gear as a beam. Its depth goes down by a factor of 2 which by itself raises stress by a factor of 4. But the length of the beam also drops by a factor of 2 and that reduces stress linearly.

Strength of Gears

- Any good catalog will have a formula and tables
- What factors must enter the equation?
  - –
  - –
  - –
- Where do the teeth wear the most?

Gear wear the most where they experience sliding motion the most. That's away from the pitch circle.

Gear Reference Guide

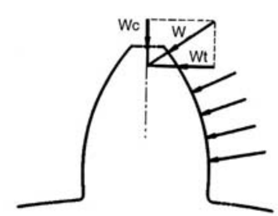
GEAR TOOTH STRENGTH

Many factors must be considered when designing a gear train. The information listed on this pag should be used as a general guideline for your application. If more critical strength calculation i required W.M. Berg suggests that you consult our engineering department or any one of the many gea handbooks that are readily available.

When a gear train is transmitting motion, it is save to assume that all of the load is being carried b one tooth. This is because as the load approaches the end of the tooth, where the bending force woul be the greatest, a second tooth comes into mesh to share the load. Simple results can be obtaine from the Lewis bending strength equation.

$$W_t = \frac{SFY}{D.P.}$$

W_t = Maximum transmitted load (lbs or N)
S = Maximum bending tooth stress (taken as 1/3 of the tensile strength) See Table C on Page 5
F = Face width of gear (in. or mm)
D.P. = Diametral Pitch = 1/module (for equation only)
Y = Lewis Factor (See Table)



NOTE: The maximum bending tooth stress (S) is valid for well lubricated, low shock applications. For high shock, poorly lubricated applications, the safe stress could be as low as .025S. If your design calls for an unfriendly environment for gears, you might want to lower S to assure a reasonable amount of gear life.

LEWIS FACTOR - Y

NO. OF TEETH	14 1/2° INVOLUTE	20° INVOLUTE
10	0.176	0.201
11	0.192	0.226
12	0.210	0.245
13	0.223	0.264
14	0.236	0.276
15	0.245	0.289
16	0.255	0.295
17	0.264	0.302
18	0.270	0.308
19	0.277	0.314
20	0.283	0.320
22	0.292	0.330
24	0.302	0.337
26	0.308	0.344
28	0.314	0.352
30	0.318	0.358
32	0.322	0.364
34	0.325	0.370
36	0.329	0.377
38	0.332	0.383
40	0.336	0.389
45	0.340	0.399
50	0.346	0.408
55	0.352	0.415
60	0.355	0.421
65	0.358	0.425
70	0.360	0.429
75	0.361	0.433
80	0.363	0.436
90	0.366	0.442
100	0.368	0.446
150	0.375	0.458
200	0.378	0.463
300	0.382	0.471
RACK	0.390	0.484

The Lewis Formula

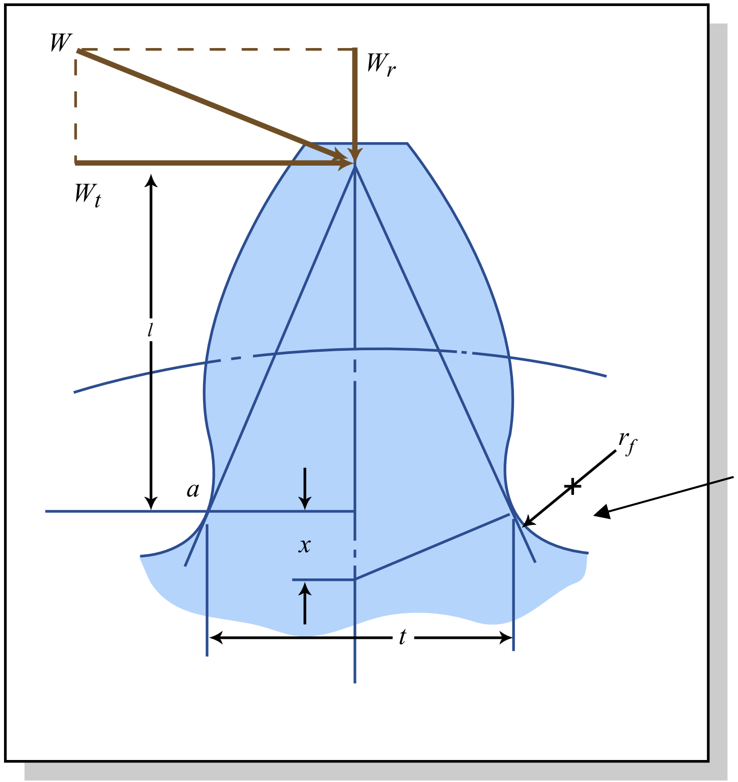


Figure by MIT OpenCourseWare.

$$\sigma = \frac{W_t P}{F y}$$

Diametral pitch (teeth/inch)

Face width

"Lewis form factor"

Low form factor → High stress

Point of max stress due to bending

Or Use a Canned Tool

Please see “Spur Gear Tooth Strength” at http://www.wmberg.com/tools/

Discussion Questions

- I glued the third stage teeth of this servo together
- Now I will apply a load to the output shaft (up to 10lbs)
- What's going to happen?

The gears nearest the output shaft will fail since they experience the highest loads. The mode for Delrin gears is most probably in bending or "stripping". I would estimate that the smaller gear (black in the photo) will fail rather than the white one since it has a narrower base and so a lower Lewis factor.

Concept Question

- For a gear to provide the highest strength at a fixed diameter, we prefer

1. High pressure angle
2. Low pressure angle
3. It doesn't matter much

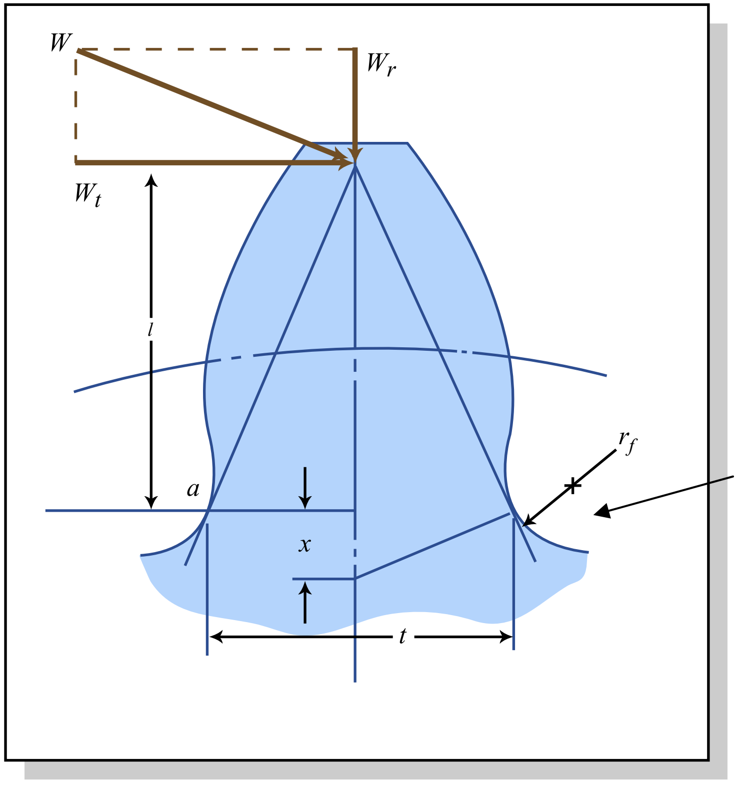
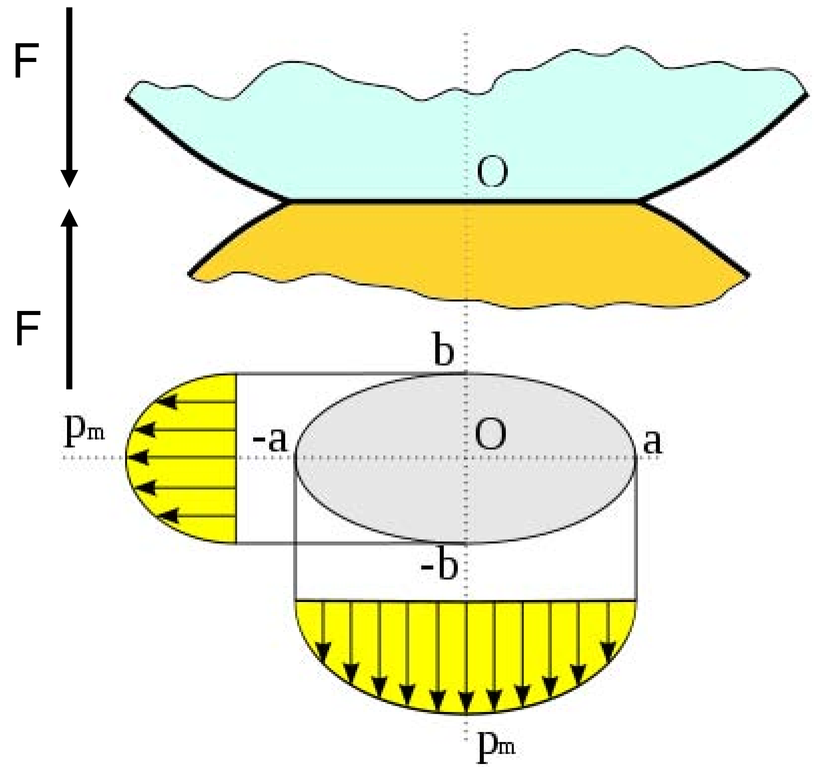


Figure by MIT OpenCourseWare.

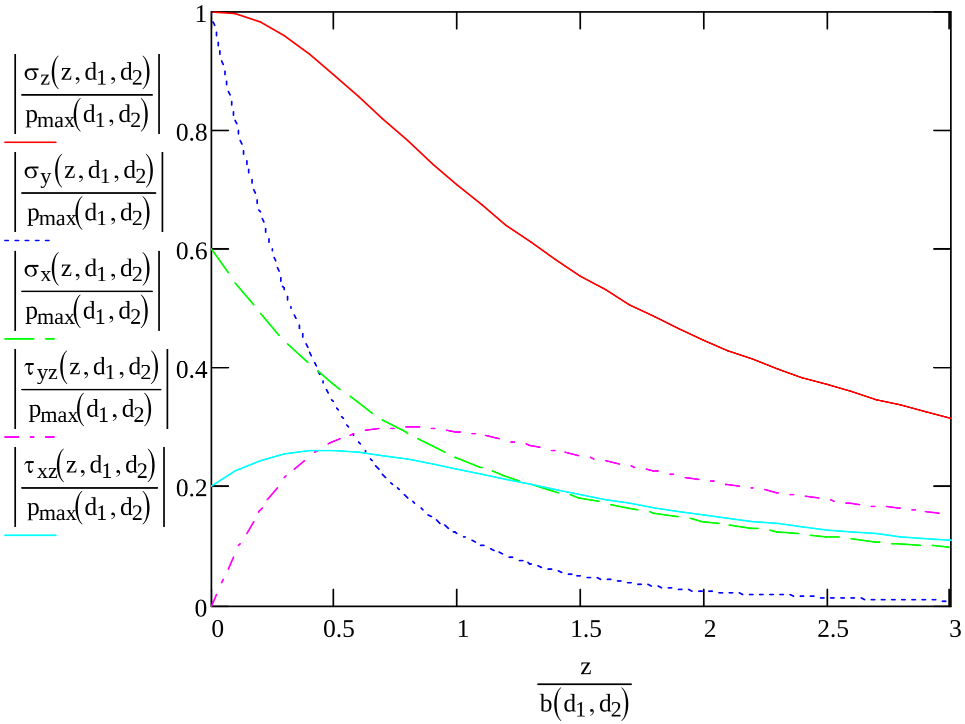
Answ =1. High pressure angle will help raise the Lewis factor and lower stress. Comparing 14.5 deg and 20 deg pressure angle (back a couple slides), the difference is 10 to 20%, so not a negligible difference.

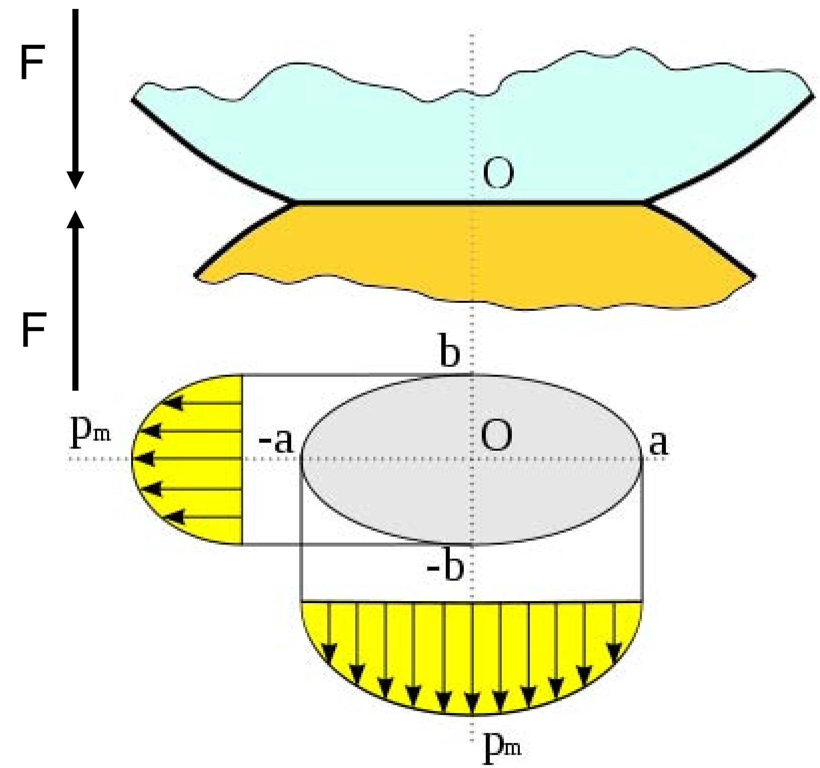
Contact Stress (Hertzian Stress)



Contact Stress

Quantitative Characterization

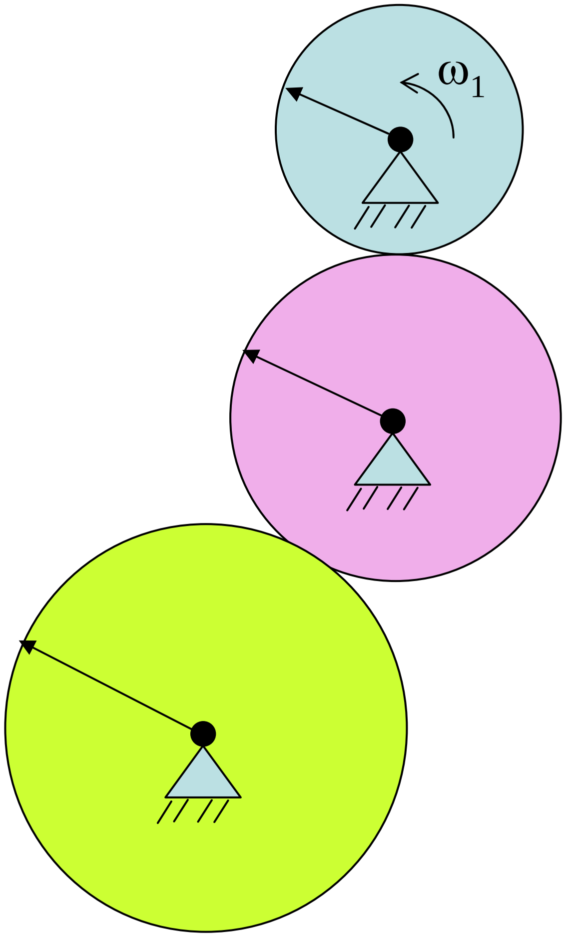




$$b(d_1,d_2) := \sqrt{\frac{2\cdot F}{\pi\cdot l}\cdot\frac{\frac{\left(1-\nu_1^{\,2}\right)}{E_1}+\frac{1-\nu_2^{\,2}}{E_2}}{\frac{1}{d_1}+\frac{1}{d_2}}} \qquad p_{max}(d_1,d_2) := \frac{2\cdot F}{\pi\cdot b(d_1,d_2)\cdot l}$$

Simple Gear Trains

- A "simple" gear train has only one gear on each shaft
- How does this arrangement behave?



The gears turn in alternating directions. Such an arrangement might be useful to get a motion the same direction as that of the servo but at a different rate. The speed of the driven (yellow) one is not a function of the dia of the middle (pink) one.

Compound Gear Trains

- A “compound” gear train has at least one shaft with multiple gears
- How does this arrangement behave?

Image from Wikimedia Commons, http://commons.wikimedia.org

The key thing is that the total reduction ratio is a product of the ratios of the two mating pairs.

Manual Transmissions

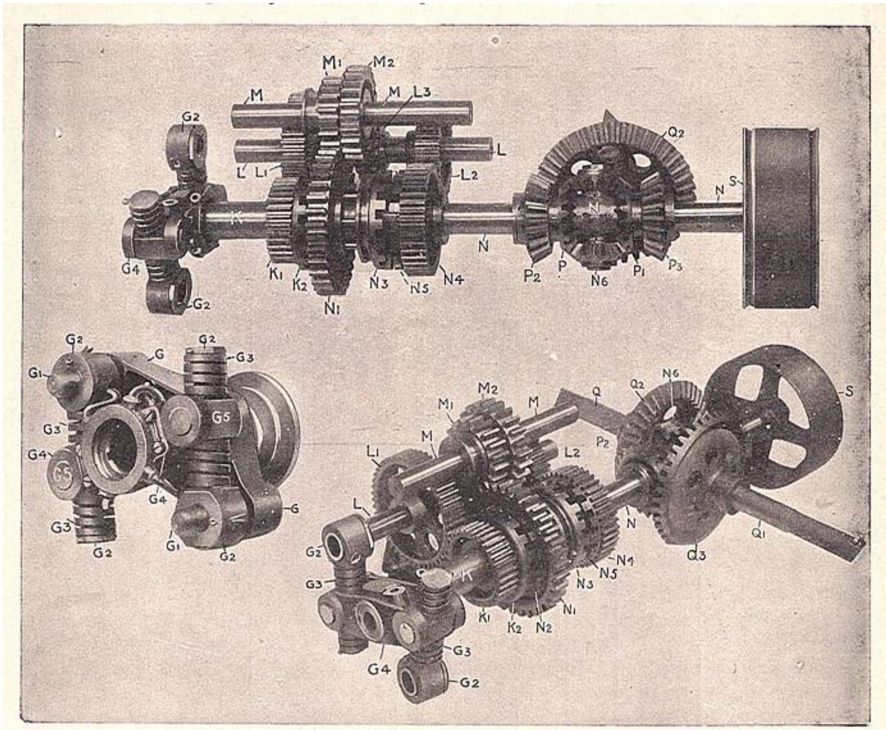


Fig. 56.—Albion Change Speed Gear.

Image from Wikimedia Commons, http://commons.wikimedia.org.
Please see http://mossmotors.com/Graphics/Products/Schematics/SPM-025.gif

If you find just two axles in a machine, does that nean there are just two stages?

No, you probably have a “reverting” arrangement with many compound gears sharing a single pair of shafts.

Discussion Questions

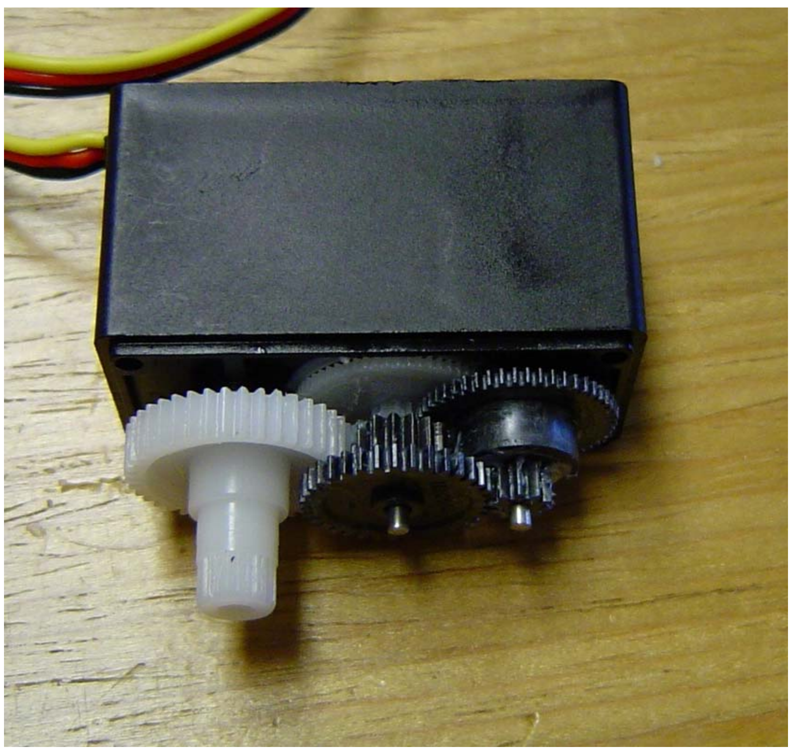
Image from Wikimedia Commons, http://commons.wikimedia.org

- Are there any disadvantage to a helical gear as compared to a spur gear?
- How can the disadvantages be remedied?
- Is a helical gear set stronger than a spur gear of the same diameter, pitch, face width, & material?

Yes, helical gears cause axial loads. They are also more expensive.
You can pair up helical gears to cancel the axial loads resulting in a "herring-bone" pattern. Helical gears are not really stronger, they are mostly quieter and smoother.

Concept Question

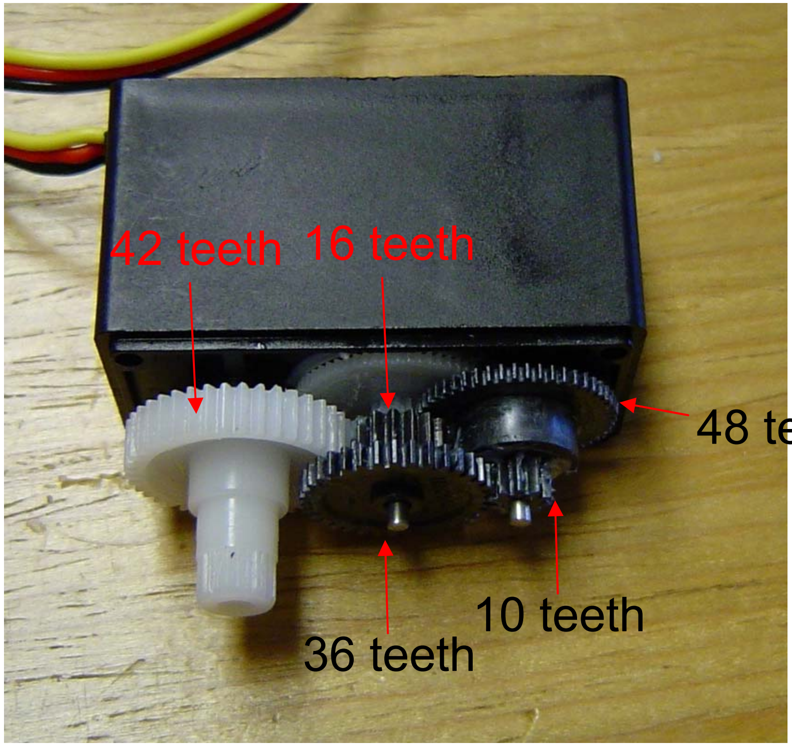
A compound gear train is formed of eight gears. As we proceed from the pinion on the electric motor to the gear on the output shaft, how do the pitch and face width vary?

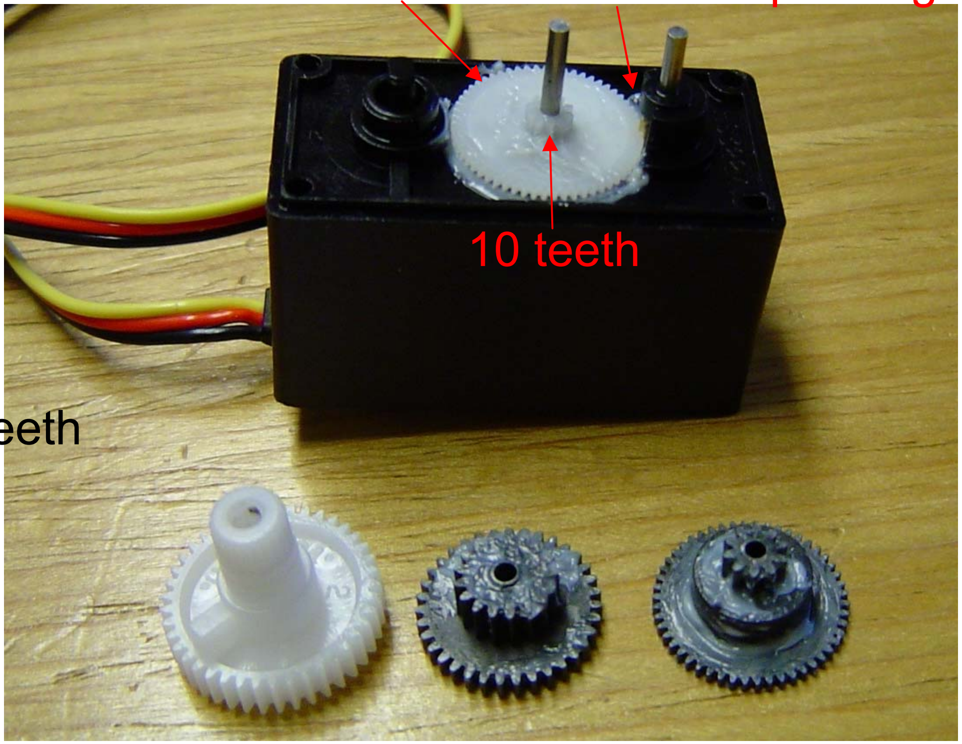


1. Pitch rises, face width rises
2. Pitch rises, face width falls
3. Pitch falls, face width rises
4. Pitch falls, face width falls

Discussion Questions

- How many stages in this device? 4 stages
- How do you suppose this number is chosen? Usually not much more than 10 to 1 ratios per stage are practical.
- Are the reduction ratios typically all nearly the same in all successive stages? No, less reduction ratio as we approach the output shaft.





Differentials

- Allows shafts to move at different speeds
- Applies same torque to both
- Slippage problem

Image removed due to copyright restrictions. Please see http://mossmotors.com/Graphics/Products/Schematics/SPM-027.gif

http://static.howstuffworks.com/flash/differential.swf

Next Steps

- Begin Homework #3
- Next lecture Thursday 19 March
  - CAD case study
- Spring break
- Lecture Tuesday 31 March
  - More gears, and also springs
- HW#3 due 7 April
- Quiz #2 on 16 April
- Impounding week 29 April to 1 May

Planetary Gear Trains

- One or more of the gear axes are allowed to rotate
- aka “epicyclic”
- Used in
  – Power tools
  – Automatic transmissions
  – Gear boxes

Courtesy NASA.

Please also see
http://commons.wikimedia.org/wiki/File:Epicyclic_carrier_locked.png
http://i.i.com.com/cnwk.1d/i/ss/2007/0828_Driving_it/DSG_440.jpg

Analysis of Planetary Gear Trains

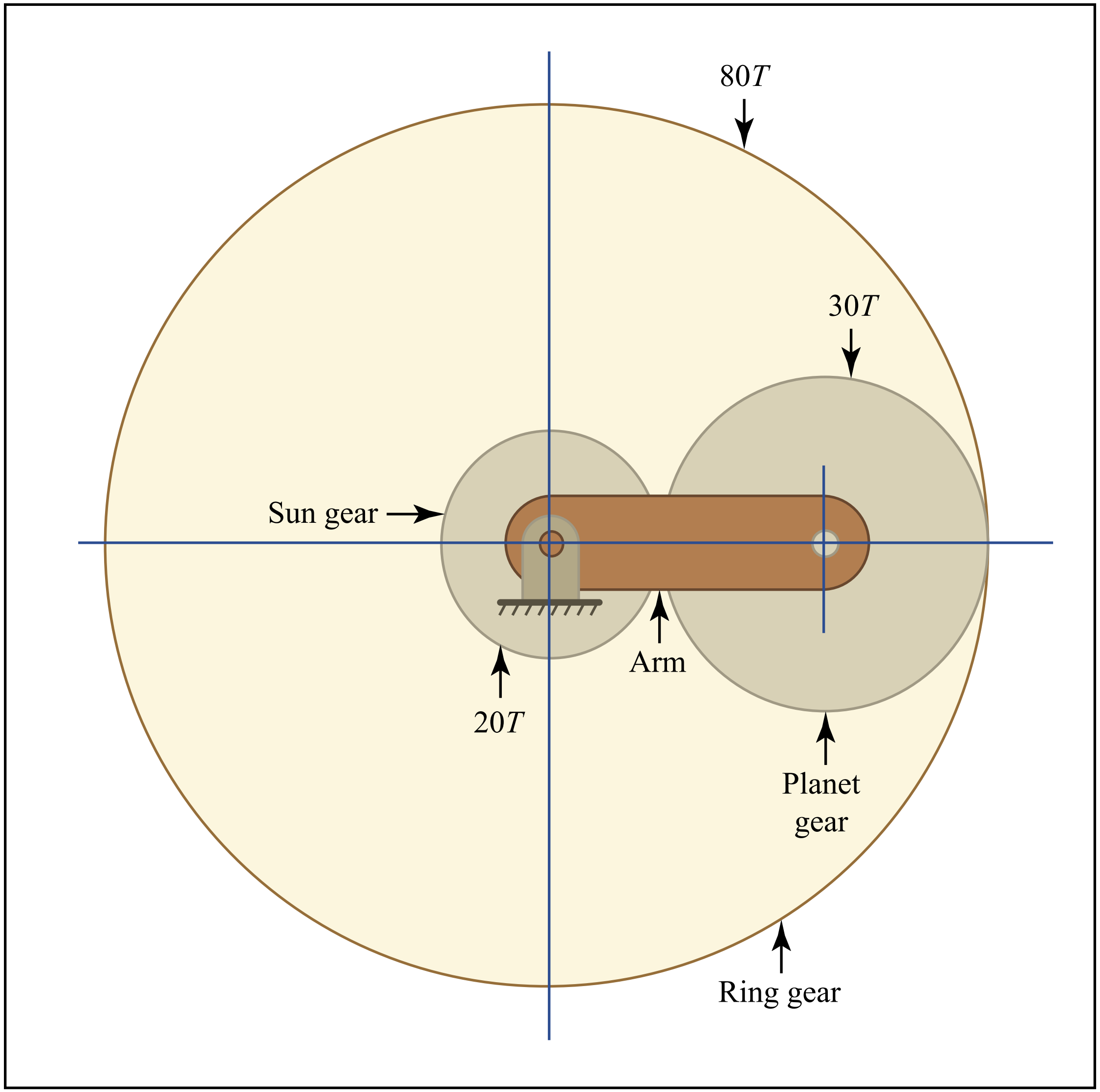


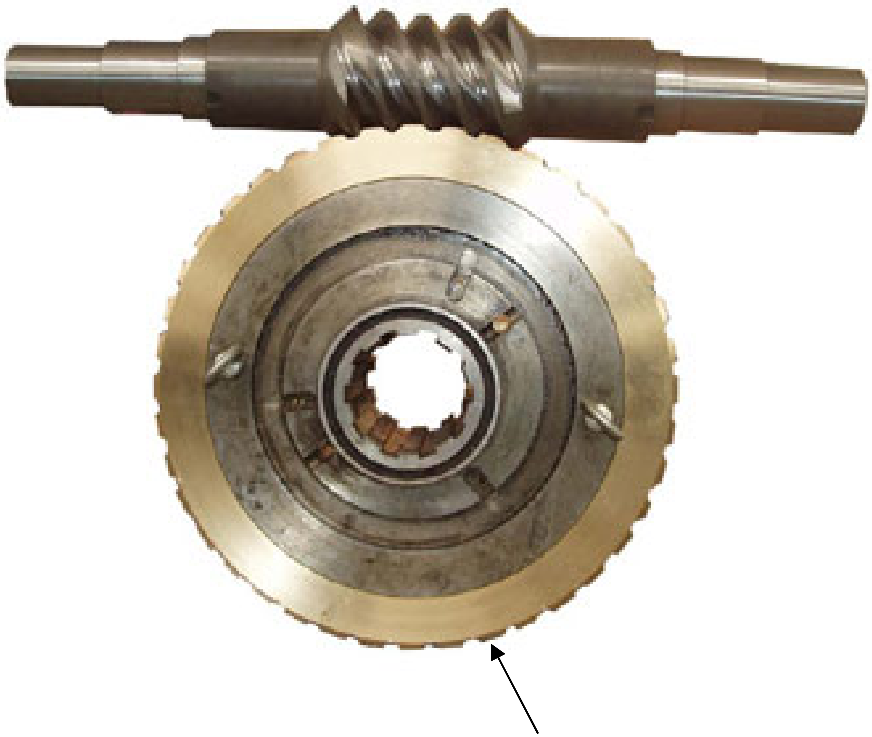
Figure by MIT OpenCourseWare.

Name That Gear

What type of worm gear set is this?

1) Single-enveloping, single threaded
2) Single-enveloping, multi-threaded
3) Double enveloping single threaded worm gear
4) Double enveloping multi- threaded

Follow up



What is the reduction ratio of this gear set?

1) 10:1
2) 20:1
3) 40:1
4) 80:1