Belts, Clutches and Brakes

Belts, ropes, chains are used to convey power over a long distance

It often used as a replacement for gears. , they are less nosy, and absorb shocks and vibration

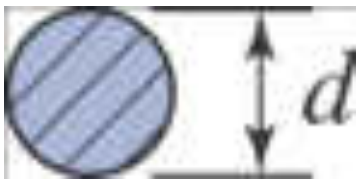
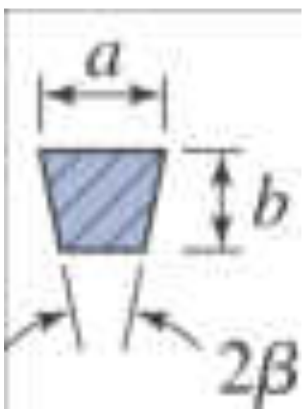
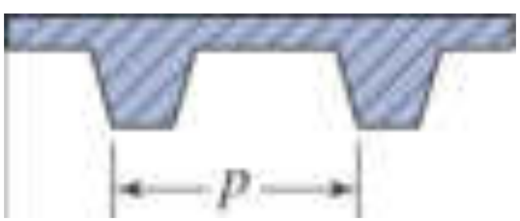
In contrast to other system that friction is no good, here we rely on the friction to transmit power

Brakes and clutches are essentially the same devices. Each is associated with the rotation

- Brakes, absorb kinetic energy of the moving bodies and covert it to heat
- Clutches Transmit power between two shafts

Belts

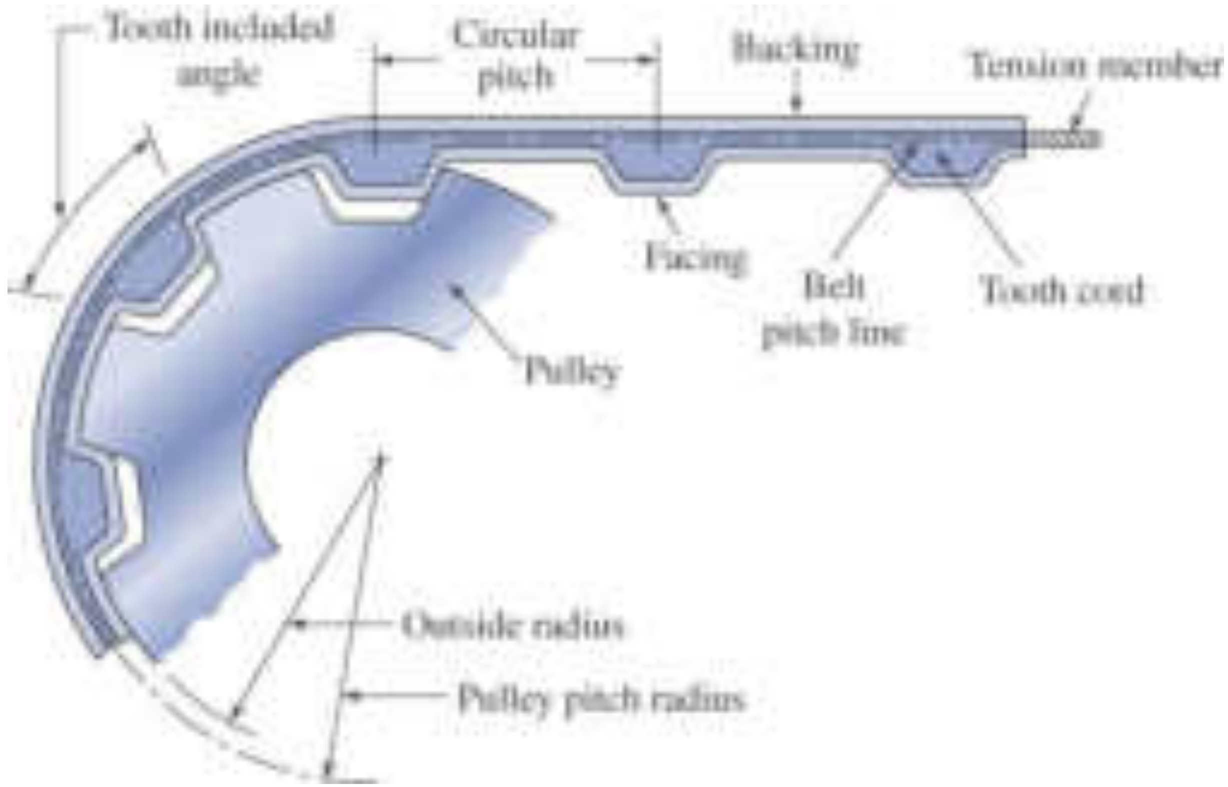
- They are four types of the belts

	Size range	center distance
	$T=0.75$ to 5 mm	No upper limit
	$d= 3$to 19 mm	No upper limit
	$A=13$ to 38 mm $B=8$ to 23 mm $2\beta= 34^o$ to 40^o	Limited
	$p=2$ mm and up	Limited

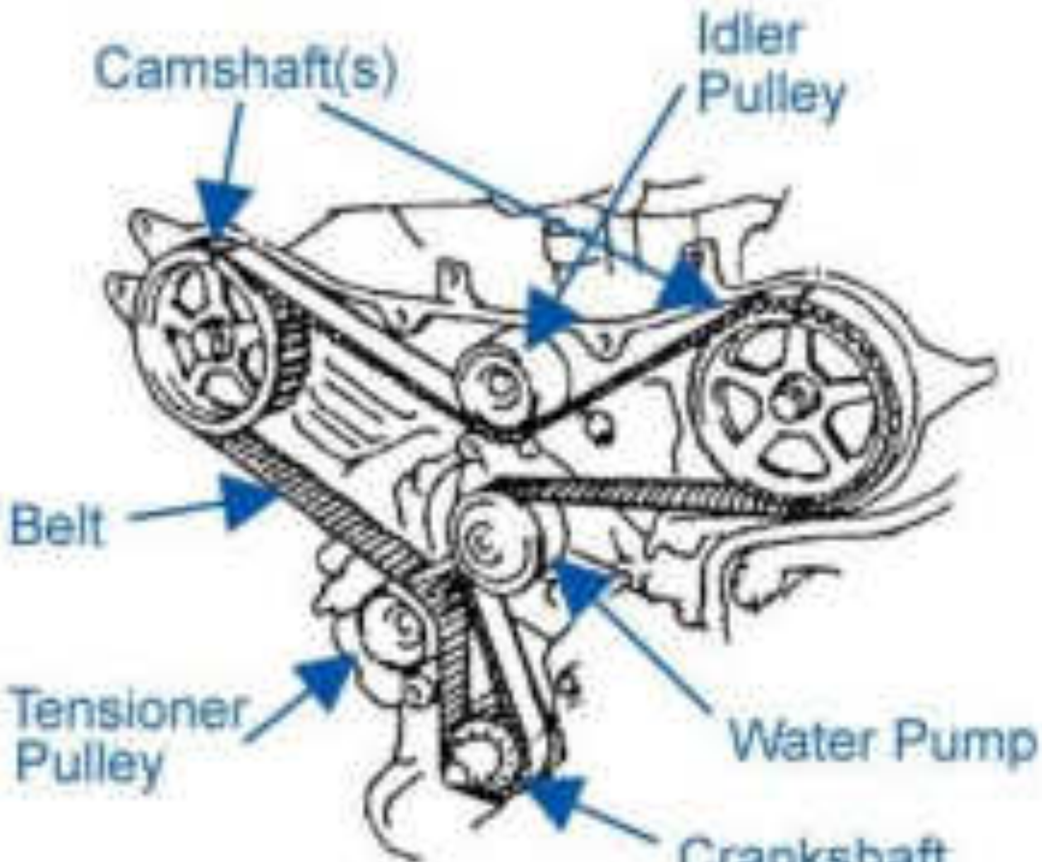
Belts are made from fiber reinforce urethane or rubber-impregnated fabric reinforced with steel or Nylon

- Flat belts has to operate at higher tension than the V belt
- V belt speed should be in the range of 7000 fpm.
- V belts are slightly less efficient than flat belts, but it can transmit more power.

Timing Belt

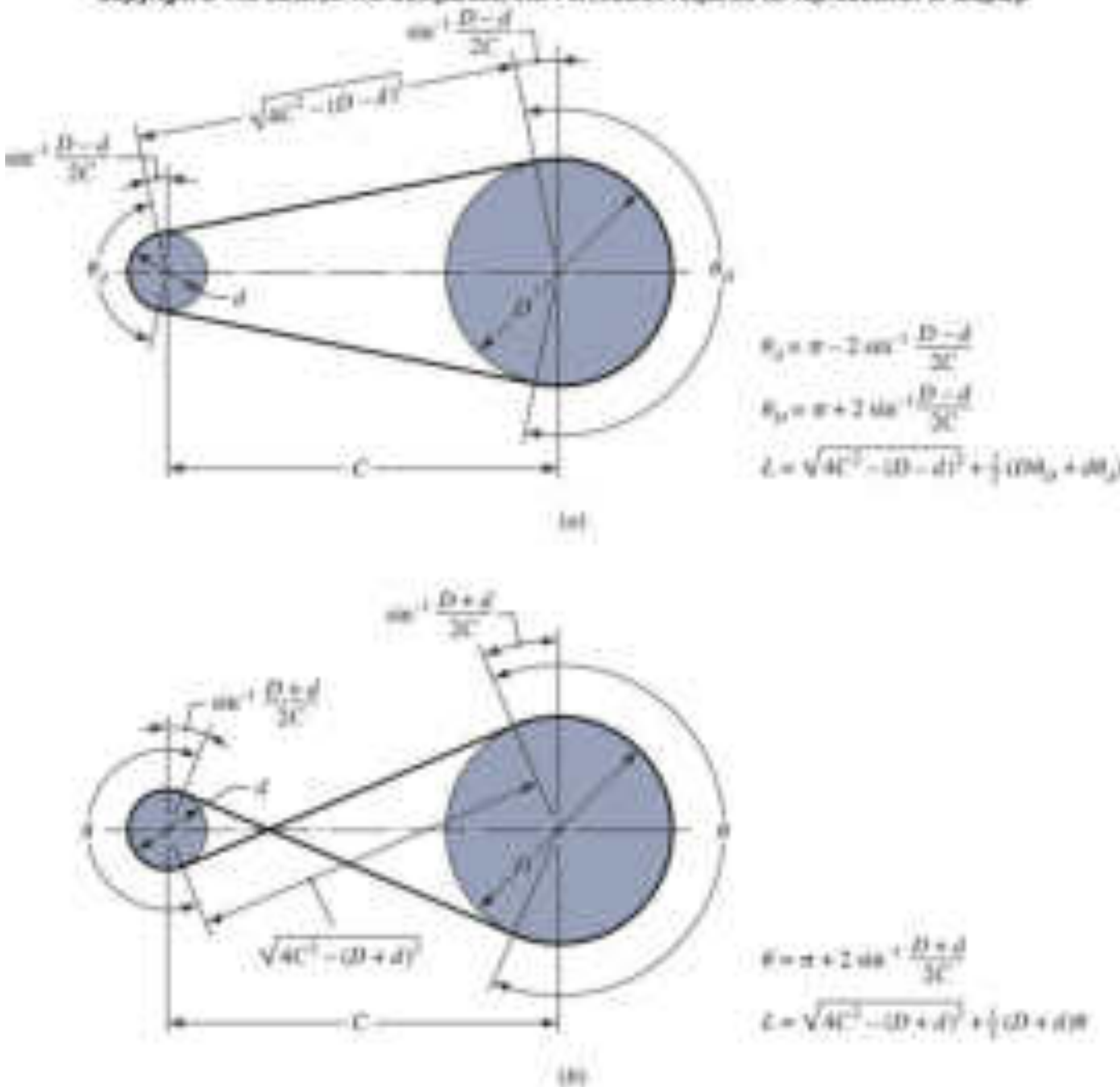


Timing belts transmit power at the constant angular velocity ratio, application when precise speed ratio is important

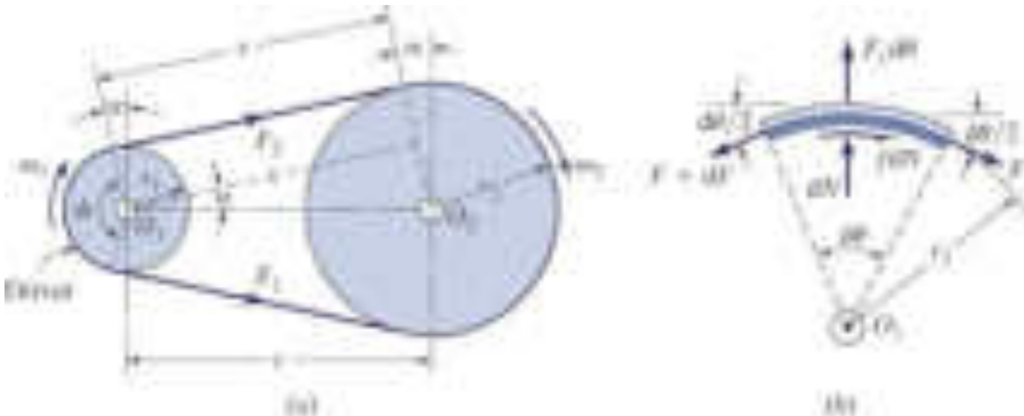


Typical V6 Timing Belt

Belt Drives, and its dimensions

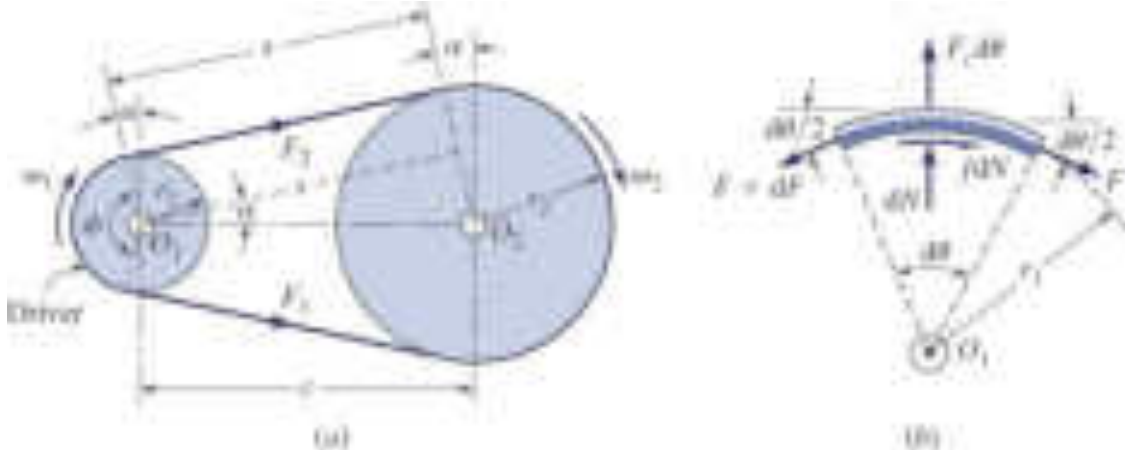


Due to friction, the tight-side tension is greater than the slack-side tension.



$$T = (F_1 - F_2) r$$

Initial tension recommended $$F_i = \frac{1}{2}(F_1 + F_2)$$



Due to friction, the tight-side tension is greater than the slack-side tension.

$$T = (F_1 - F_2)r$$

r= pitch radius, from the center to the neutral axis of the belt

F_1 =tension on the tight side

F_2=tension on the slack side

Initial tension recommended

$$F_i = \frac{1}{2}(F_1 + F_2)$$

Transmitted horse power

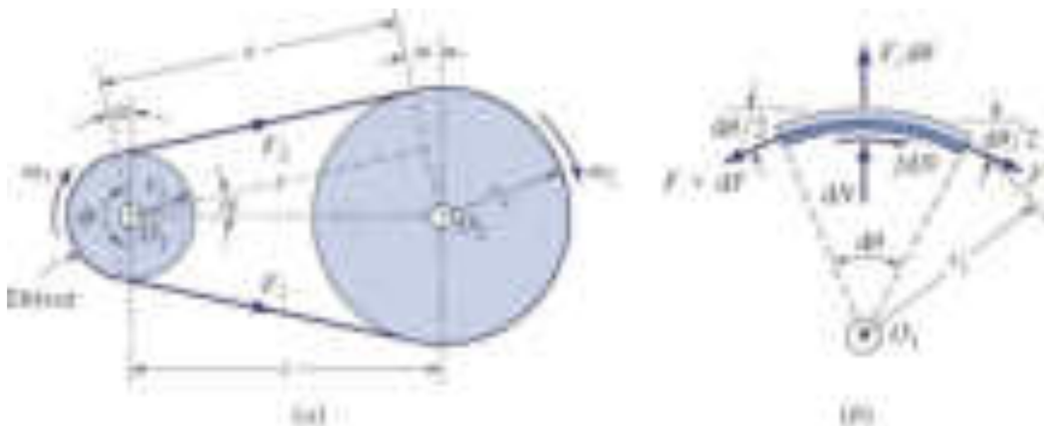
$$hp = \frac{(F_1 - F_2)V}{33000} = \frac{Tn}{63000}$$

$$V = \frac{\pi dn}{12}$$

T torque lb-in, n rpm, d pitch in, V fpm

Speed ratio

$$\frac{n_1}{n_2} = \frac{r_2}{r_1}$$



$$F_c = \frac{w}{g} V^2$$

Tension in the flat belt or round belt

From the free body Diagram

$$\sum F_x = 0 \Rightarrow \qquad (F + dF)\cos\frac{d\theta}{2} - fdN - F\cos\frac{d\theta}{2} = 0$$

$$\sum F_y = 0 \Rightarrow \qquad dN + F_c\, d\theta - (F + dF + F)\sin\frac{d\theta}{2} = 0$$

$$\frac{dF}{F - F_c} = fd\theta$$

$$\frac{F_1 - F_c}{F_2 - F} = e^{f\varphi}$$

For the V belt

$$\frac{F_1 - F_c}{F_2 - F} = e^{f\varphi/\sin\beta}$$

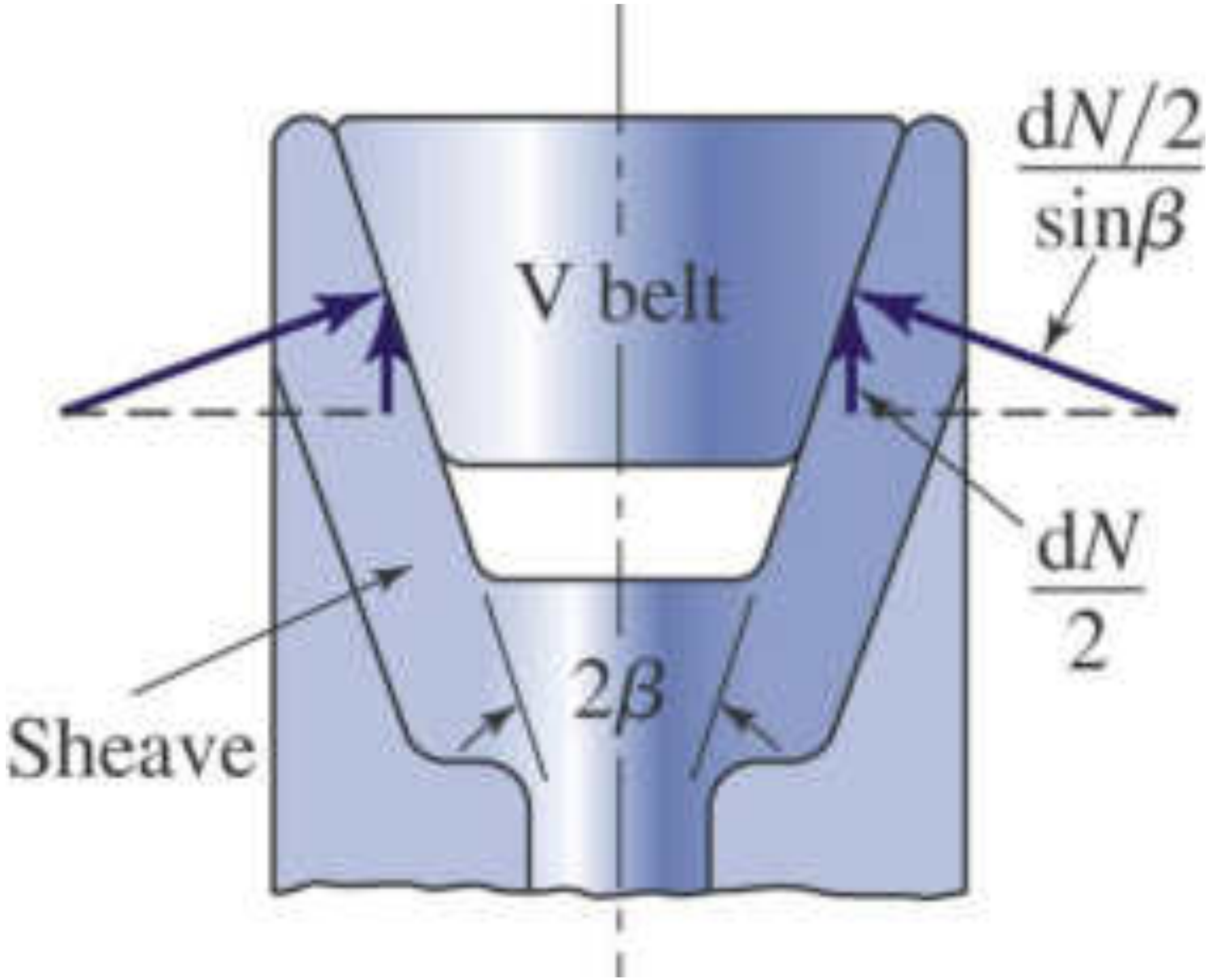
From these equation s you can evaluate tension in the belt

$$\gamma = e^{f\varphi/\sin\beta}$$

$$T = (F_1 - F_2)r_1$$

$$\frac{F_1 - F_c}{F_2 - F} = e^{f\varphi/\sin\beta}$$

$$F_1 = F_c + (\frac{\gamma}{\gamma - 1})\frac{T_1}{r_1}$$


dN/2
sinβ
V belt
dN
2
2β
Sheave

Maximum tension in the belt considering the effects of bending in the belt

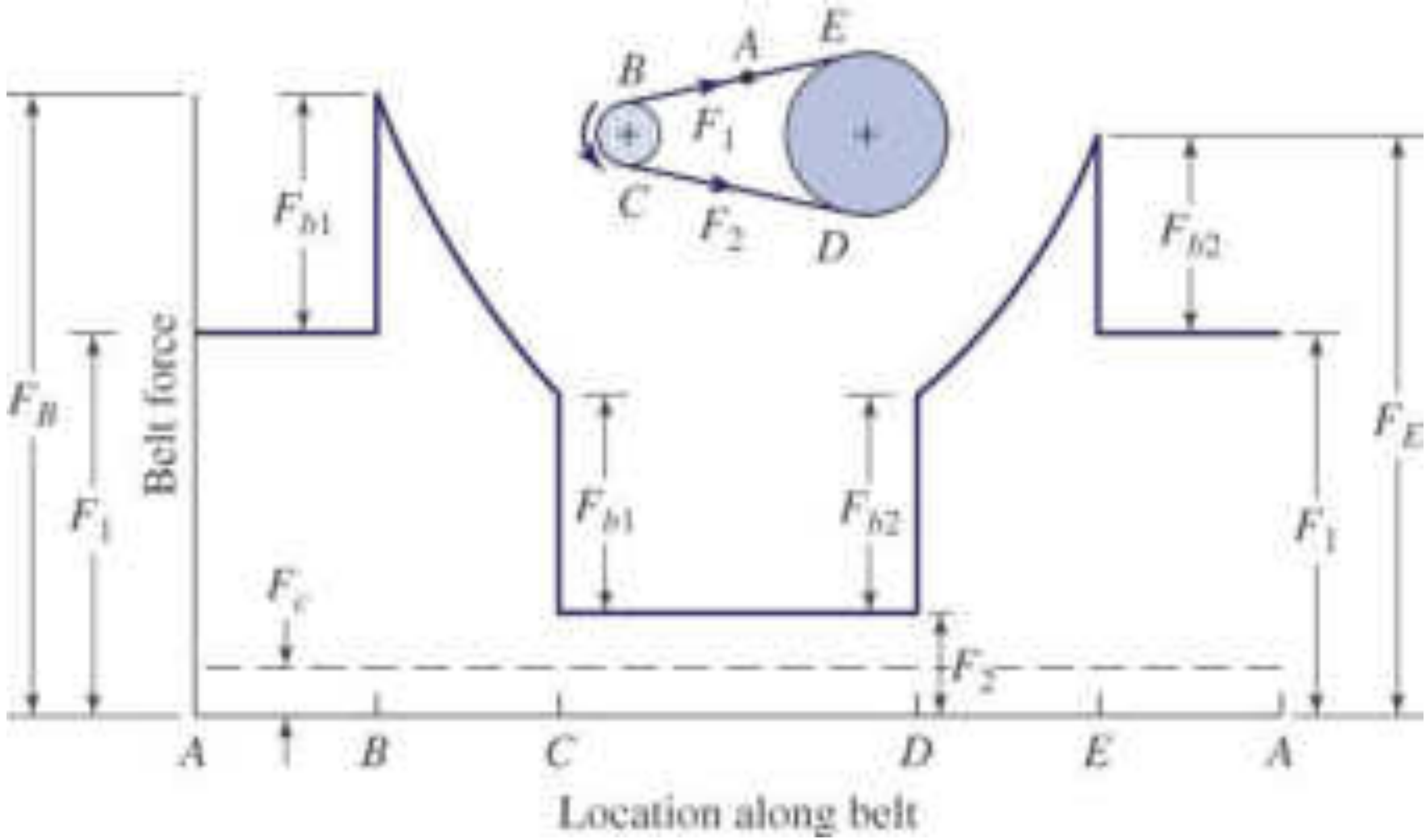
- $F_{max} = K_s F_1$

- K_s Service factor

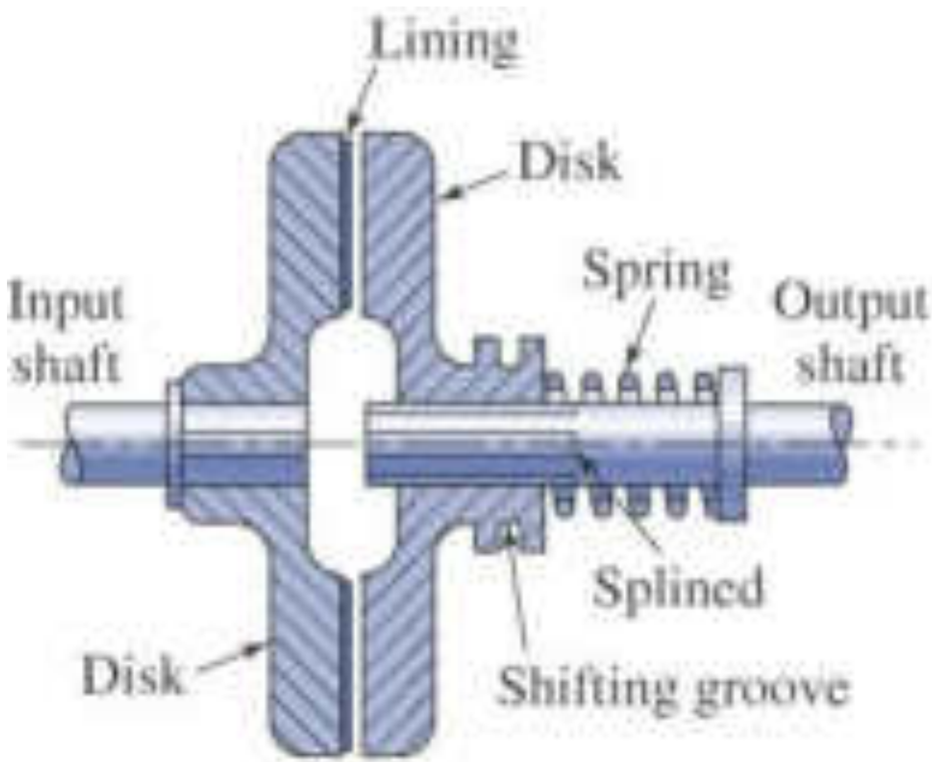
Table 13.5 Service factors K_s for V-belt drives

	Driver (motor or engine)	
Driven machine	Normal torque characteristic	High or nonuniform torque
Uniform	1.0 to 1.2	1.1 to 1.3
Light shock	1.1 to 1.3	1.2 to 1.4
Medium shock	1.2 to 1.2	1.4 to 1.6
Heavy shock	1.3 to 1.5	1.5 to 1.8

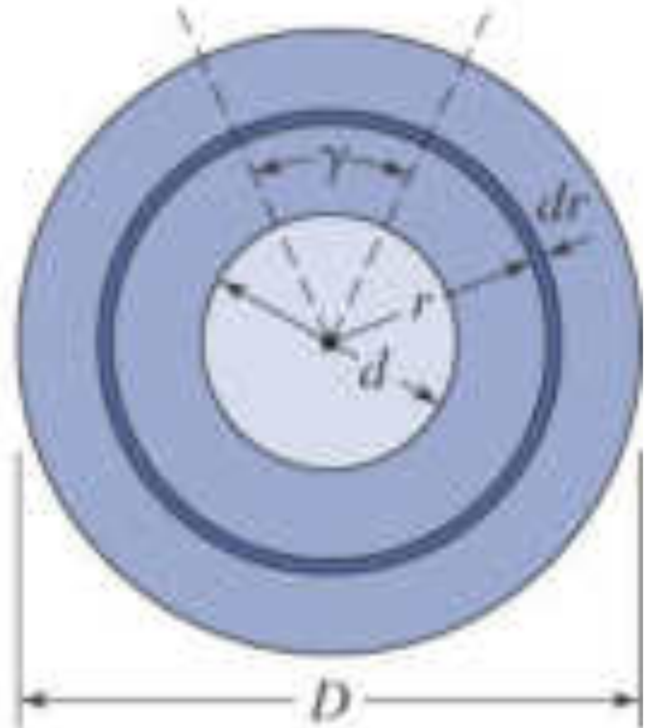
Belts are subjected to the fatigue loading



Clutches

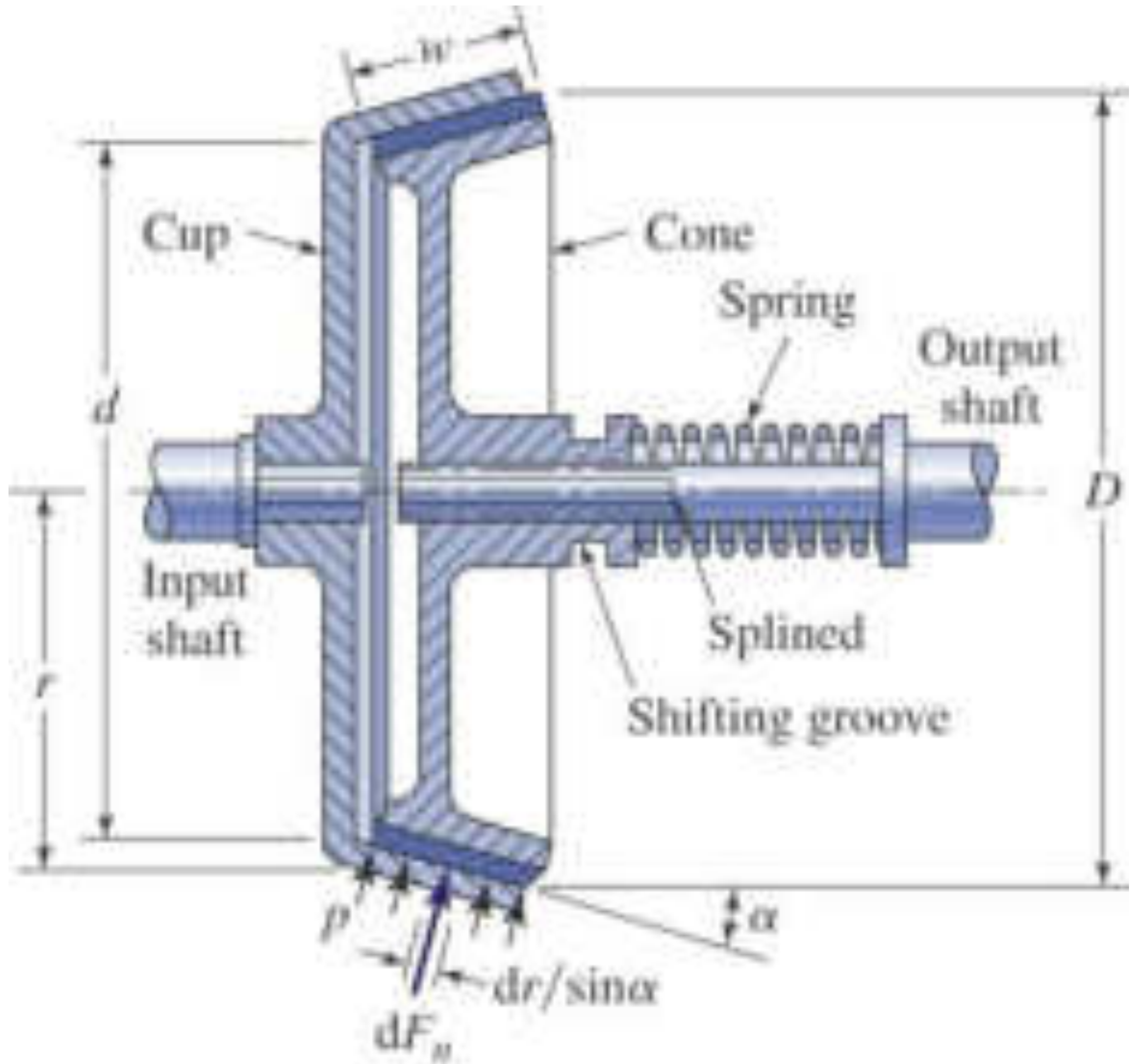


Lining
Disk
Spring
Input shaft
Output shaft
Splined
Disk
Shifting groove

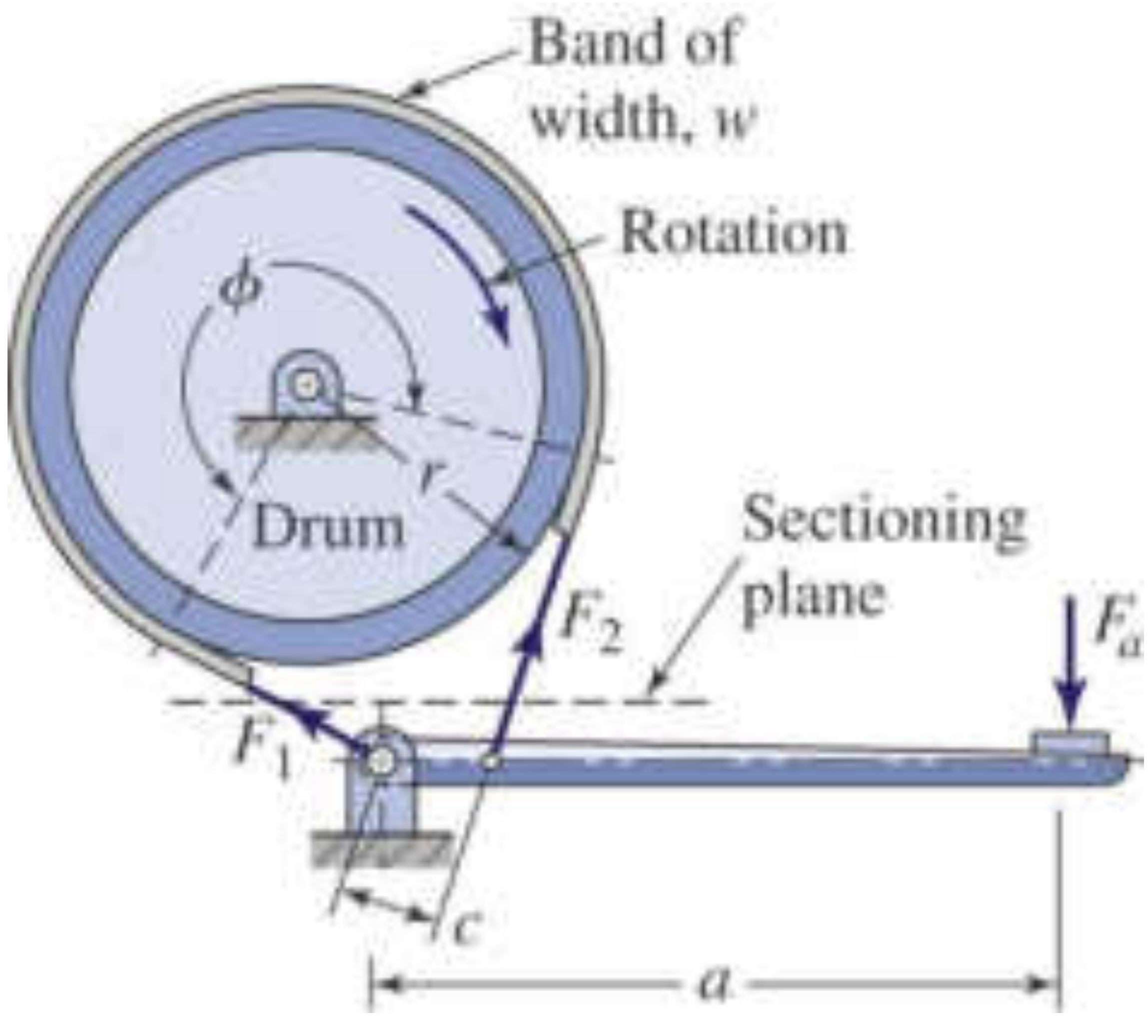


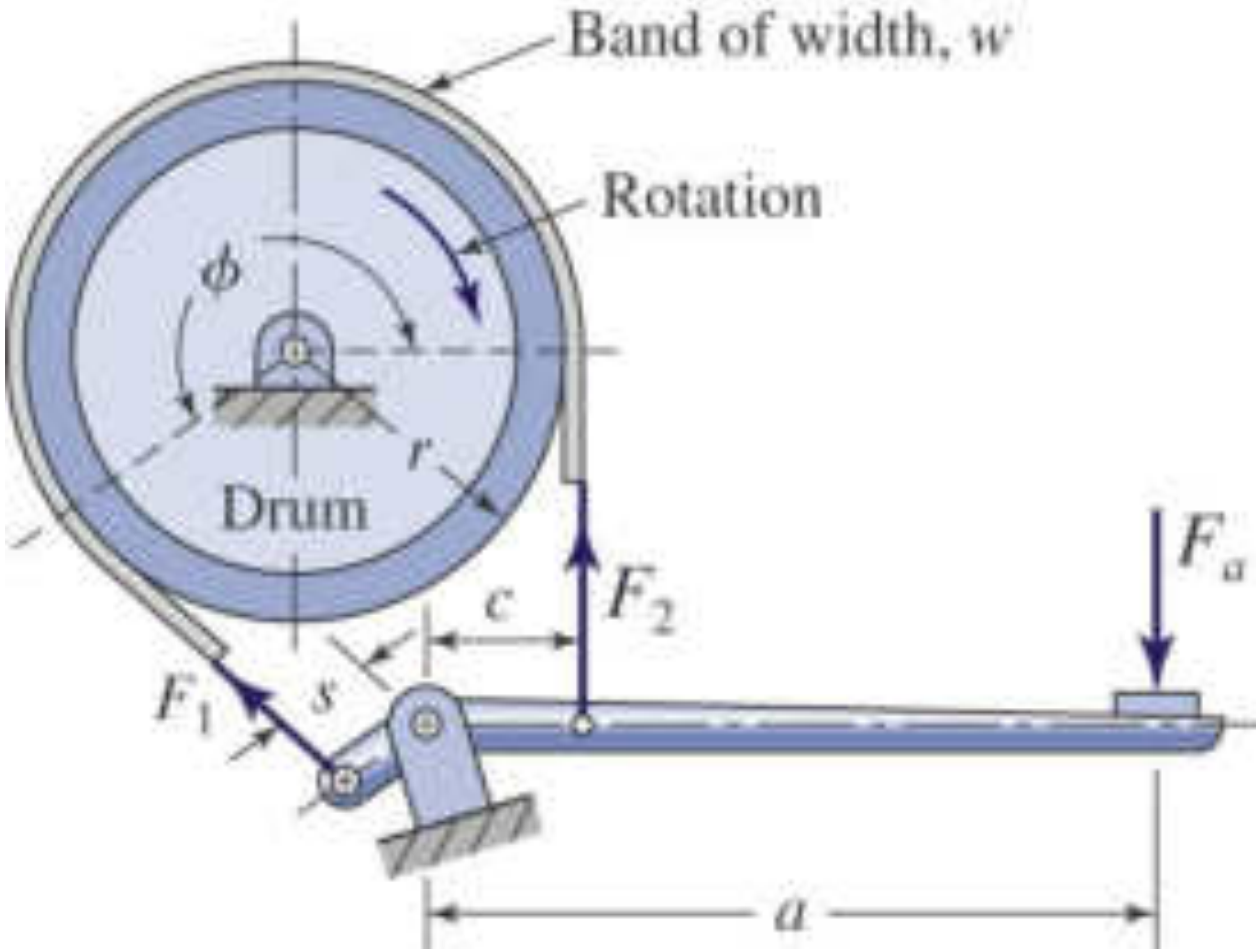
γ
dr
r
d
D

Important issue , how much force we need to stop the rotation

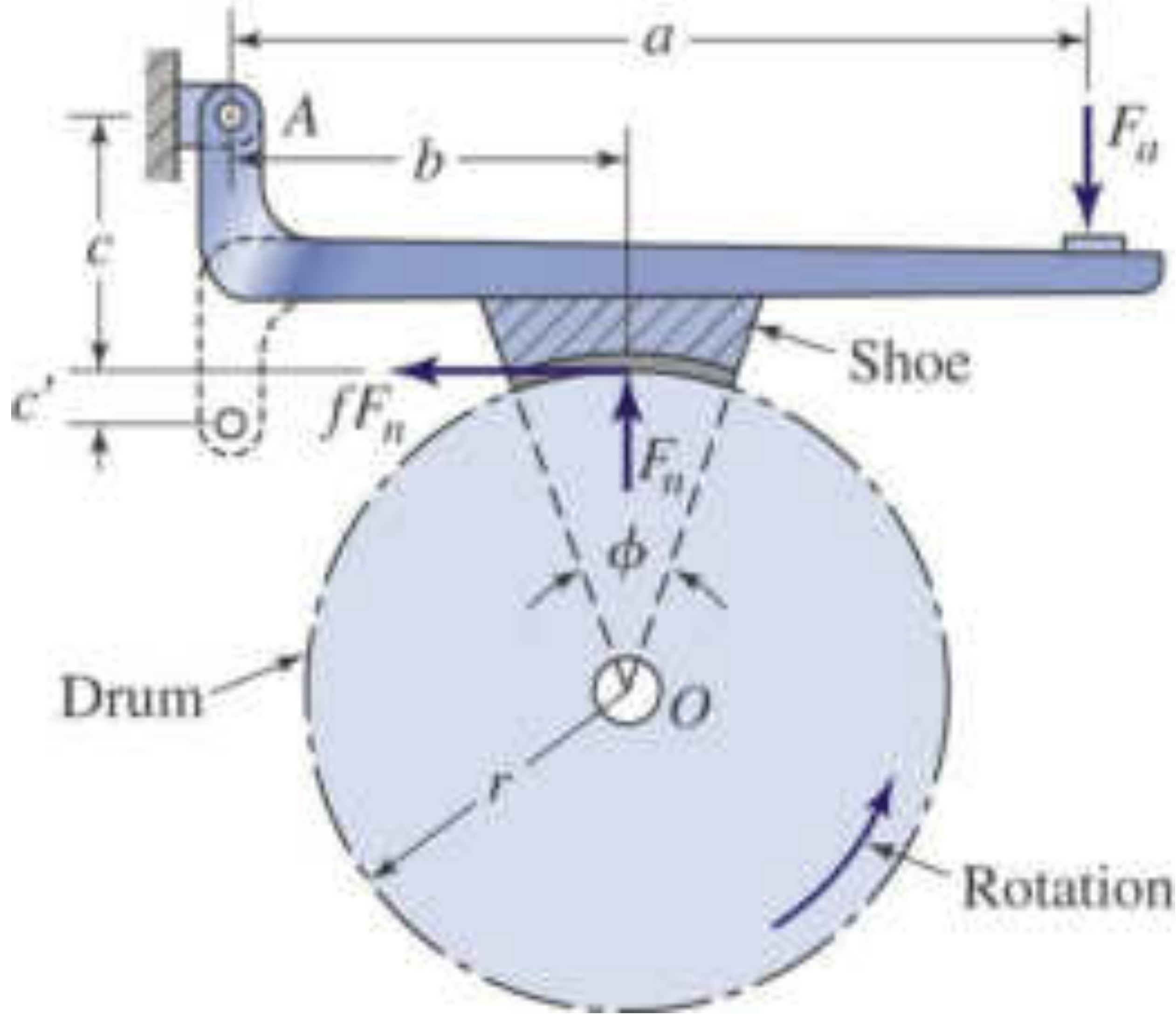


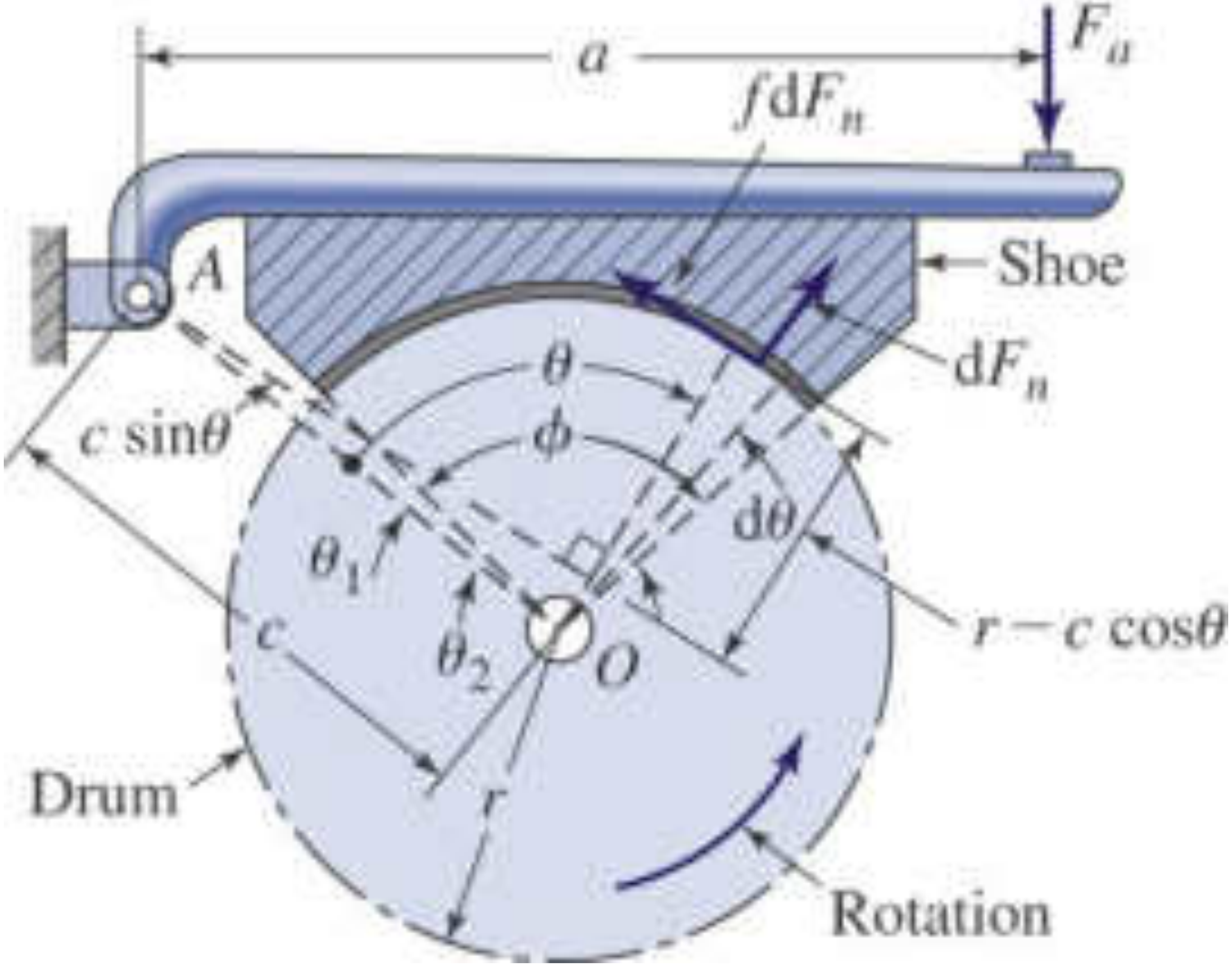
How much force is needed to stop the Drum



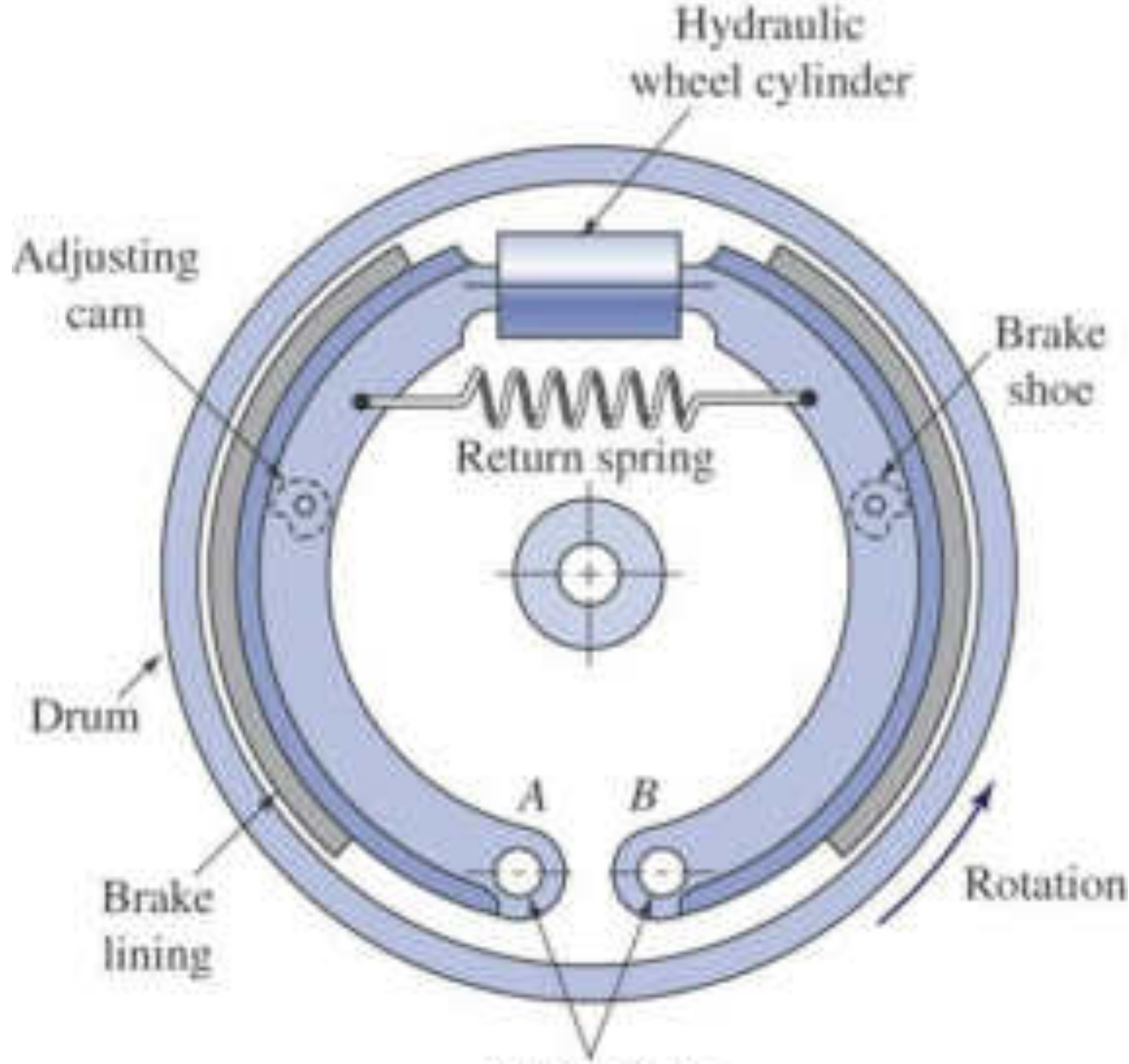


Band of width, w
Rotation
ϕ
r
Drum
c
F₂
Fₐ
F₁
s
a


a
A
b
F_a
c
Shoe
c'
fF_n
F_n
ϕ
Drum
O
r
Rotation



a
F_a
$f\mathrm{d}F_n$
Shoe
A
$\mathrm{d}F_n$
$c\sin\theta$
θ
ϕ
dθ
θ_1
θ_2
c
O
$r - c\cos\theta$
Drum
r
Rotation



Hydraulic
wheel cylinder
Adjusting
cam
Brake
shoe
Return spring
Drum
A
B
Brake
lining
Rotation

GEARS

Gears

- Rugged
- Durable
- Can transmit power with up to 98% efficiency
- Long service life

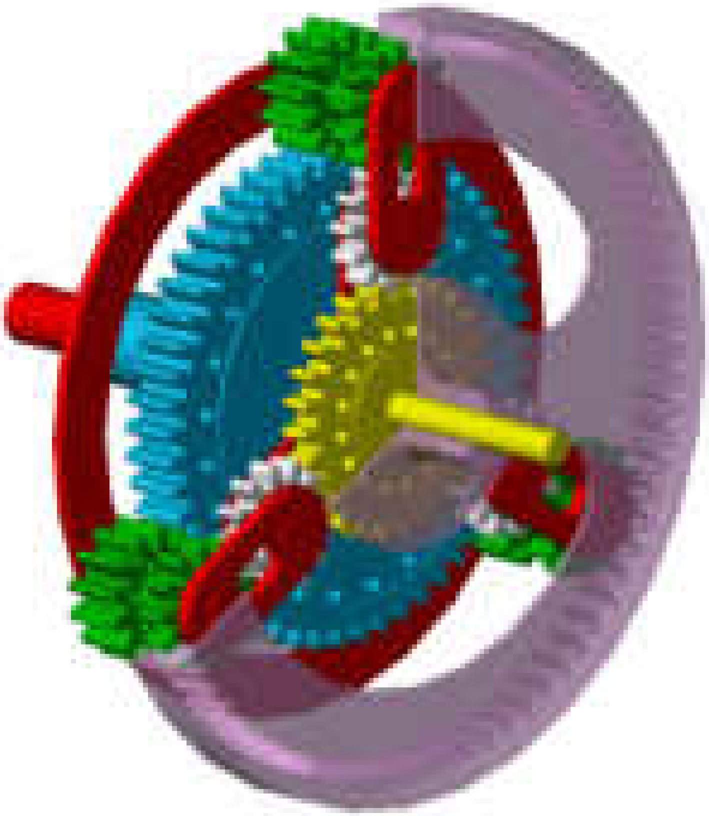
Motors

- Motors convert electrical energy to mechanical energy.
- Mechanical energy moves our robot
- Motors drive the gears

http://www2.towerhobbies.com/cgi-bin/wti0001p?&I=LR9520&P=DS

Gears

- Spur
  - Flat
  - Pinion
- Bevel
  - Crown
- Worm
- Rack and Pinion
- Differential



www.mathworks.com

Gears

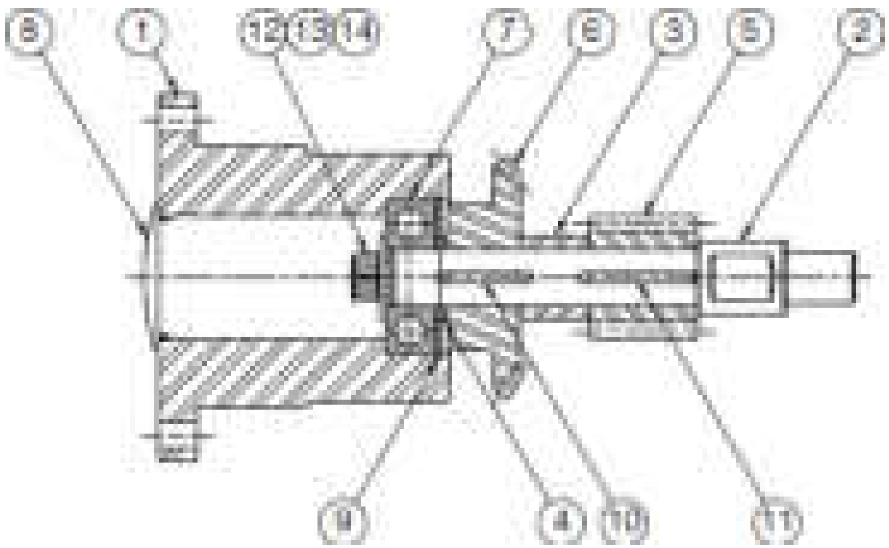
- Toothed wheels fixed to an axle.
- Drive gear – connected to the input axle.
- Driven gear – connected to the output axle.
- Gear train – when an number of gears are connected together.

$$\text{Gear Ratio} = \frac{\text{Number of driven teeth (output)}}{\text{Number of driver teeth (input)}}$$

Gear and Bearing Assemblies

- Use as few views as possible
  - A full sectional view may be the only view necessary
- Dimensions are normally omitted
- Typically include balloons correlated with a parts list
- May include torque data and lubricant information

Gear and Bearing Assemblies



Applications of Gears

- *Toys and Small Mechanisms* – **small, low load, low cost**

  kinematic analysis
- *Appliance gears* – **long life, low noise & cost, low to moderate load**

  kinematic & some stress analysis
- *Power transmission* – **long life, high load and speed**

  kinematic & stress analysis
- *Aerospace gears* – **light weight, moderate to high load**

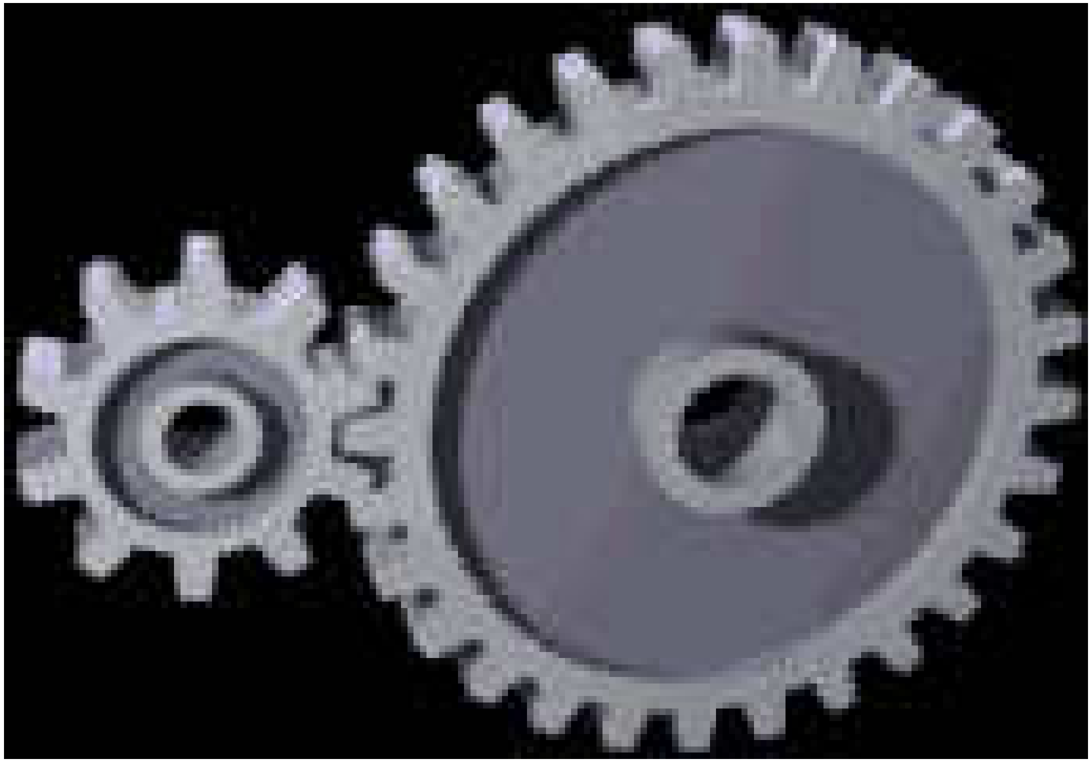
  kinematic & stress analysis
- *Control gears* – **long life, low noise, precision gears**

  kinematic & stress analysis

Spur Gears

- Straight teeth mounted on parallel shafts
- Many used at once to create very large gear reductions

- Flat
- Pinion

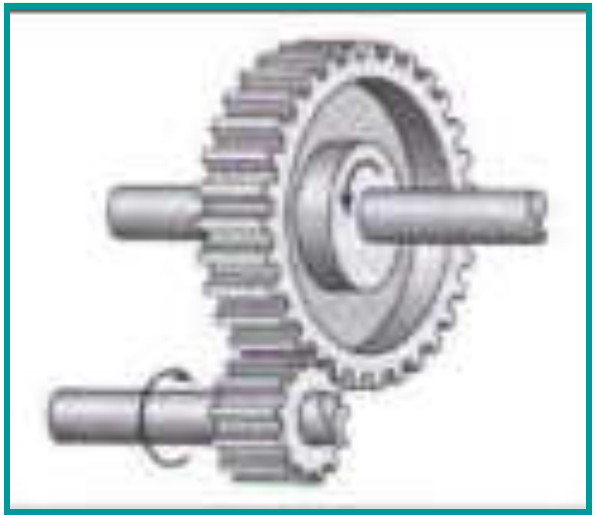


http://en.wikipedia.org/wiki/Gear#Worm_gear

Types of Gears

Spur gears – tooth profile is parallel to the axis of rotation, transmits motion between parallel shafts.

Gear (large gear)



Pinion (small gear)

Internal gears

Helical gears – teeth are inclined to the axis of rotation, the angle provides more gradual engagement of the teeth during meshing, transmits motion between parallel shafts.

Spur Gear Terminology

- Teeth are straight and parallel to the gear shaft axis
- Establish gear tooth profile using an involute curve
- Basic rule:
  - No fewer than 13 teeth on the running gear and 26 teeth on the mating gear

Spur Gear Terminology

- Pressure angle
  - 14.5° and 20° are standard
- Diametral pitch
- Gear accuracy
  - Maximum tooth-to-tooth tolerances allowed, as specified by the American Gear Manufacturers Association (AGMA)
- Several additional formulas and specifications

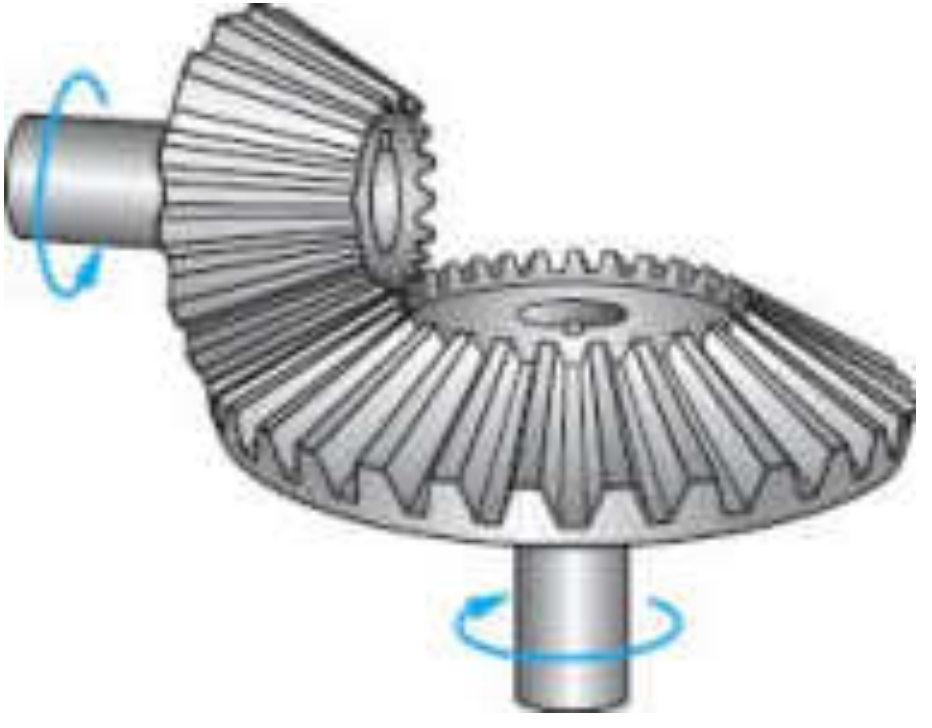
Bevel Gears

- Gears that mesh at an angle, usually 90°
- Changes the direction of rotation

http://science.howstuffworks.com/gear4.htm

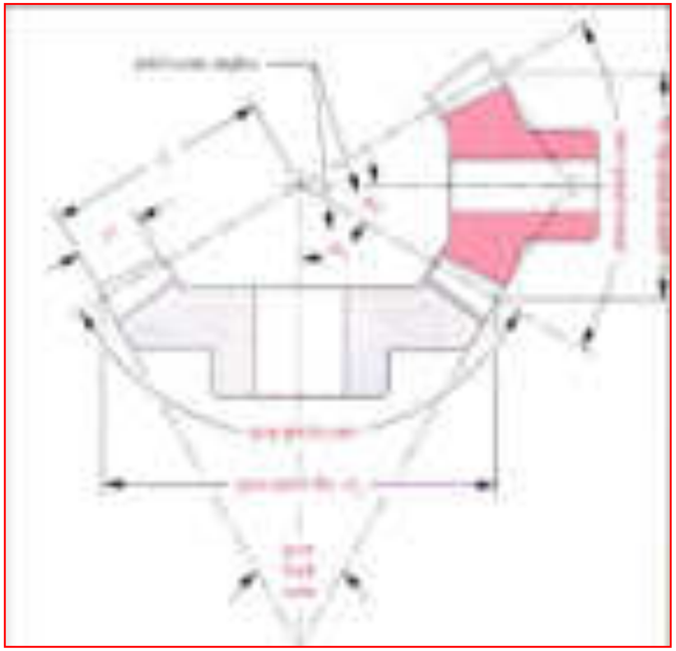
Bevel Gears

- Shafts of the gear and pinion can intersect at 90°or any desired angle
- Provide for a speed change between the gear and pinion, unless designed as miter gears



Types of Gears

Bevel gears – teeth are formed on a conical surface, used to transfer motion between non-parallel and intersecting shafts.



Straight bevel gear

Spiral bevel gear

Crown Gears

– Special form of bevel gear
– Has right angles to the plane of the wheel

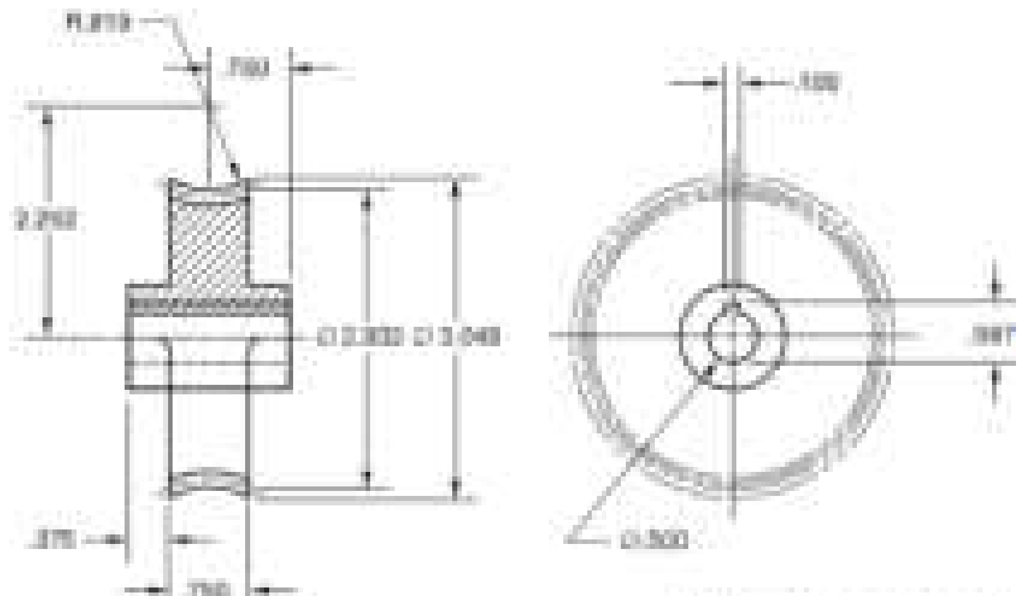
http://www.plastic-gear-manufacturer.com/industrial-gear.htm

Worm Gears

- Changes the direction of turning motion by 90°
- Decreases the speed of turning from screw to gear and increases the force

http://blogs.toolbarn.com/brianm/labels/Tool%20Inner%20Workings.html

Worm Gear Print



3. PITCH TOLERANCE ±.002.
2. INTERPRET GEAR DATA PER ANSI Y14.7.1.
1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M.

NOTES:

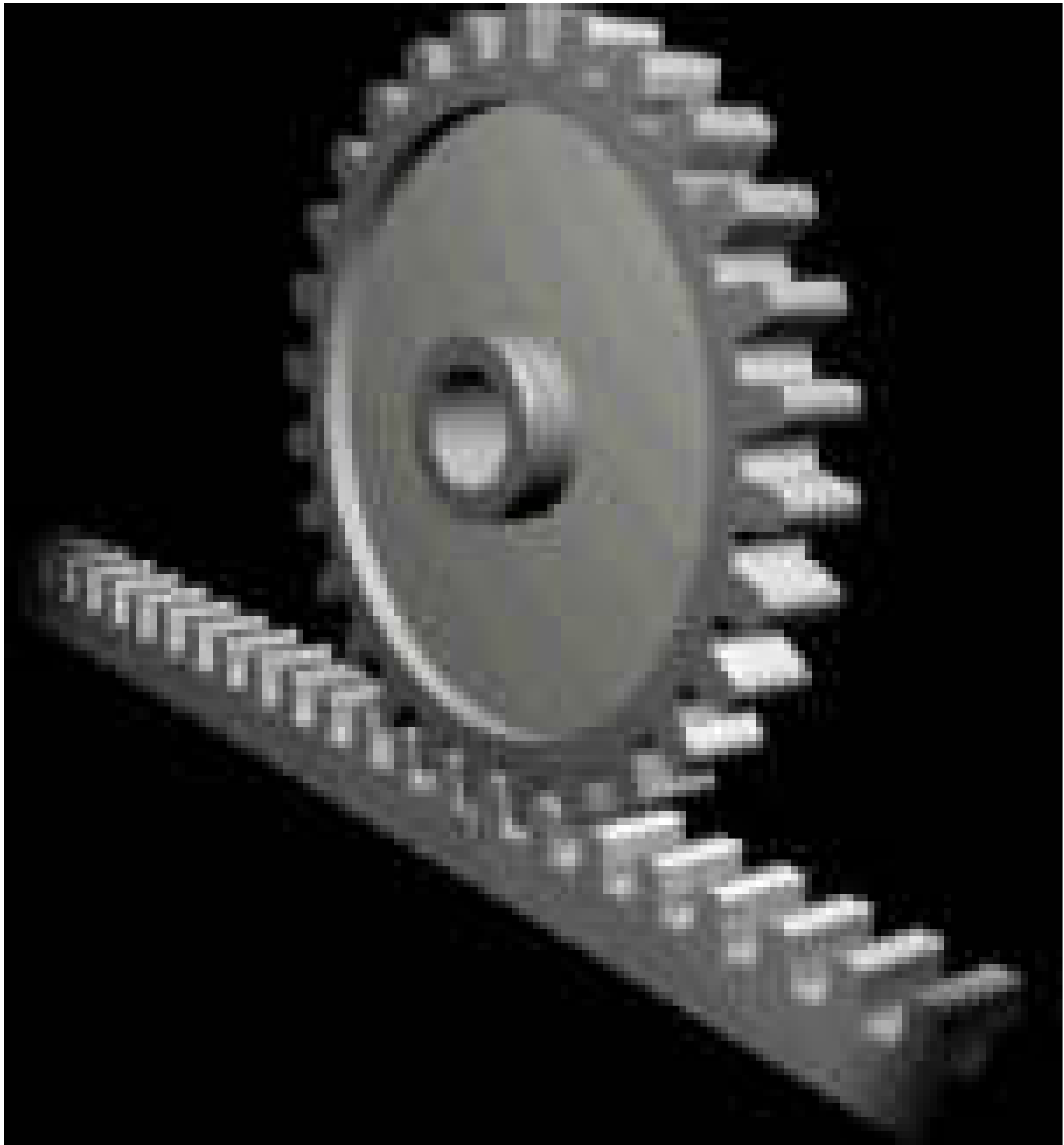
WORM GEAR DATA	
NUMBER OF TEETH	27
PITCH DIAMETER	2.933
ADDENDUM	.067
WHOLE DEPTH	.114
TOOTH THICKNESS	.100

Worm Gears

- Use a worm and worm gear
- Large speed reduction in a small space
- Worm locks in place when not in operation

Rack and Pinion

– Converts rotary motion to back and forth motion



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

Rack and Pinion

- Spur pinion operating on a flat straight bar rack
- Converts rotary motion into straight-line motion

Differential Gears

– Splits torque two ways, allowing each output to spin at a different speed

http://nxtasy.org/wp-content/uploads/2006/08/Differential2-00.html

Spur Gears

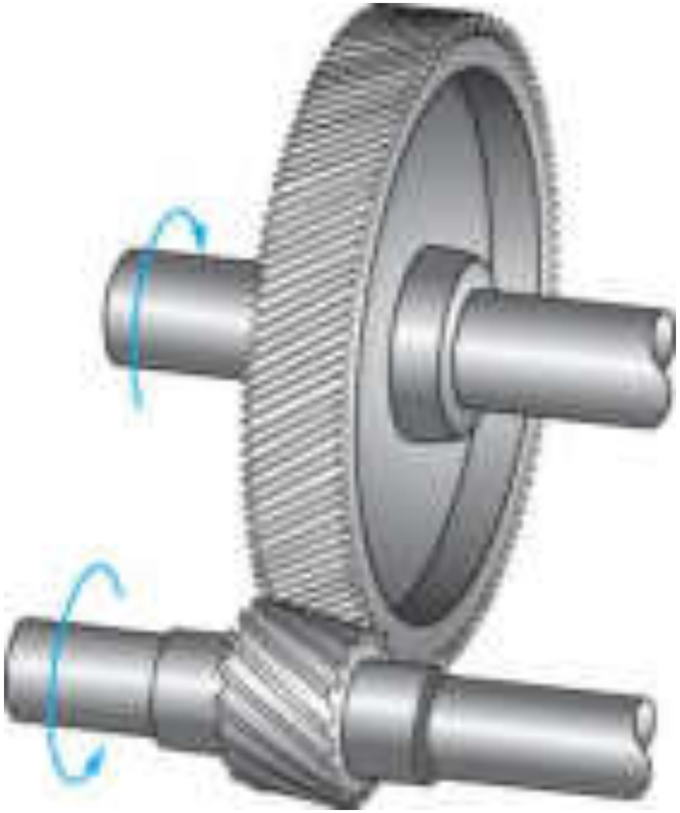
- Transmit motion and power between parallel shafts
- Two basic types:
  - External spur gears
  - Internal spur gears
- Cluster gears

Spur Gears

- Advantages:
  - Economical
  - Simple design
  - Ease of maintenance
- Disadvantages:
  - Less load capacity
  - Higher noise levels

Helical Gears

- Teeth cut at an angle
  - Allows more than one tooth to be in contact



Crossed Helical Gears

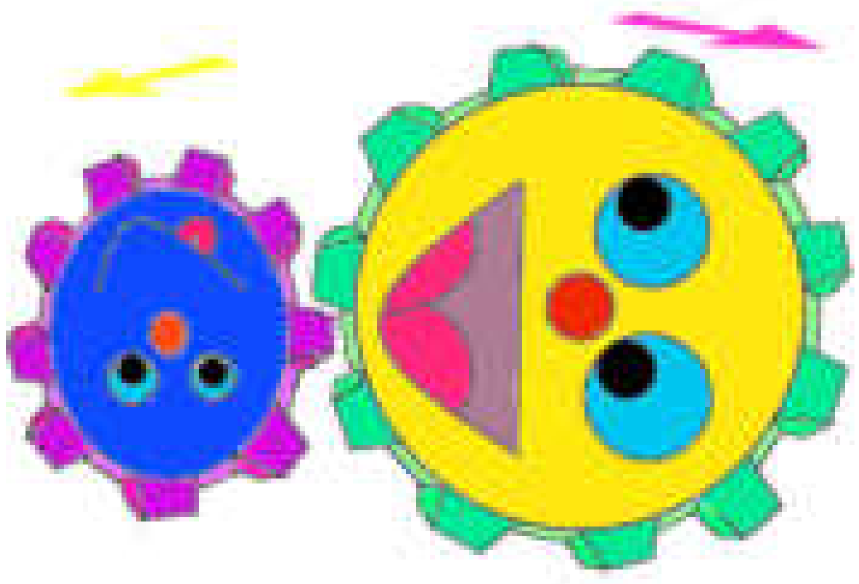
- Also known as:
  - Right angle helical gears
  - Spiral gears
- Low load-carrying capabilities

Helical Gears

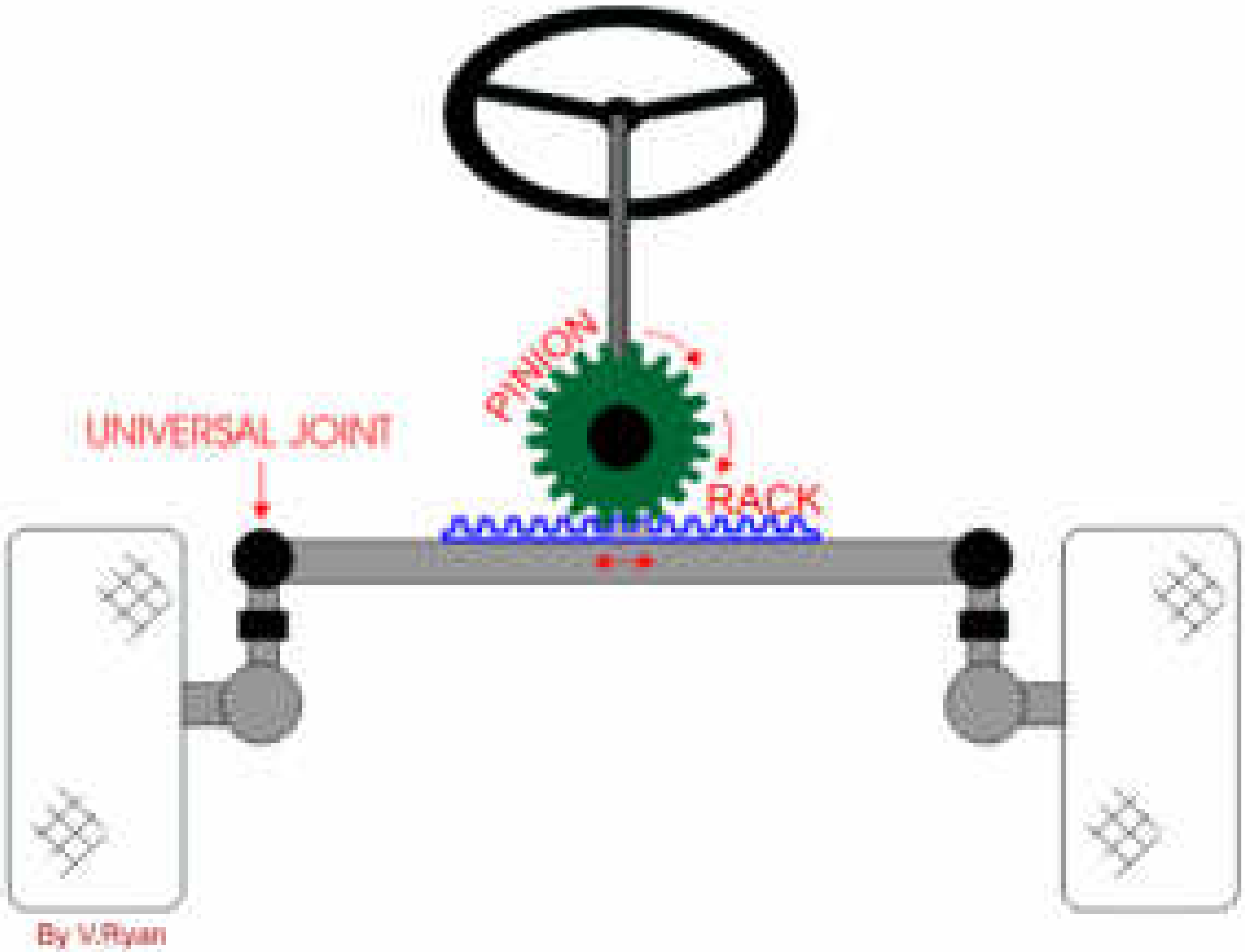
- Carry more load than equivalent-sized spur gears
- Operate more quietly and smoothly
- Develop end thrust
  - Can be eliminated using double helical gears, such as a herringbone gear

Gear Assemblies

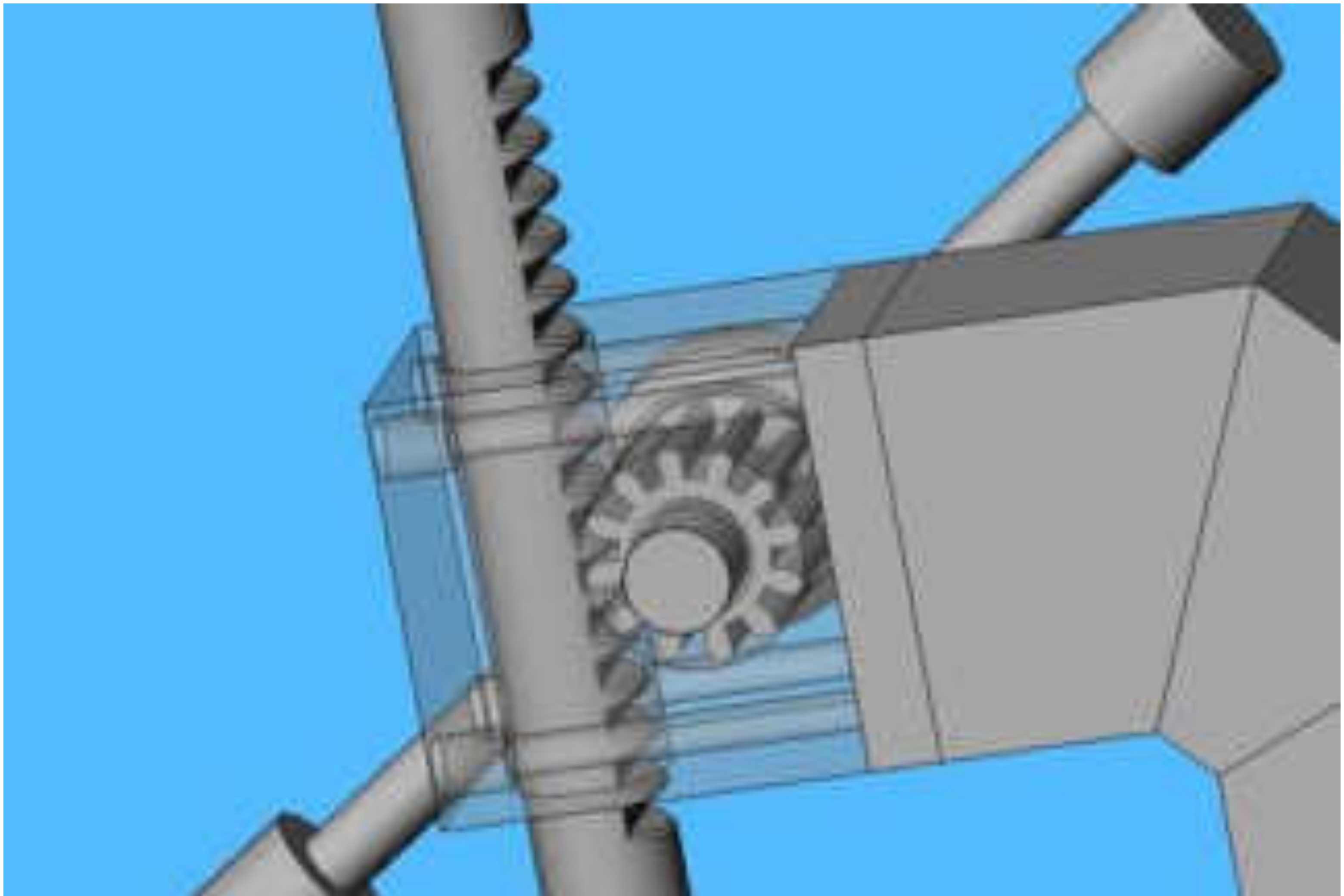
GEARS-Wheel and Axel



- **Each gear in a series reverses the direction of rotation of the previous gear. The smaller gear will always turn faster than the larger gear.**



PINION
UNIVERSAL JOINT
RACK
By V.Ryan



Common Gear Materials

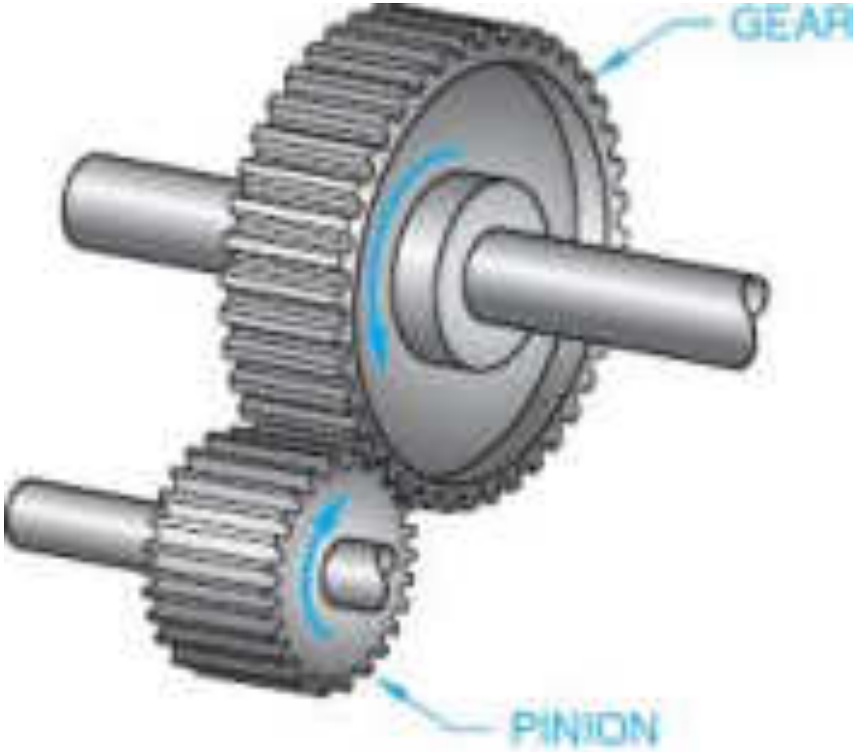
- Cast iron
- Steel
- Brass
- Bronze alloys
- Plastic

Gear Selection and Design

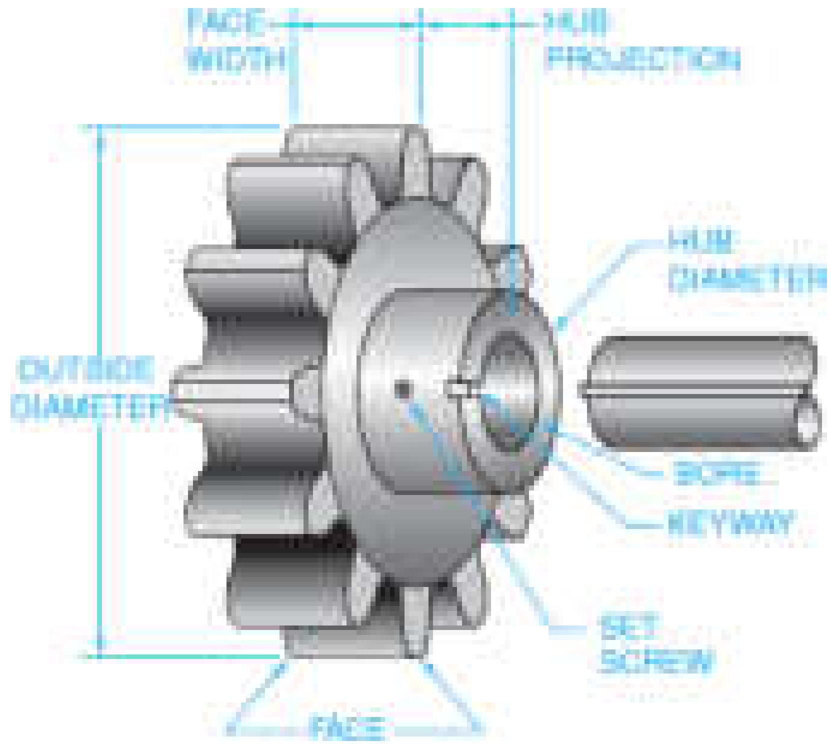
- Often done through vendors’ catalogs or the use of standard formulas
  - American Gear Manufacturers Association (AGMA)
    - AGMA 2000-A88, Gear Classification and Inspection Handbook - Tolerances and Measuring Methods for Unassembled Spur and Helical Gears, including Metric Equivalents
  - American Society of Mechanical Engineers (ASME)
    - ASME Y14.7.1 Gear Drawing Standards - Part 1: For Spur, Helical, Double Helical and Rack
    - ASME Y14.7.2 Gear and Spline Drawing Standards - Part 2: Bevel and Hypoid Gears

Gear Train

- Increase or reduce speed
- Change the direction of motion from one shaft to another



Gear Structure



Splines

- Often used when it is necessary for the gear or pulley to easily slide on the shaft
- Can also be nonsliding
- Stronger than keyways and keys

Intersecting Shafting Gears

- Bevel gears
- Face gears

Face Gears

- Combination of bevel gear and spur pinion, or bevel gear and helical pinion
- Requires less mounting accuracy
- Caries less load

Nonintersecting Shafting Gears

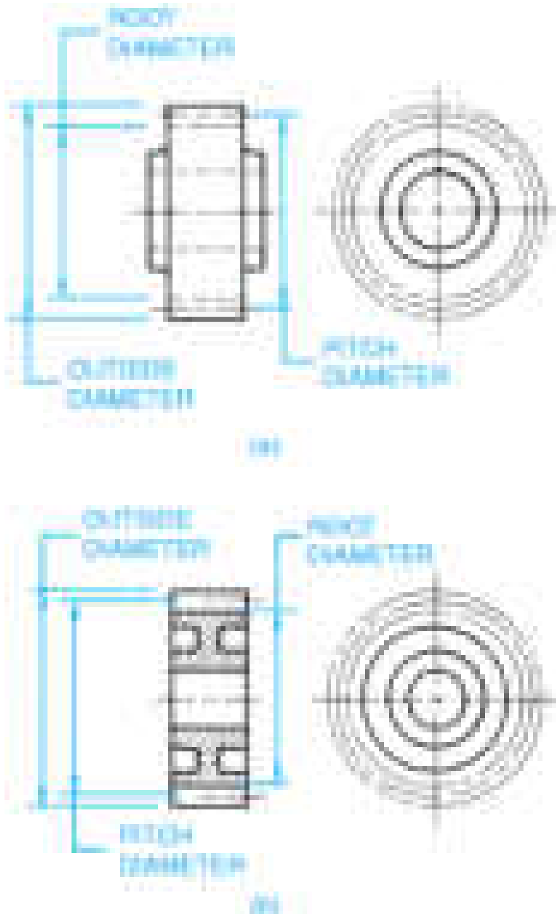
- Crossed helical gears
- Hypoid gears
- Worm gears

Hypoid Gears

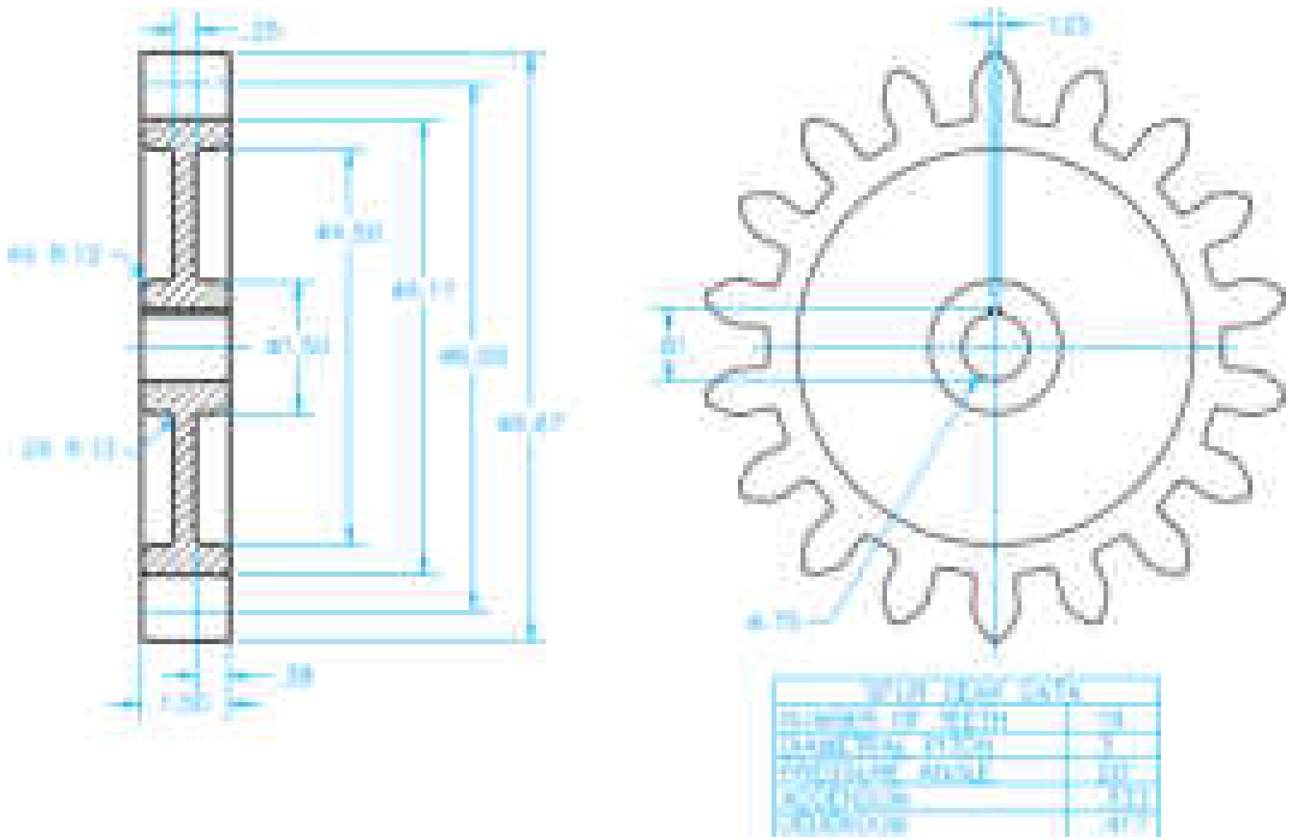
- Offset, nonintersecting gear shaft axes
- Very smooth, strong, and quiet

Hypoid Gear Representations

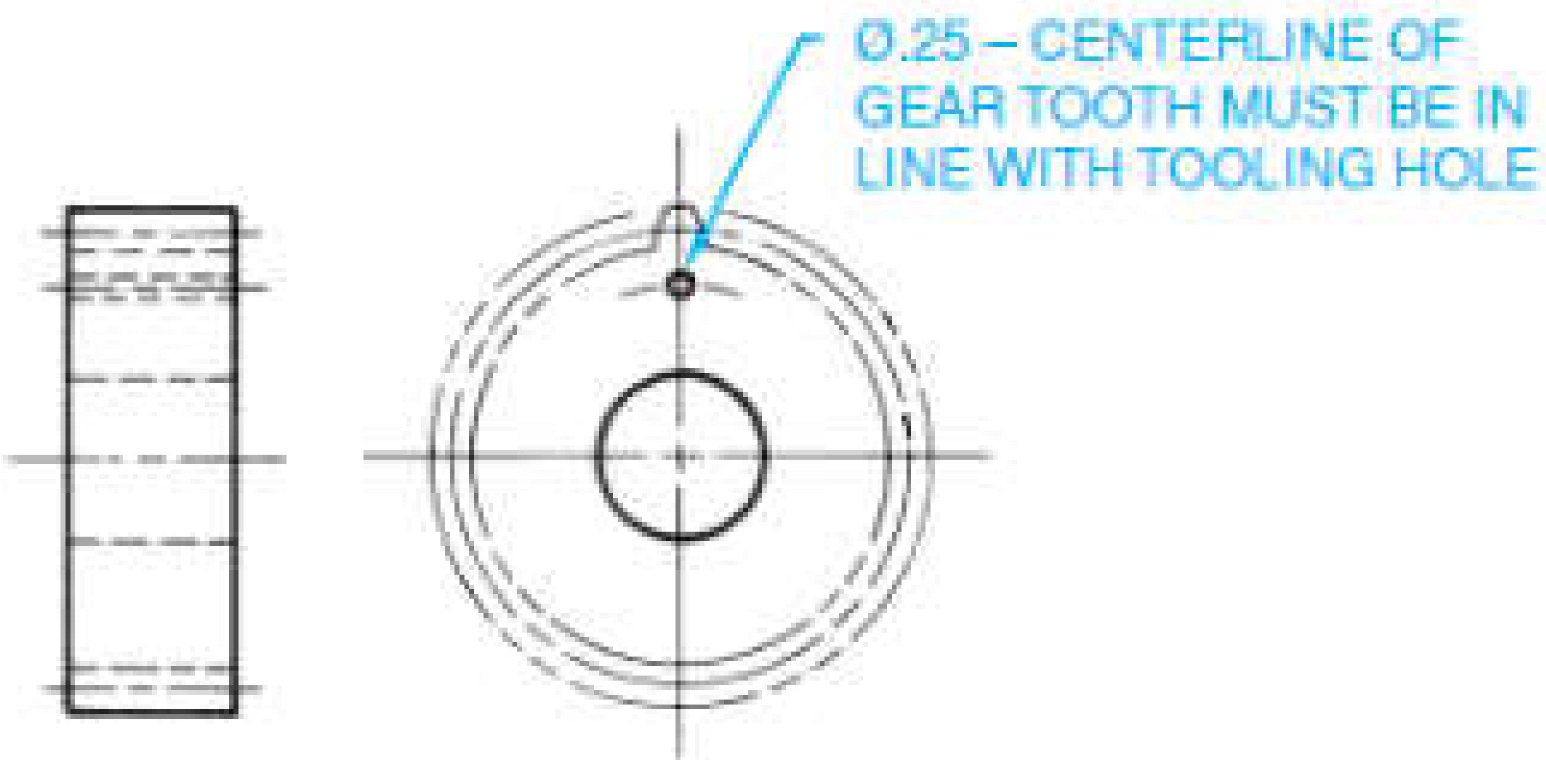
Simplified Gear Representation



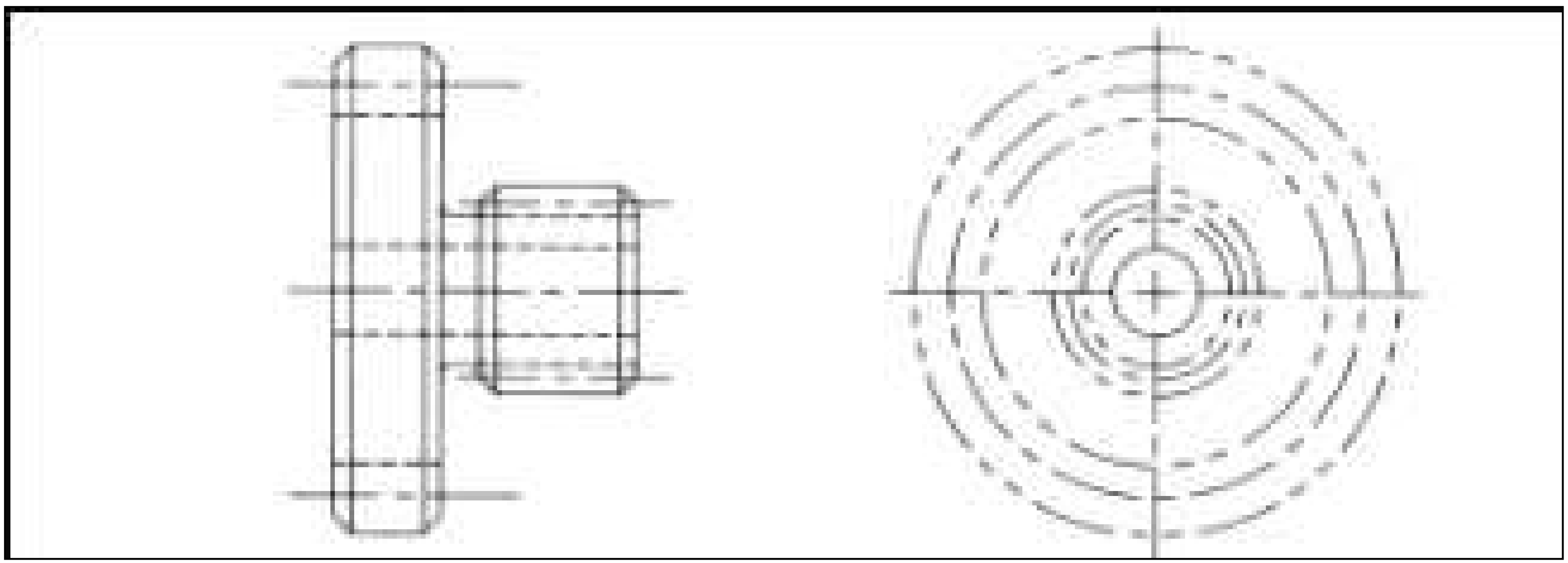
Detailed Spur Gear Representation



Showing a Gear Tooth Related to Another Feature



Cluster Gear Print



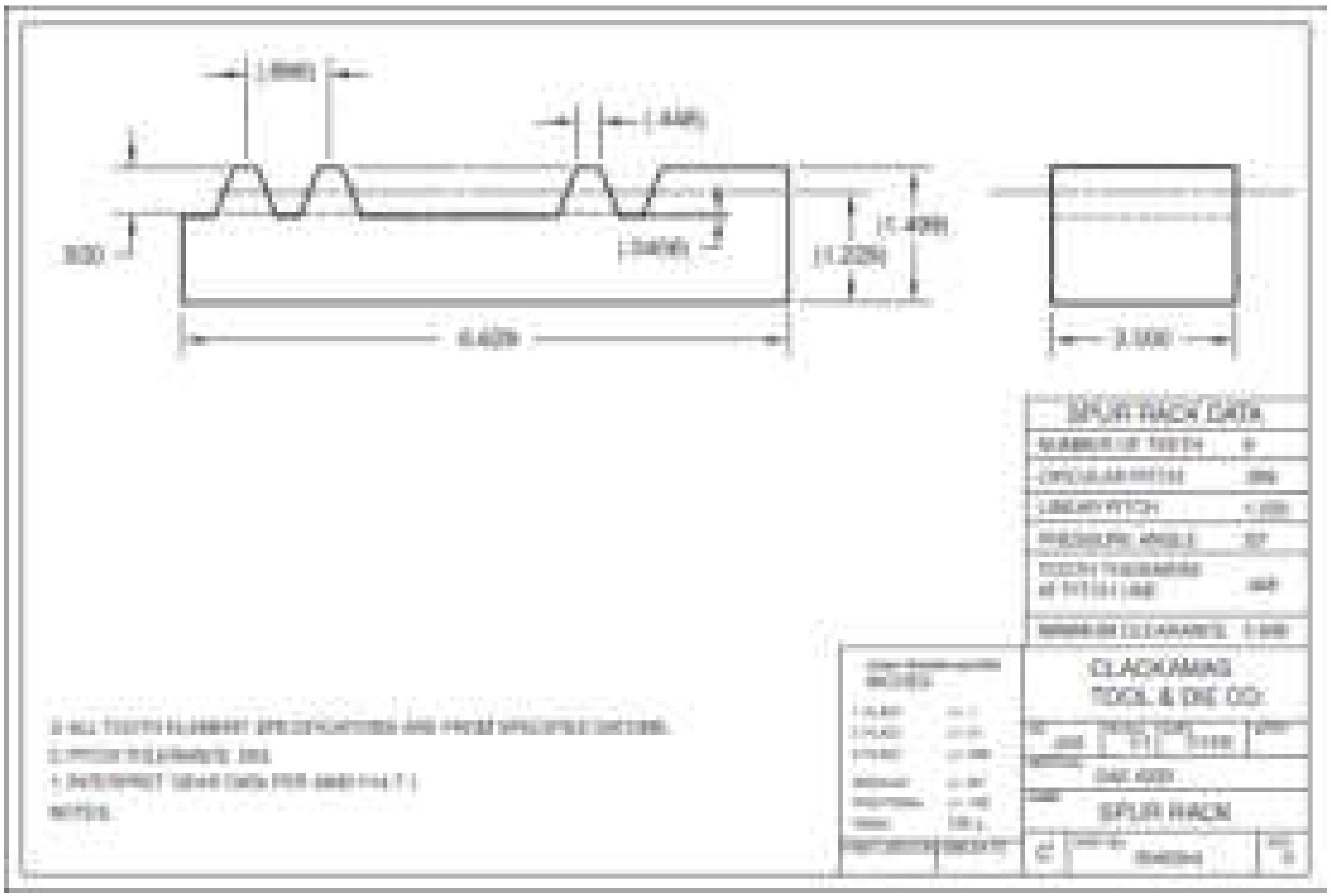
Gear Trains

- Transmit motion between shafts
- Decrease or increase the speed between shafts
- Change the direction of motion

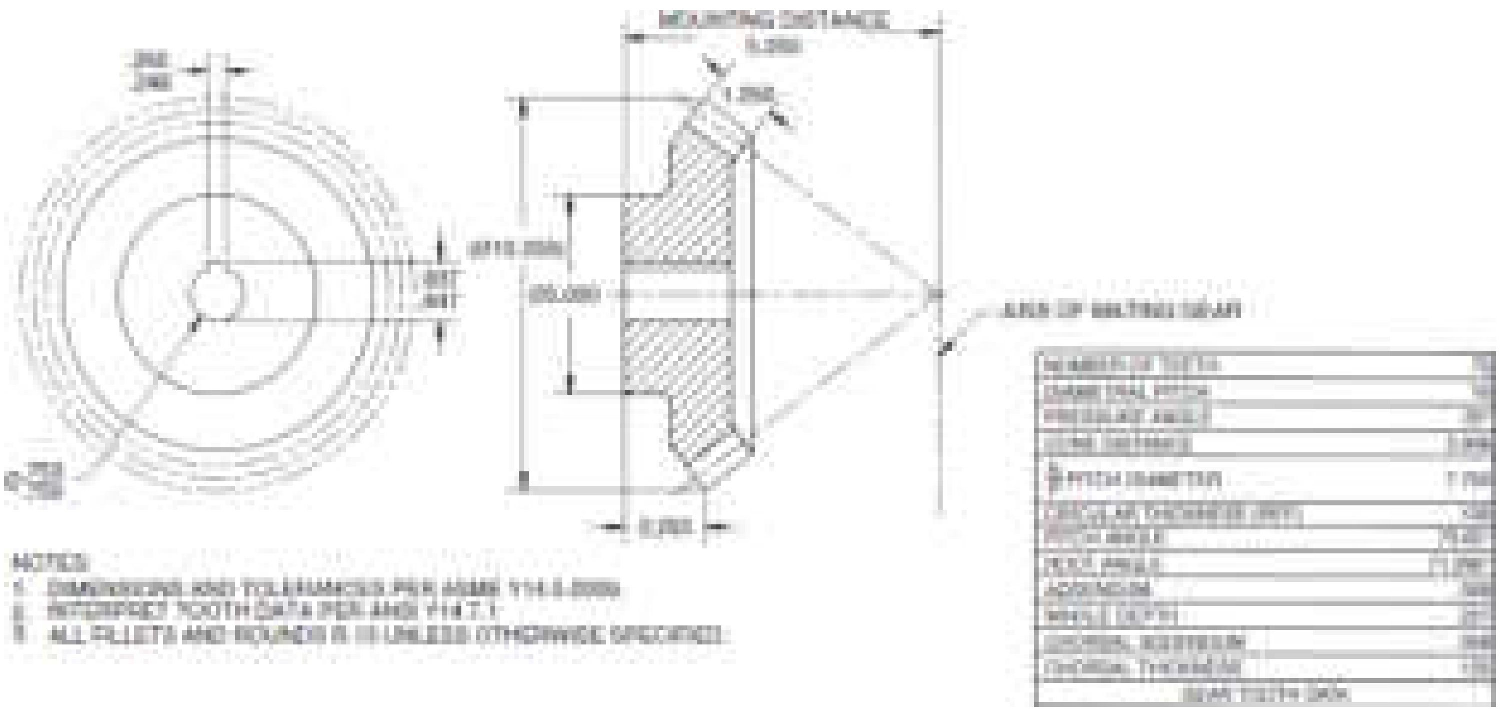
Gear Ratio

- Important when designing gear trains
- Applies to any two gears in mesh
- Expressed as a proportion, such as 2:1 or 4:1

Rack and Pinion Print



Bevel Gear Print



Plastic Gears

- Generally designed in the same manner as gears made from other materials
- Glass fiber adds reinforcement and reduces thermal expansion
- Additives that act as built-in lubricants and provide increased wear resistance:
  - Polytetrafluoroethylene (PTFE)
  - Silicones
  - Molybdenum disulphide

Advantages of Molded Plastic Gears

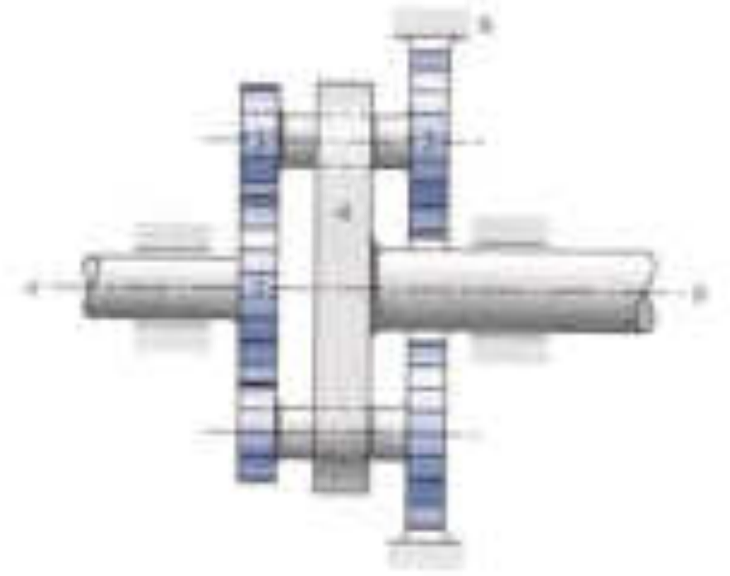
- Reduced cost
- Increased efficiency
- Self-lubrication
- Increased tooth strength with nonstandard pressure angles
- Reduced weight
- Corrosion resistance
- Less noise
- Available in colors

Disadvantages of Molded Plastic Gears

- Lower strength
- Greater thermal expansion and contraction
- Limited heat resistance
- Size change with moisture absorption

Planetary Gear Trains - Example

For the speed reducer shown, the input shaft *a* is in line with output shaft *b*. The tooth numbers are N_2=24, N_3=18, N_5=22, and N_6=64. Find the ratio of the output speed to the input speed. Will both shafts rotate in the same direction? Gear 6 is a fixed internal gear.



$$\text{Train value} = (-N_2 / N_3)(N_5 / N_6) = (-24/18)(22/64) = -.4583$$

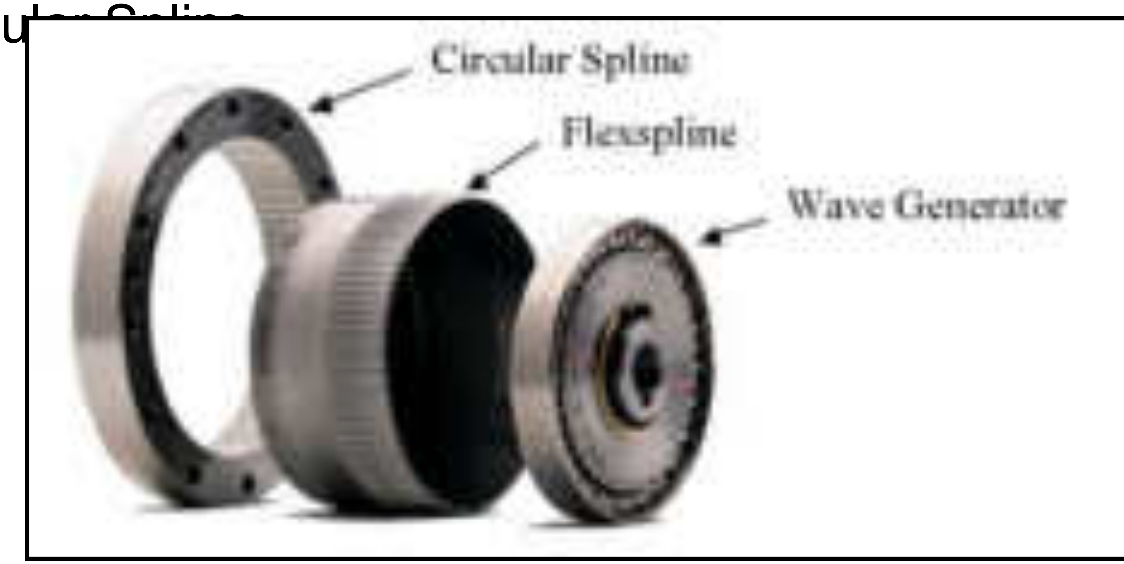
$$-.4583 = (\omega_L - \omega_{arm}) / (\omega_F - \omega_{arm}) = (0 - \omega_{arm}) / (1 - \omega_{arm})$$

ω_{arm} = .125, reduction is 8 to 1
Input and output shafts rotate in the same direction

$$d_2 + d_3 = d_6 - d_5$$

Harmonic Drive

The mechanism is comprised of three components: Wave Generator, Flexspline, and Circular Spline.



Wave Generator

Consists of a steel disk and a specially design bearing. The outer surface has an elliptical shape. The ball bearing conforms to the same elliptical shape of the wave generator. The wave generator is usually the input.

Flexspline

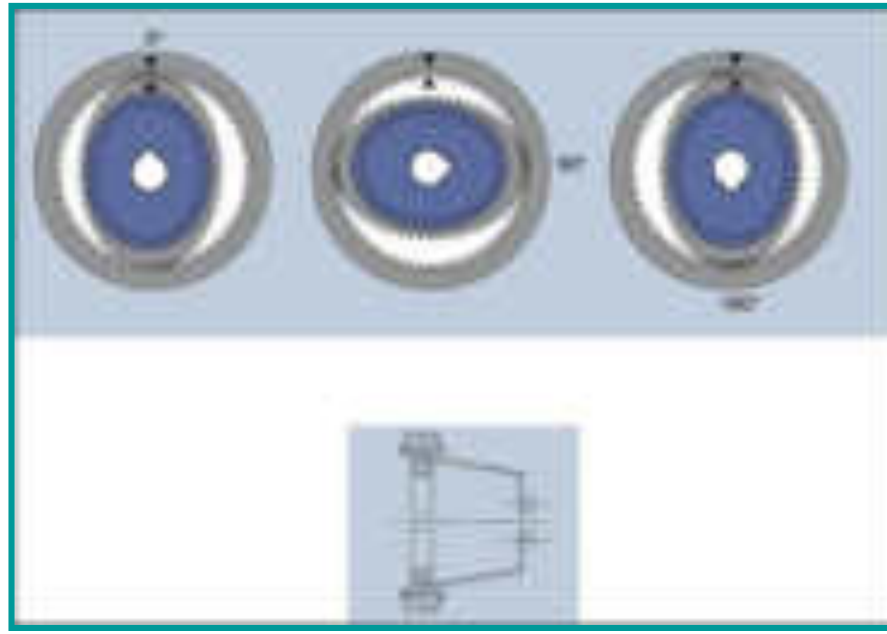
The Flexspline is a thin-walled steel cup with gear teeth on the outer surface near the open end of the cup. Flexspline is usually the output.

Circular Spline

Rigid internal circular gear, meshes with the external teeth on the Flexspline.

Harmonic Drive

Teeth on the Flexspline and circular spline simultaneously mesh at two locations which are 180° apart.



As the wave generator travels 180°, the flexspline shifts one tooth with respect to circular spline in the opposite direction.

The flexspline has two less teeth than the circular spline.

Gear Ratio = - ($N_{flex\ spline}$)/ 2

$\omega_{Wave\ Generator}$ = input, $\omega_{Flexspline}$ = output, $\omega_{Circular\ Spline}$ = 0

Bearings

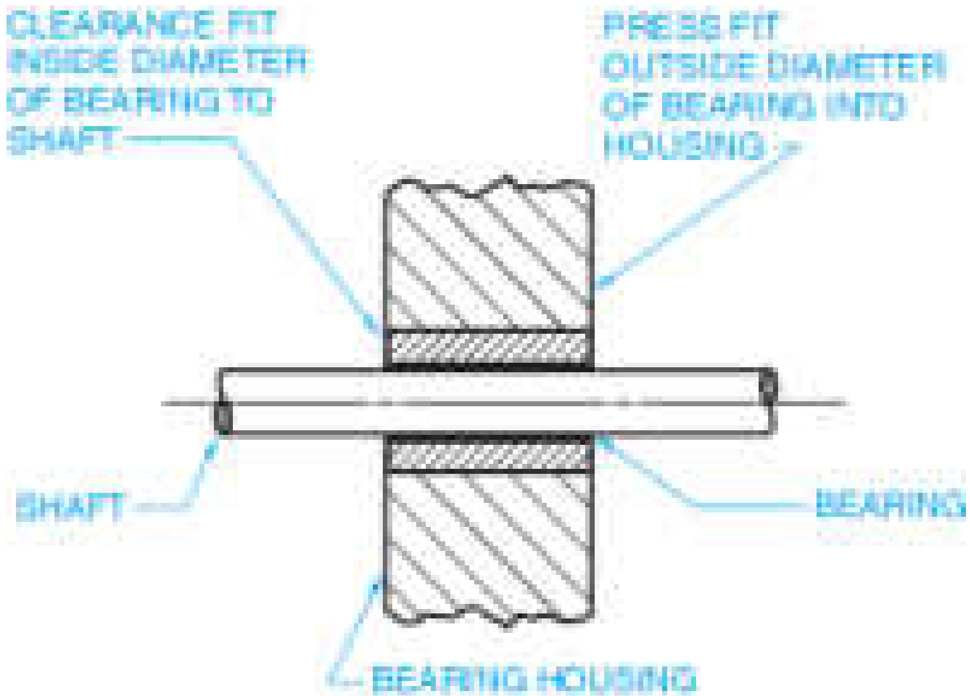
Bearings

- Two large groups:
  - Plain bearings
  - Rolling element bearings
- Accommodate either rotational or linear motion

Plain Bearings

- Often referred to as:
  - Sleeve bearings
  - Journal bearings
  - Bushings
- Operation is based on a sliding action between mating parts
- Clearance fit between the inside diameter of the bearing and the shaft is critical

Plain Bearings

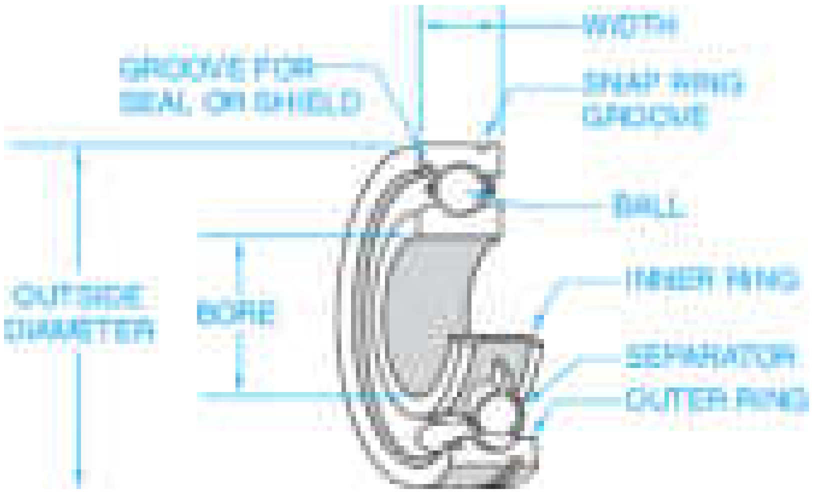


Rolling Element Bearings

- Common classes:
  - Ball bearings
  - Roller bearings

Ball Bearings

- Typically have higher speed and lower load capabilities than roller bearings
- May have a shield or seal

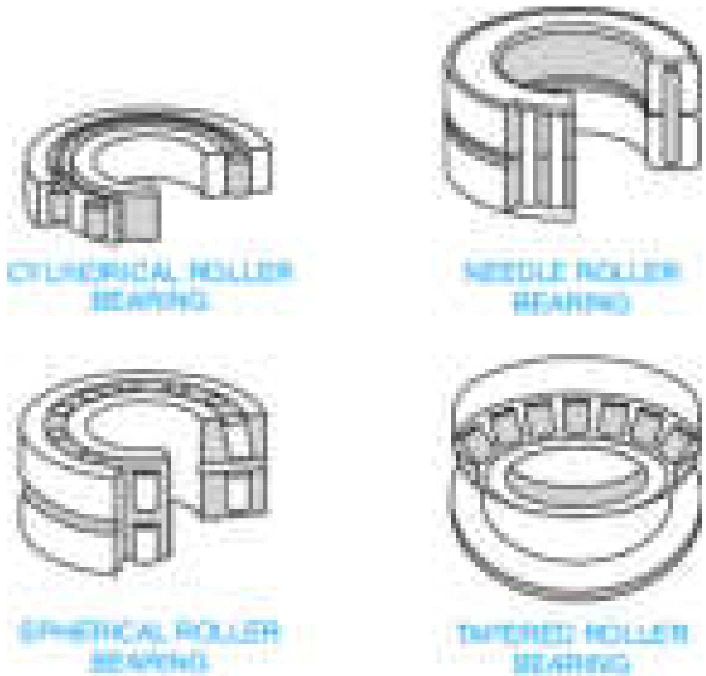


Typical Ball Bearings

- Single-row ball bearings
- Double-row ball bearings
- Angular contact ball bearings
- Thrust bearings

Roller Bearings

- More effective than ball bearings for heavy loads



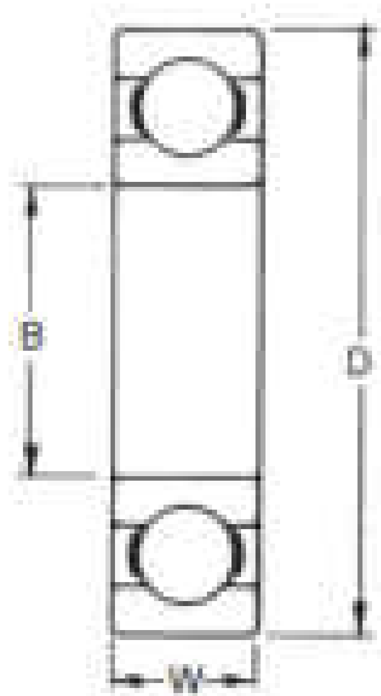
Bearing Codes

- Typically specify:
  - Material
  - Bearing type
  - Bore size
  - Lubricant
  - Type of seals or shields

Bearing Selection

- A variety of bearing types are available depending on use requirements
- Common classes:
  - Light bearings
  - Medium bearings
  - Heavy bearings

Bearing Bore, Outside Diameters, and Width



Shaft and Housing Fits

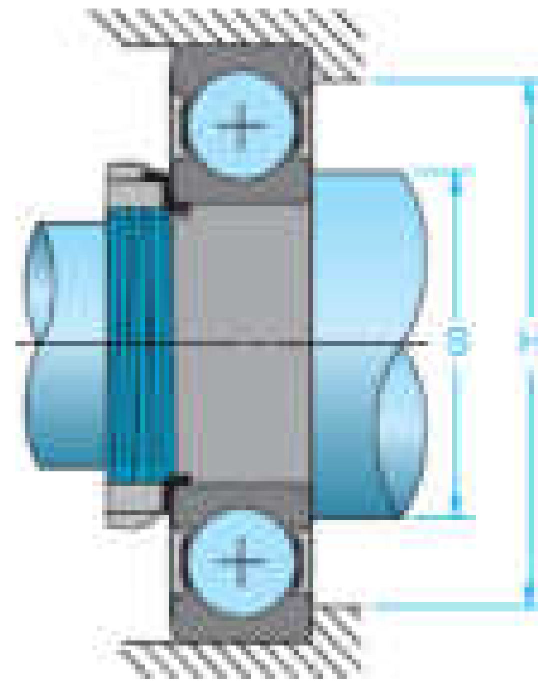
- Important consideration
  - Tight fits can cause failure of the balls, rollers, lubricant, or overheating
  - Loose fits can cause slippage of the bearing in the housing, resulting in overheating, vibration, or excessive wear

Shaft and Housing Fits

- General shaft fits
  - Shaft diameter and tolerance are the same as the bearing bore diameter and tolerance
- General housing fits
  - Minimum housing diameter is .0001 larger than the maximum bearing outside diameter
  - Maximum housing diameter is .0003 larger than the minimum housing diameter

The Shaft Shoulder and Housing Shoulder Dimensions

- Shoulders should be large enough to rest flat on the face of the bearing and small enough to allow bearing removal



Surface Finish of Shaft and Housing

- Shafts under 2 inches (50 mm) in diameter:
  - 32 microinches (0.80 micrometer)
- Shafts over 2 inches in diameter
  - 63 microinch (1.6 micrometer)
- Housing diameter:
  - 125 microinch (3.2 micrometer)

Bearing Lubrication

- Necessary requirement based on:
  - Type of operation, such as continuous or intermittent
  - Service speed in rpm (revolutions per minute)
  - Bearing load, such as light, medium, or heavy

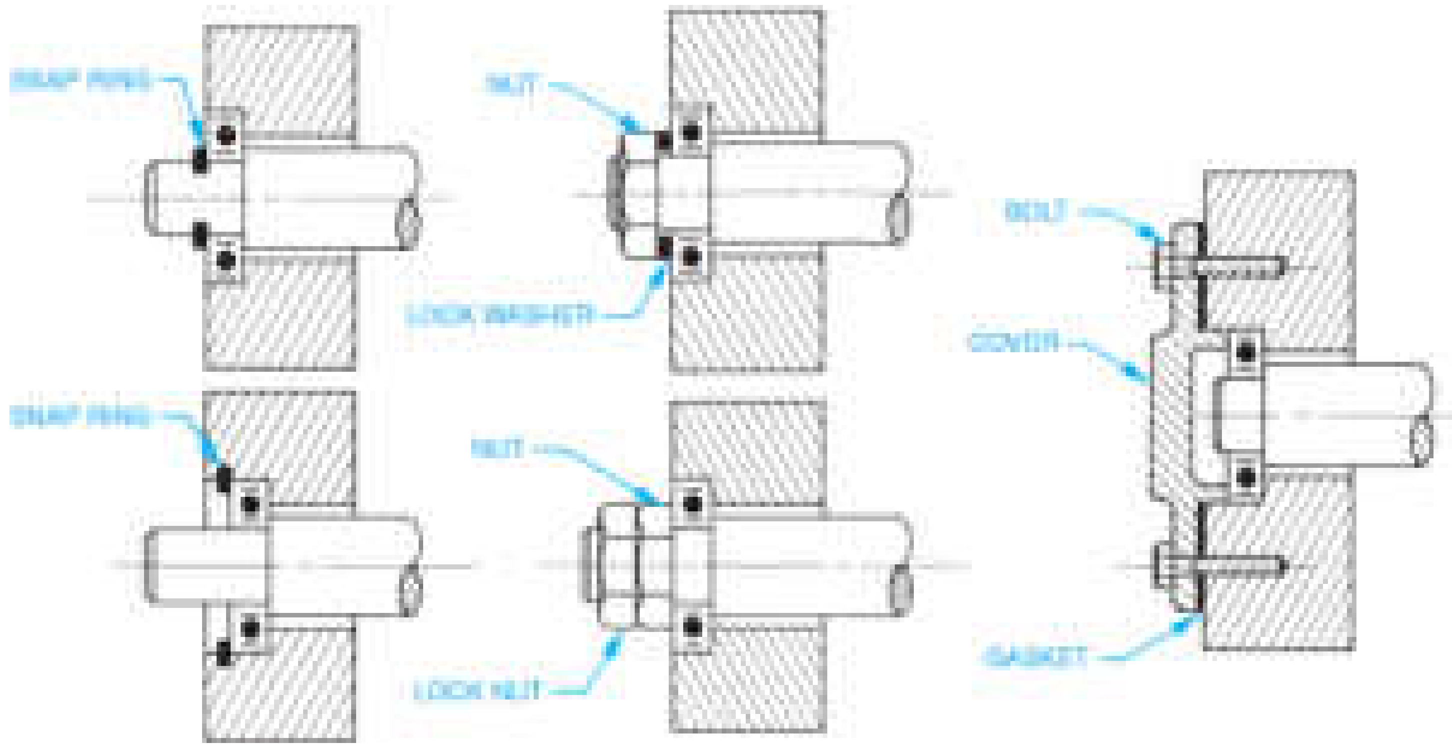
Oil Grooving of Bearings

- Grooves for the proper flow of lubrication to the bearing surface
  - Help provide the proper lubricant between the bearing surfaces and maintain cooling
- Several methods available

Sealing Methods

- Static sealing
- Dynamic seals
- Gaskets
- Molded lip packings
- Molded ring seals
  - Labyrinth
  - O-ring seal
  - Lobed ring seal
- Felt seals and wool seals

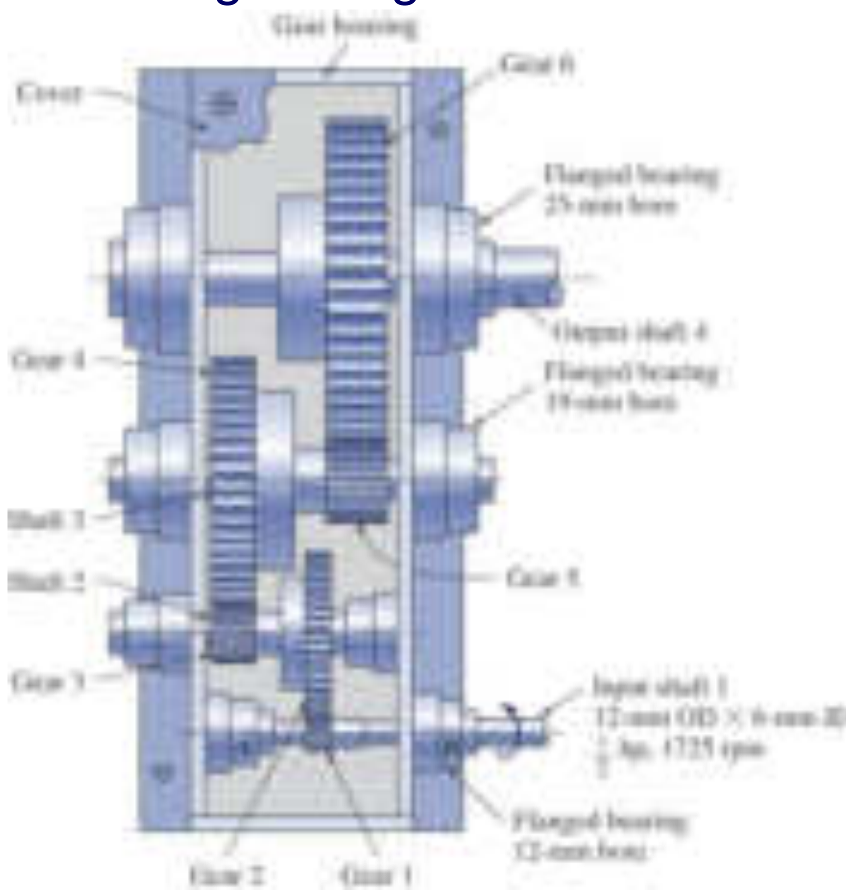
Bearing Mountings



Gears

What we need to Know about them.

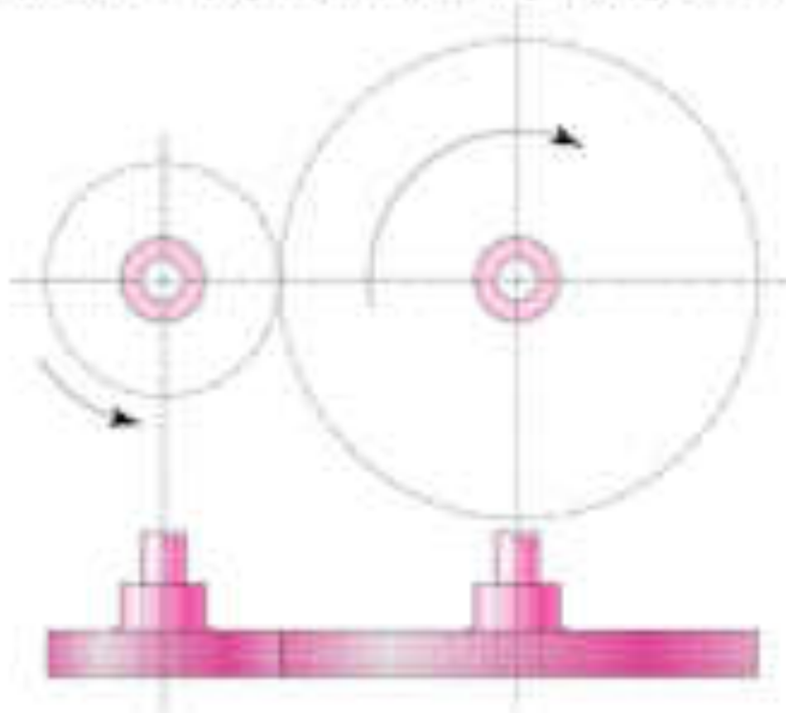
1. Type of gears
2. Terminologies or nomenclatures
3. Forces transmitted
4. Design of a gear box



Type of Gears

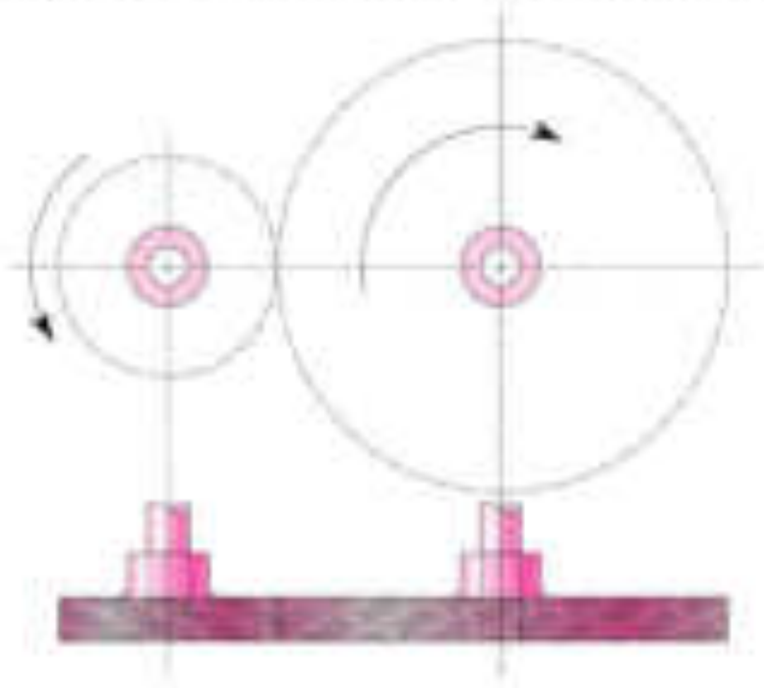
- Spurs
- Helical
- Bevel
- And Worm Gears

Spur Gears



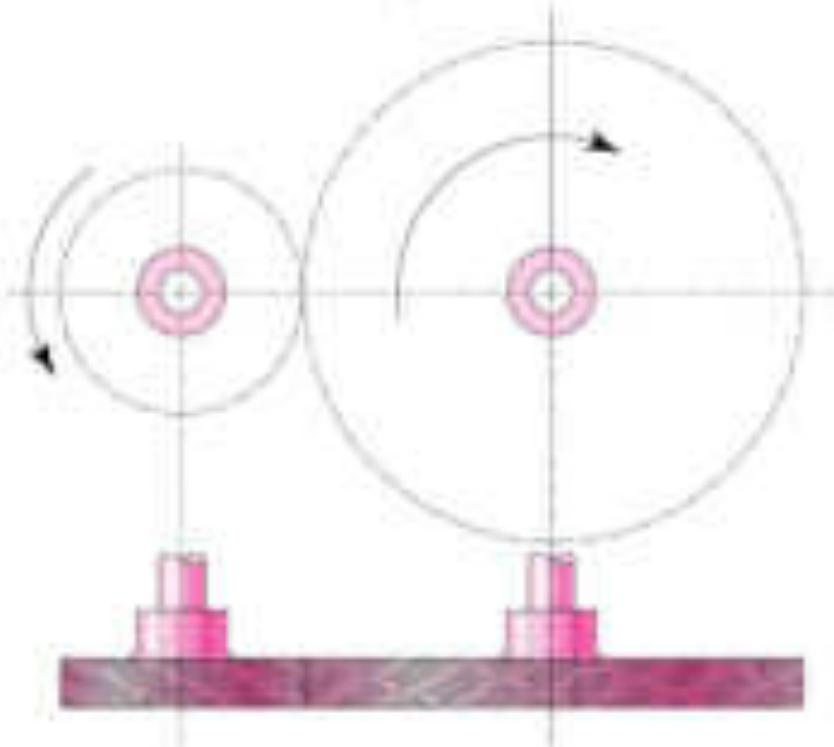
Are used in transmitting torque between parallel shafts

Helical Gears



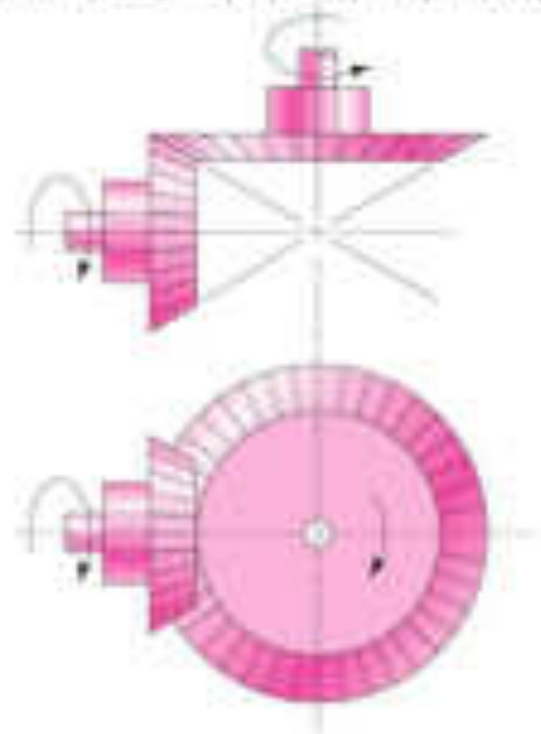
Are used in transmitting torques between parallel or non parallel shafts, they are not as noisy as spur gears

Fig. 13.2



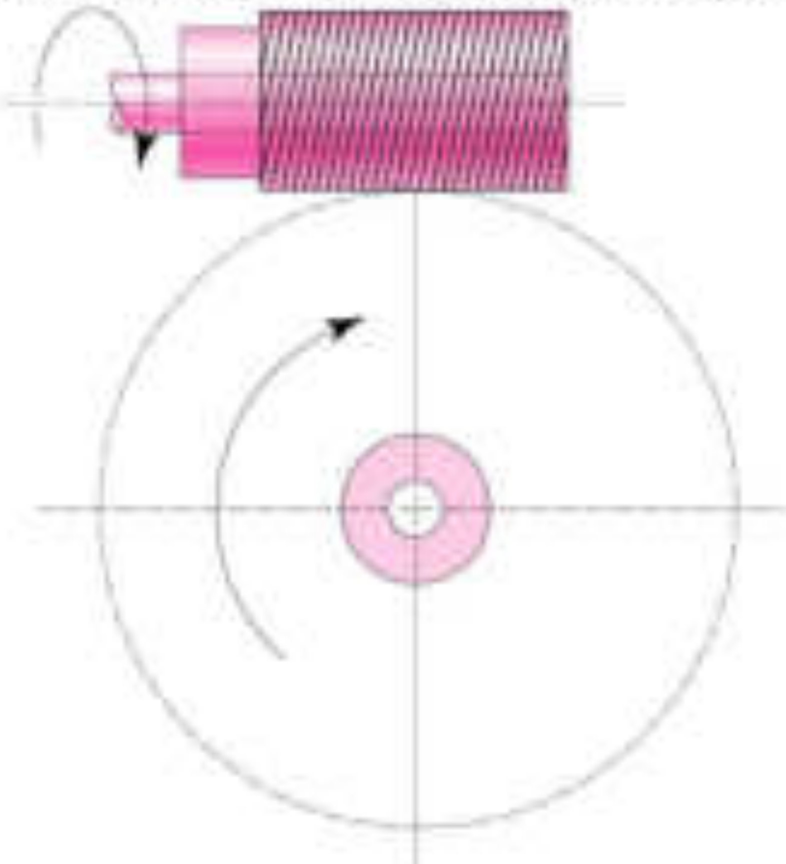
Bevel Gears

- Are used to transmit rotary motion between intersecting shafts



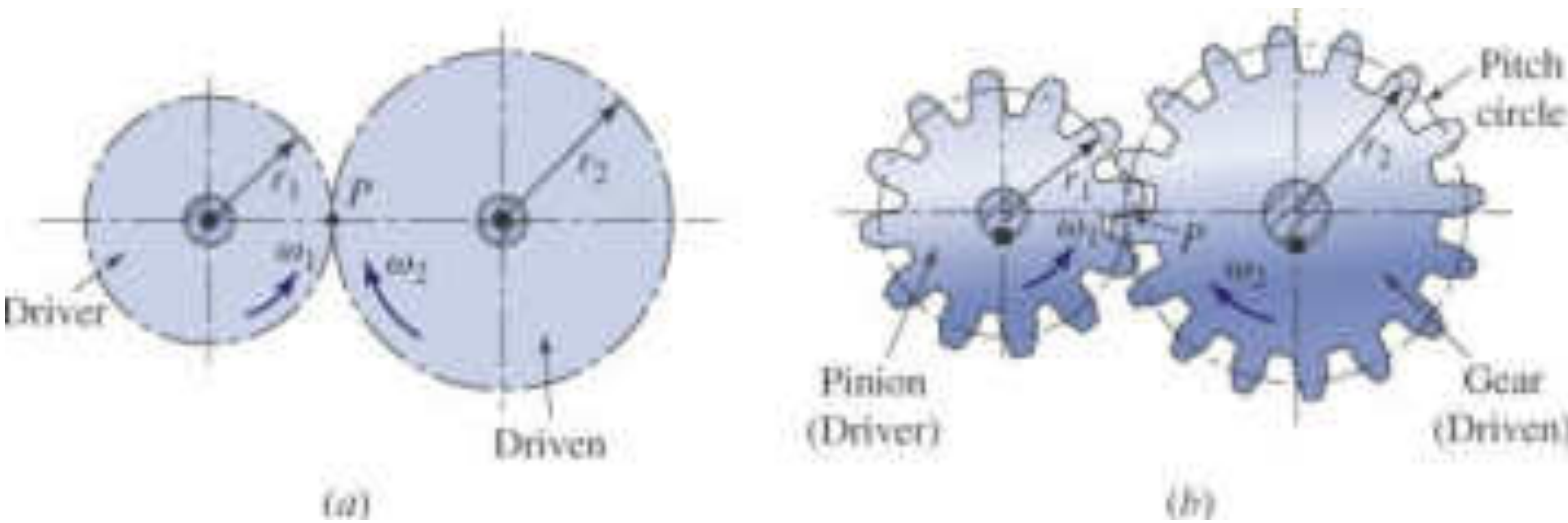
Teeth are formed on conical surfaces, the teeth could be straight or spiral.

Worm Gears



Are used for transmitting motion between non parallel and non transmitting shafts, Depending on the number of teeth engaged called single or double. Worm gear mostly used when speed ratio is quiet high, 3 or more

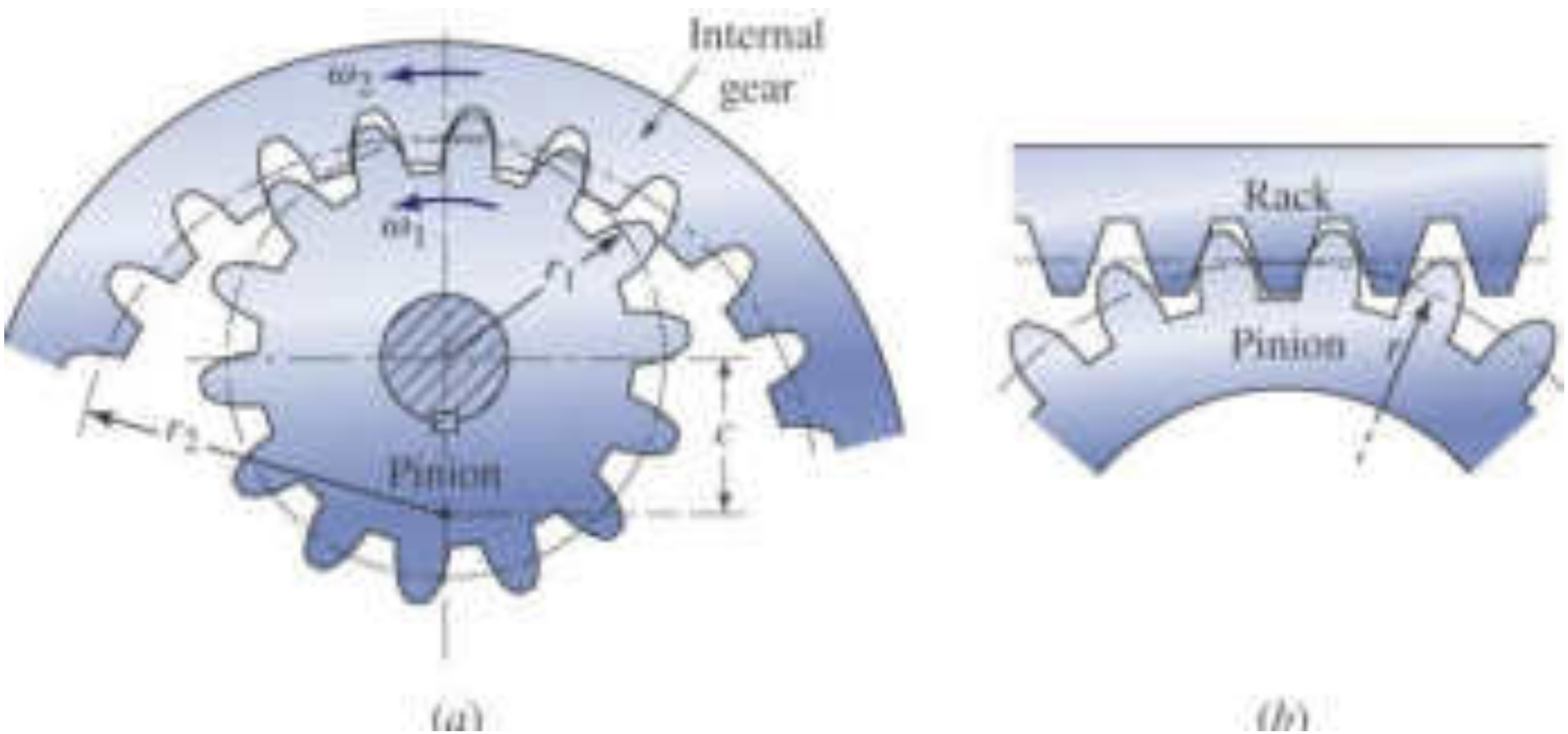
Nomenclature

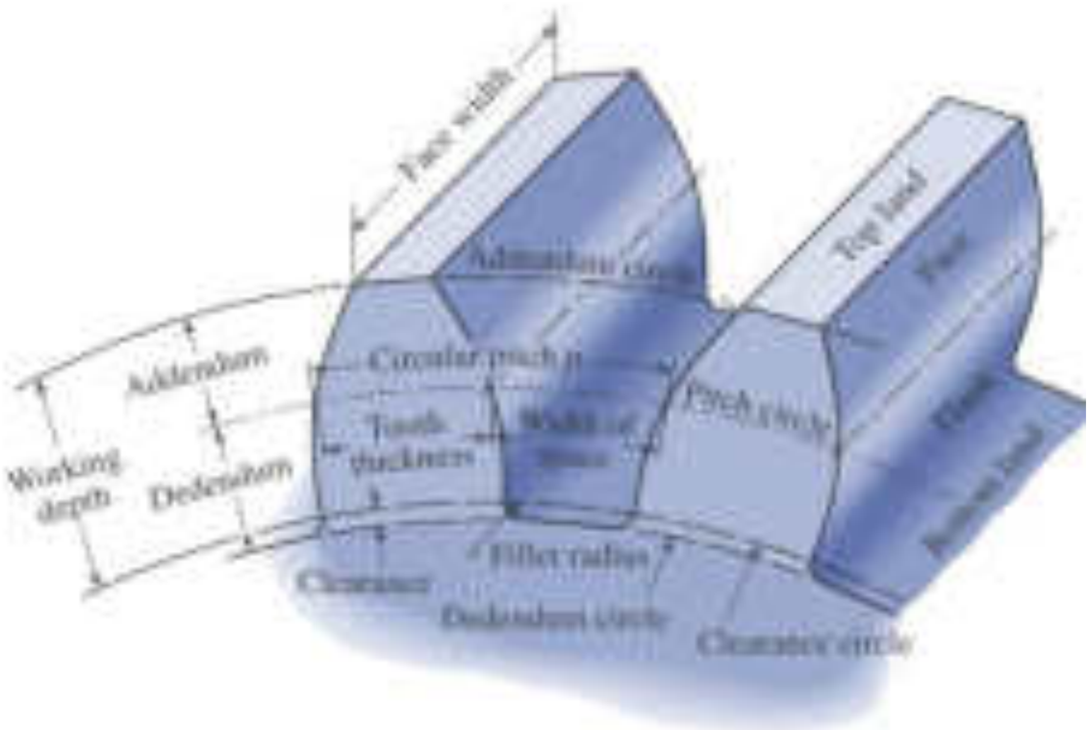


Smaller Gear is Pinion and Larger one is the gear

In most application the pinion is the driver, This reduces speed but it increases torque.

Internal Spur Gear System





pitch circle, theoretical circle upon which all calculation is based

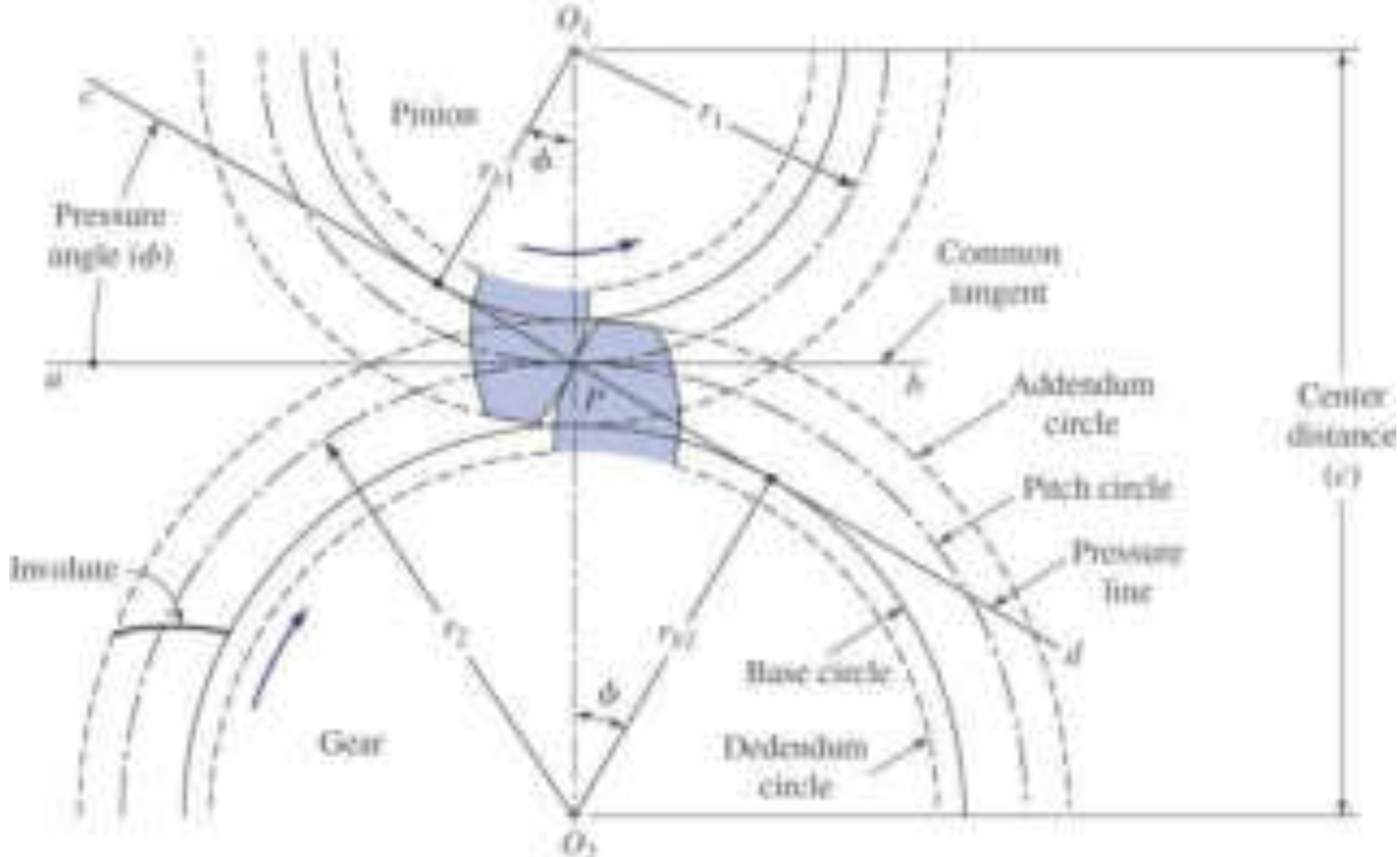
p, Circular pitch, p the distance from one teeth to the next, along the pitch circle. $p=\pi d/N$

m, module=d/N pitch circle/number of teeth

$p= \pi m$

P, Diametral Pitch $P=N/d$

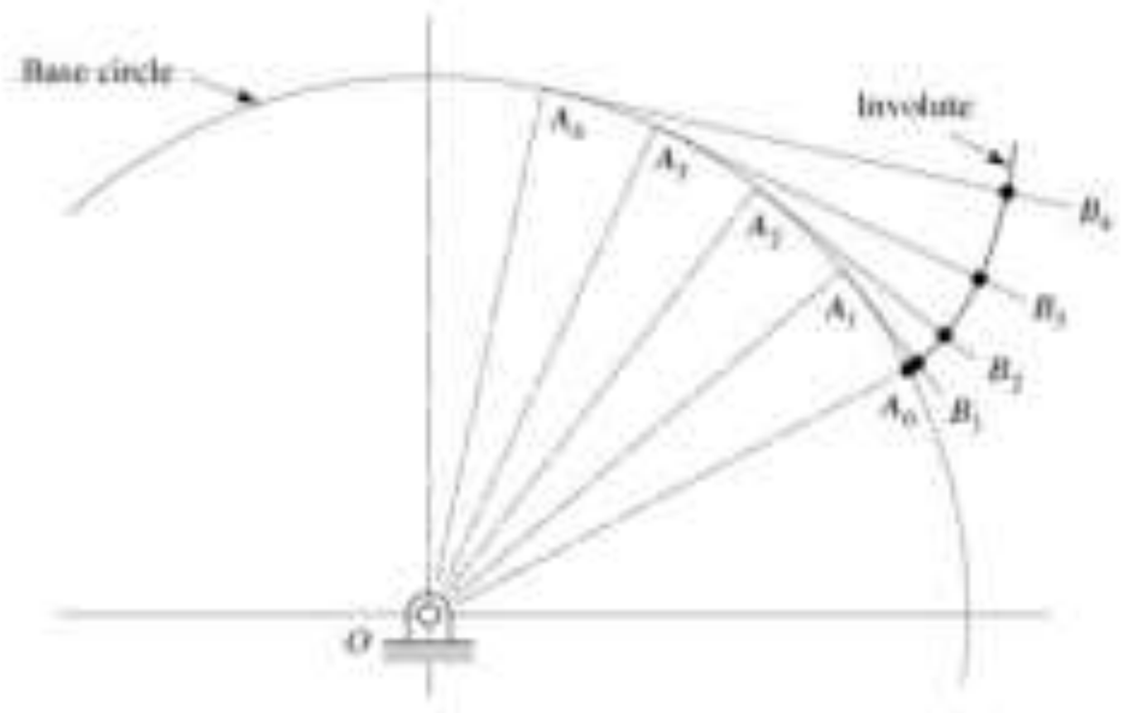
$pP= \pi$



Angle Φ has the values of 20 or 25 degrees. Angle 14.5 have been also used.

Gear profile is constructed from the base circle. Then additional clearance are given.

How Gear Profile is constructed

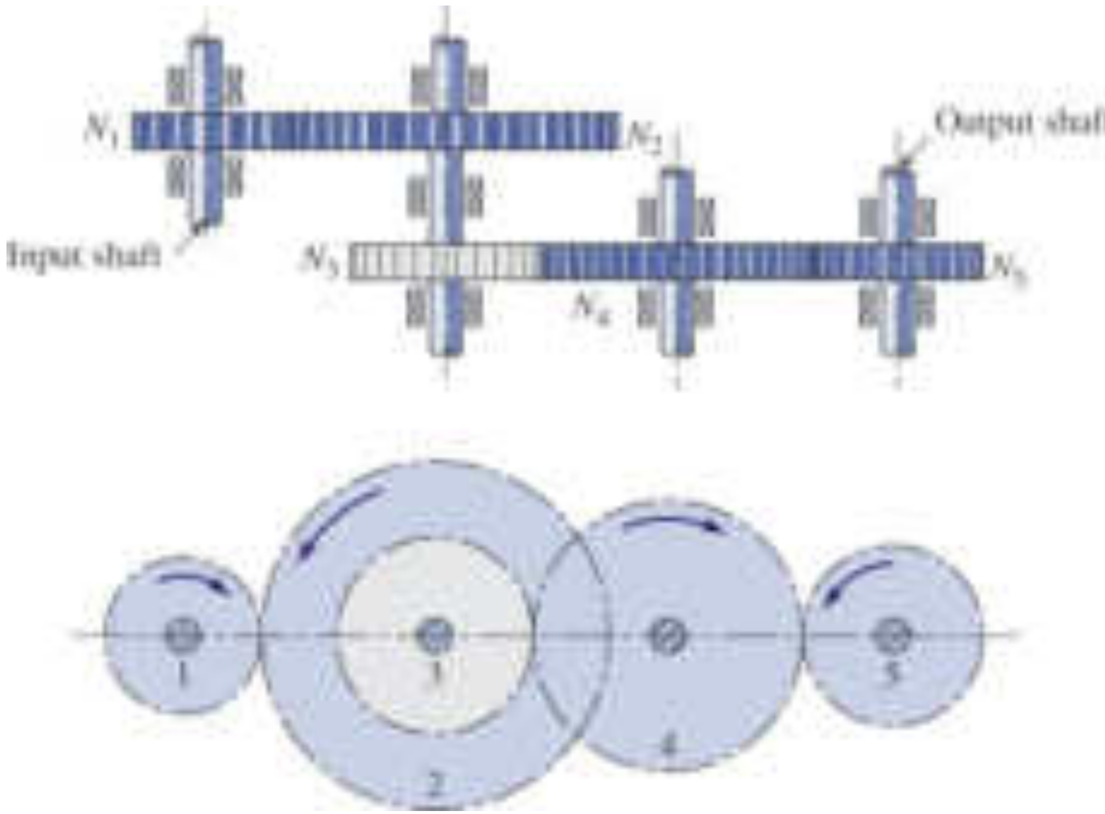


$A_1B_1 = A_1A_0$, $A_2B_2 = 2\,A_1A_0$, etc

Standard Gear Teeth

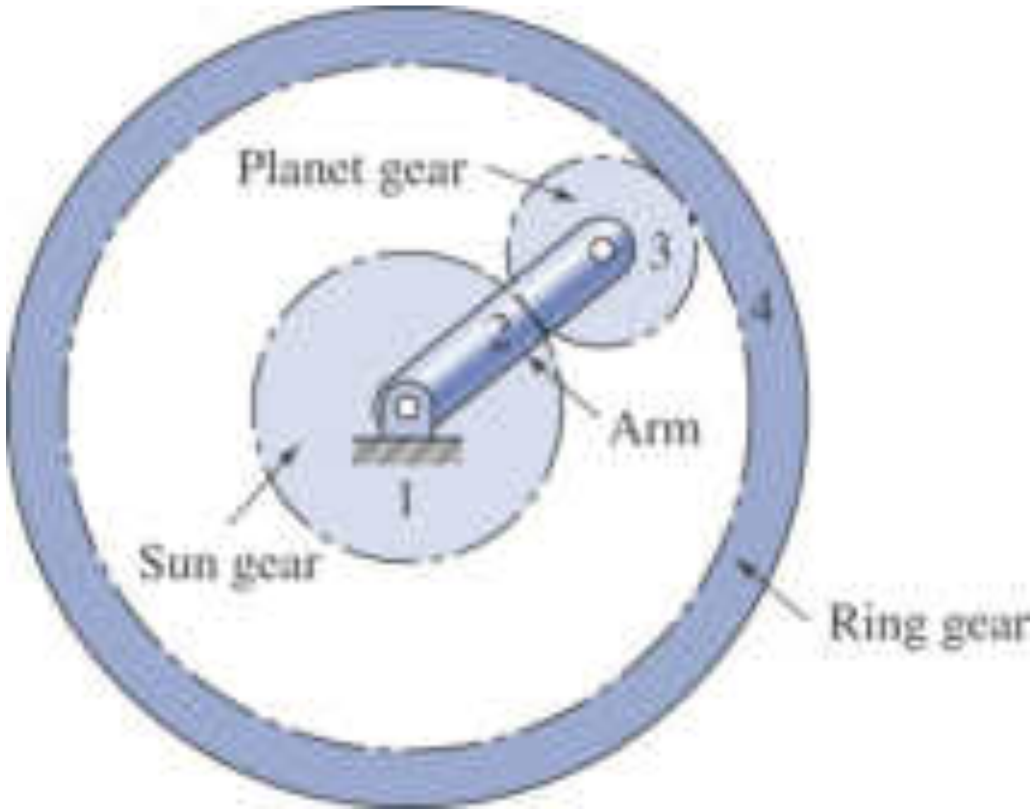
Item	20^{o} full depth	20^{o} Stub	25^{o} full depth
Addendum a	1/P	0.8/P	1/P
Dedendum	1.25/P	1/P	1.25/P
Clearance f	0.25/P	0.2/P	0.25/P
Working depth	2/P	1.6/P	2/P
Whole depth	2.25/P	1.8/P	2.25/P
Tooth thickness	1.571/P	1.571/P	1.571/P
Face width	9/P<b<13/P	9/P<b<13/P	9/P<b<13/P

Gear Trains



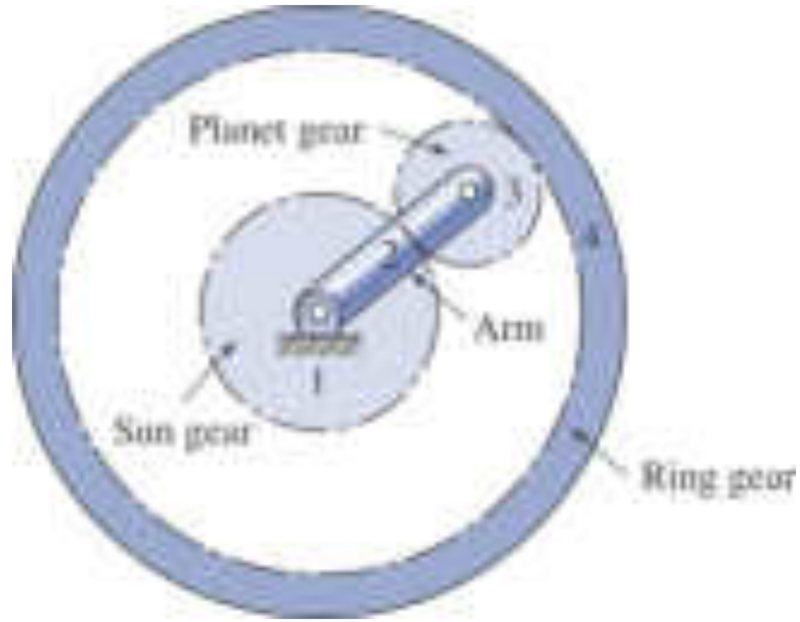
$$\frac{n_5}{n_1} = \left(-\frac{N_1}{N_2}\right)\left(-\frac{N_3}{N_4}\right)\left(-\frac{N_4}{N_5}\right)$$

Planetary Gear train
You can get high torque ratio in a smaller space



There are two inputs to the planetary gears, RPM of sun and Ring,
The out put is the speed of the arm.

Example of planetary Gear train



Gear 1, sun , RPM 1200, Number of teeth 20,

Planet Gear , Number of teeth 30

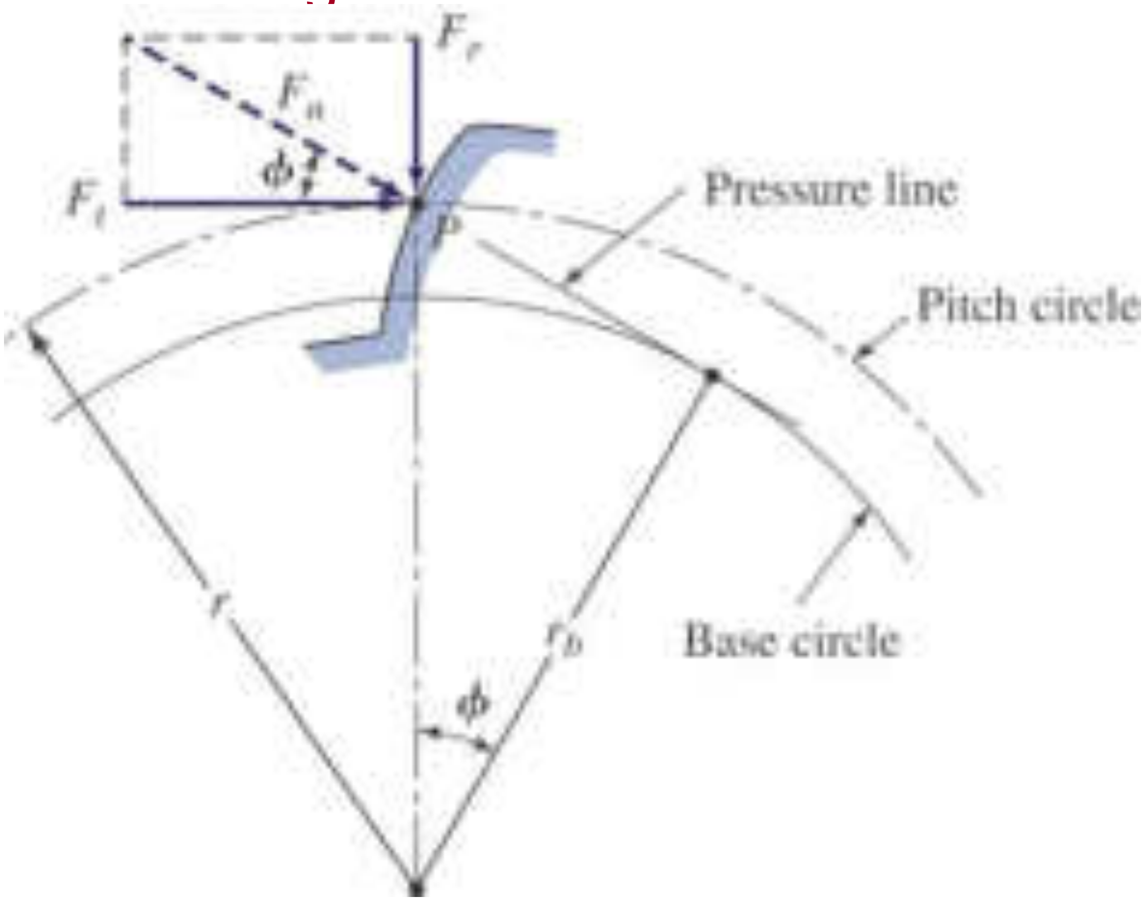
Ring Gear, Rotates RPM 120, and teeth of 80,

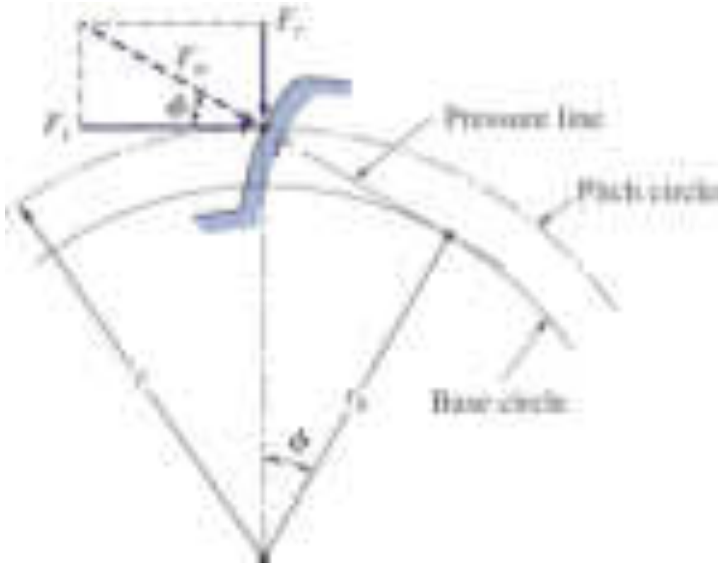
¼ horse power, find the speed of the arm and torque on the ring.

Alternatively you may have Certain Out put Torque requirements

Transmitted Load

- With a pair of gears or gear sets, Power is transmitted by the force developed between contacting Teeth





$$F_t = F_n \cos\phi$$

$$F_r = F_n \sin\phi$$

$$V = d/2\omega = d * \frac{2\pi RPM}{60}$$ d in, RPM rev./min, V in/sec

$$V = \frac{\pi d n}{12}$$ d in, n rpm, V fpm

$$hp = \frac{Tn}{63000}$$ Toque lb-in

$$F_t = \frac{33000hp}{V}$$ V fpm

$$KW = \frac{F_t V}{1000} = \frac{Tn}{9549}$$ T= N.m, V m/s, F Newton

These forces have to be corrected for dynamic effects , we discuss later, considering AGMA factors

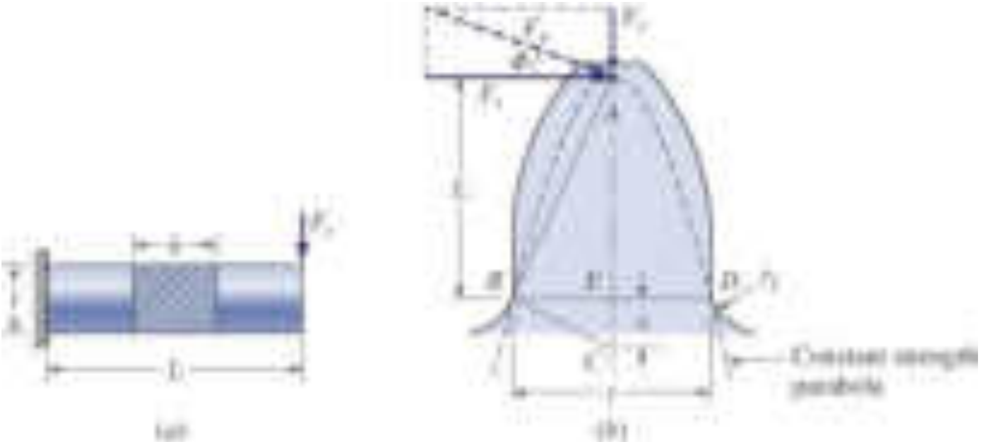
Some Useful Relations

- F=33000hp/V   V fpm   English system

- Metric System
- KW=(FV)/1000=Tn/9549
- F newton, V m/s, n rpm, T, N.m
- hp= FV/745.7=Tn/7121

Bending Strength of the a Gear Tooth

$$\sigma = \frac{Mc}{I} = \frac{(F_t L)t/2}{bt^3/12} = \frac{6F_t}{bt^2}$$



Earlier Stress Analysis of the Gear Tooth was based on

A full load is applied to the tip of a single tooth

The radial load is negligible

The load is uniform across the width

Neglect frictional forces

The stress concentration is negligible

This equation does not consider stress concentration, dynamic effects, etc.

Design for the Bending Strength of a Gear Tooth: The AGMA Method

$$\sigma = F_t K_0 K_v \frac{P}{b} \frac{K_s K_m}{J}$$ U.S. Customary

$$\sigma = F_t K_0 K_v \frac{1.0}{bm} \frac{K_s K_m}{J}$$ SI units

$\sigma =$ Bending stress at the root of the tooth

$F_t =$ Transmitted tangential load

$K_0 =$ Overload factor

$K_v =$ Velocity factor

$P =$ Diameteral pitch, P

$b =$ Face width

$m =$ Metric modue

$K_s =$ Size factor

$K_m =$ Mounting factor

$J =$ Geometry factor

Your stress should not exceed allowable stress

$$\sigma_{all} = \frac{S_t K_L}{K_T K_R}$$

$\sigma_{all} =$ Allowable bending stress

$S_t =$ Bending Strength

$K_L =$ Life factor

$K_T =$ Temperature factor

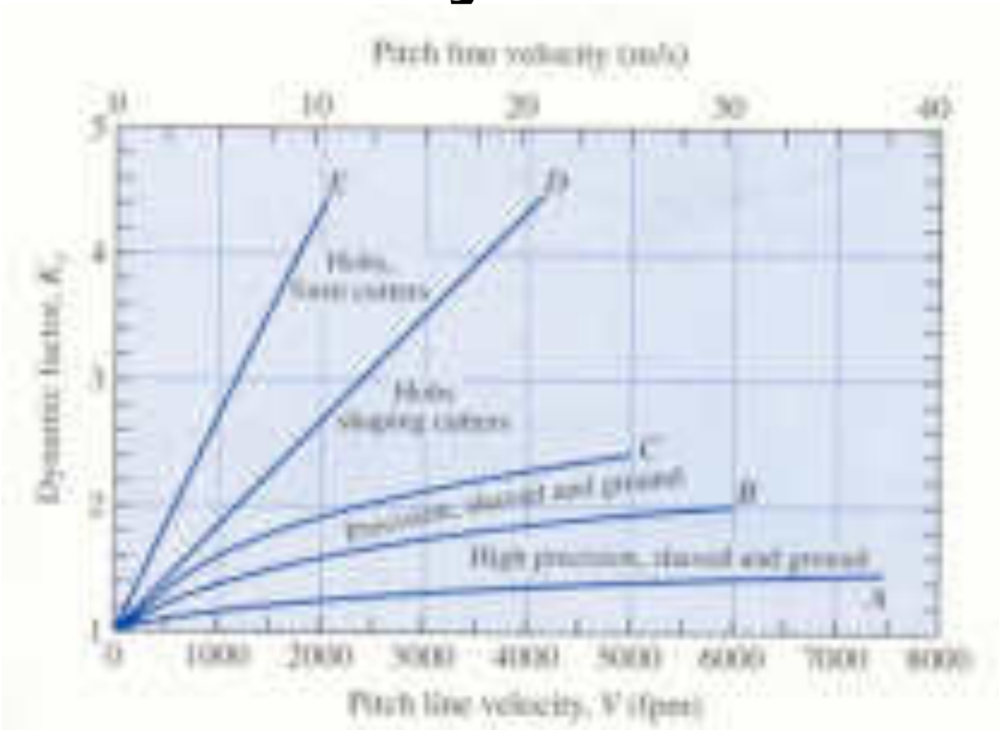
$K_R =$ Reliability factor

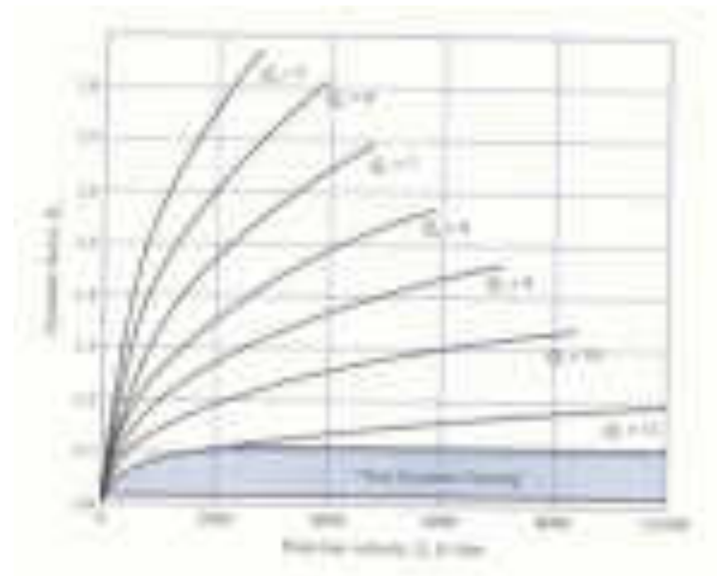
Overload Factor - K_o

Table 11.4 Overload correction factor K_o

	Load on driven machine		
Source of power	Uniform	Moderate shock	Heavy shock
Uniform	1.00	1.25	1.75
Light shock	1.25	1.50	2.00
Medium shock	1.50	1.75	2.25

Dynamic Factor - K_v





-Even with steady loads tooth impact can cause shock loading
-Impact strength depends on quality of the gear and the speed of gear teeth (pitch line velocity)
-Gears are classified with respect to manufacturing tolerances:
- -Q_v 3 – 7, commercial quality
- -Q_v 8 – 12, precision

-Graphs are available which chart K_v for different quality factors

Load Distribution Factor - K_m

Table 11.5 Mounting correction factor K_m

Condition of support	Face width (in.) 0 to 2	6	9	16 up
Accurate mounting, low bearing clearances, maximum deflection, precision gears	1.3	1.4	1.5	1.8
Less rigid mountings, less accurate gears, contact across the full face	1.6	1.7	1.8	2.2
Accuracy and mounting such that less than full-face contact exists	Over 2.2			

- -Failure greatly depends on how load is distributed across face
  - -Accurate mounting helps ensure even distribution
- -For larger face widths even distribution is difficult to attain
- -Note formula depends on face width which has to be estimated for initial iteration
  - -Form goal: $b < D_p$; $6 < b*P < 16$

Reliability Factor - K_R

Table 11.8 Reliability factor K_R

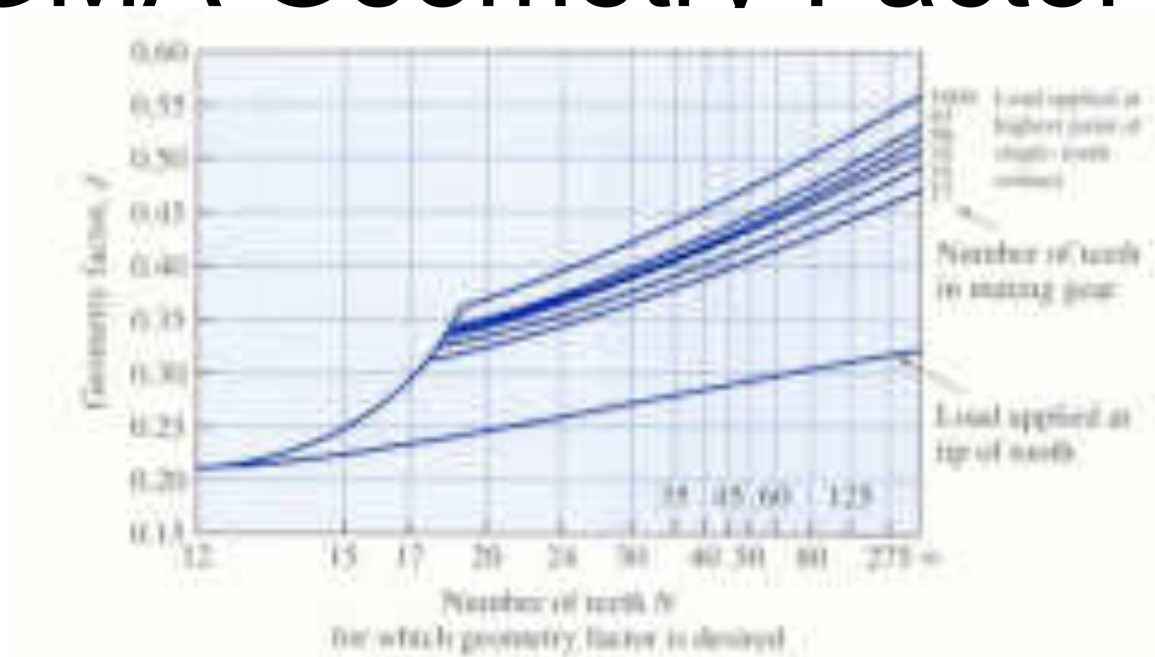
Reliability (%)	90	99	99.9	99.99
Factor K_R	0.85	1.00	1.25	1.50

1. SOURCE: The AGMA.

-Adjusts for reliability other than 99%

- $K_R = 0.658 - 0.0759 \ln(1-R)$ $0.5 < R < 0.99$
- $K_R = 0.50 - 0.109 \ln(1-R)$ $0.99 < R < 0.9999$

AGMA Geometry Factor - J



-Updated Lewis Form Factor includes effect of stress concentration at fillet
- -Different charts for different pressure angles

-Available for Precision Gears where we can assume load sharing (upper curves)
- -HPSTC – highest point of single tooth contact
- -Account for meshing gear and load sharing (contact ratio > 1)

-Single tooth contact conservative assumption (bottom curve)
- -J = 0.311 ln N + 0.15 (20 degree)
- -J = 0.367 ln N + 0.2016 (25 degree)

Bending Strength No. – S_t, Fatigue bending strength

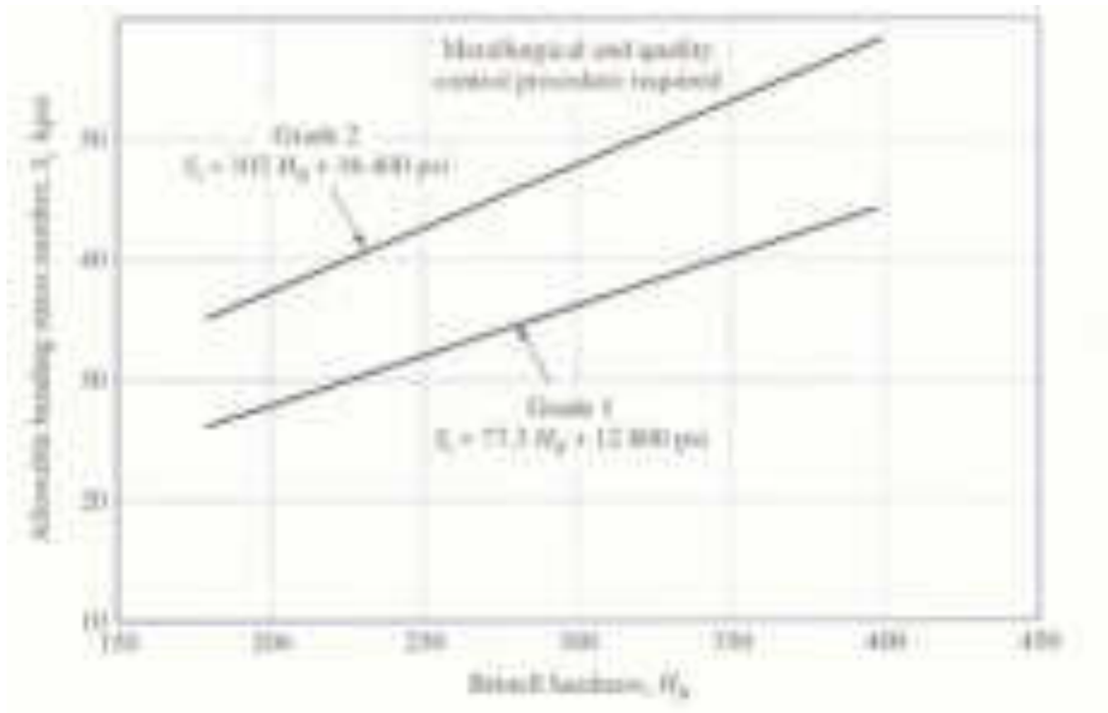
Table 11.4 Bending strength S_t of spur, helical, and bevel gear teeth

Material	Heat treatment	Minimum hardness or tensile strength	S_t ksi	S_t (MPa)
Steel	Normalized	140 Bhn	19–25	(131–172)
	Q&T	180 Bhn	25–33	(172–228)
	Q&T	300 Bhn	36–47	(248–324)
	Q&T	400 Bhn	42–56	(290–386)
	Case carburized	55 R_c	55–65	(379–448)
		60 R_c	55–70	(379–483)
	Nitrided AISI 4140	48 R_c case 300 Bhn core	34–45	(234–310)
Cast iron				
AGMA Grade 30		175 Bhn	8.5	(58.6)
AGMA Grade 40		200 Bhn	13	(89.6)
Nodular iron ASTM Grade				
60-40-18			15	(103)
80-55-06	Annealed		20	(138)
100-70-03	Normalized		26	(179)
120-90-02	Q&T		30	(207)
Bronze, AGMA 2C	Sand cast	40 ksi (276 MPa)	5.7	(39.3)

SOURCE: AGMA 218.01.
Q&T = Quenched and tempered.

- Tabulated Data similar to fatigue strength
- Range given because value depends on Grade
- Based on life of 10^7 cycles and 99% reliability

S_t – Analytical Estimate



-Through hardened steel gears

-Different charts for different manufacturing methods

-Grade 1 – good quality

$St = 77.3\ H_B + 12{,}800$

-Grade 2 – premium quality

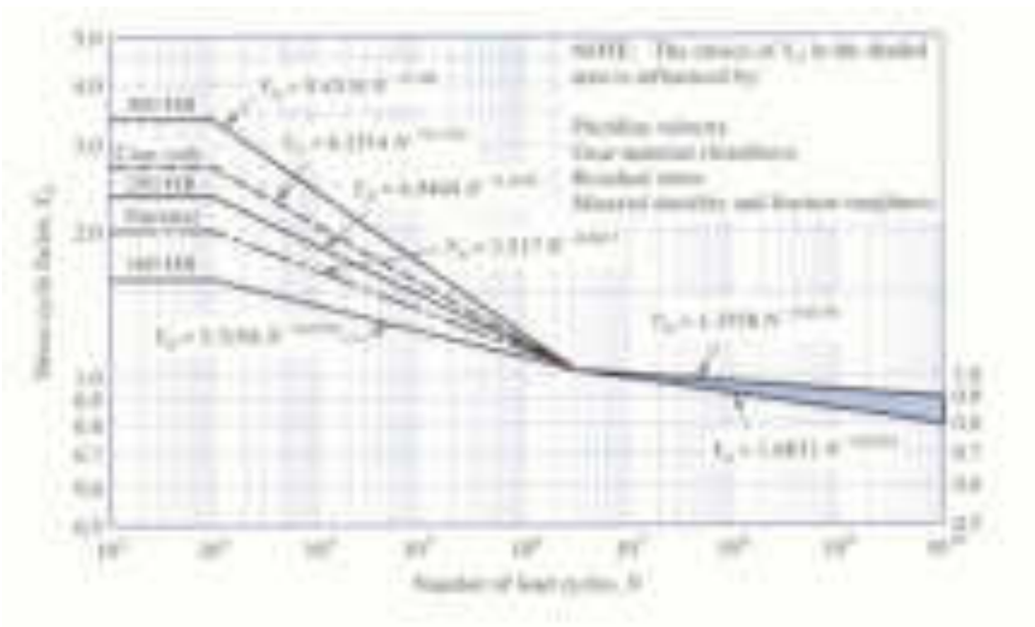
$St = 102\ H_B + 16{,}400$

Bending Strength Life Factor- K_L

Table 11.2 Life factor K_L for spur and helical steel gears

Number of cycles	160 Bhn	250 Bhn	450 Bhn	Case carburized (55-63 R_C)
10^3	1.6	2.4	3.4	2.7–4.0
10^4	1.4	1.9	2.4	2.0–3.1
10^5	1.2	1.4	1.7	1.5–2.1
10^6	1.1	1.1	1.2	1.1–1.4
10^7	1.0	1.0	1.0	1.0

SOURCE: AGMA 218.01



-Adjusts for life goals other than 10^7 cycles

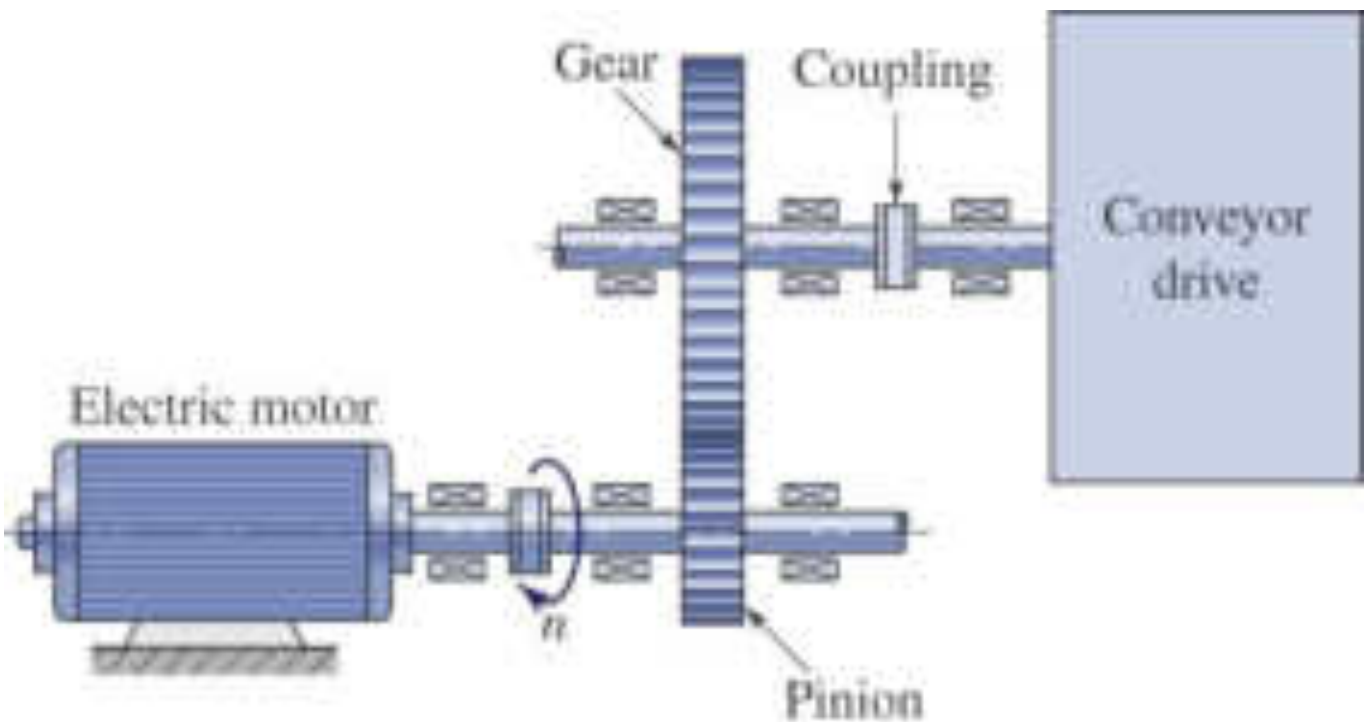
-Fatigue effects vary with material properties and surface finishes

-$K_L = 1.6831\ N^{-0.0323}$ N>3E6

Note: @ 2000 rpm reach 3 million cycles in 1 day of service

Example:

A conveyor drive involving heavy-shock torsional loading is operated by an electric motor, the speed ratio is 1:2 and the pinion has Diameteral pitch P=10 in^{-1}, and number of teeth N=18 and face width of b=1.5 in. The gear has Brinnel hardness of 300 Bhn. Find the maximum horspower that can be transmitted, using AGMA formula.



Gear Box Design