Mechanical System (4)

CEG3H3

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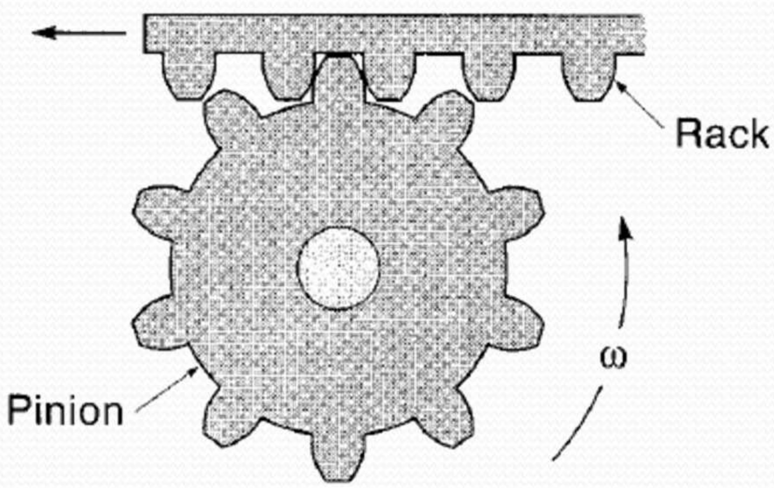
Objectives

- Understand the use of the various gear types and their terminology and perform gear train calculations
- Know the characteristics of belts and roller chains used for power transfer

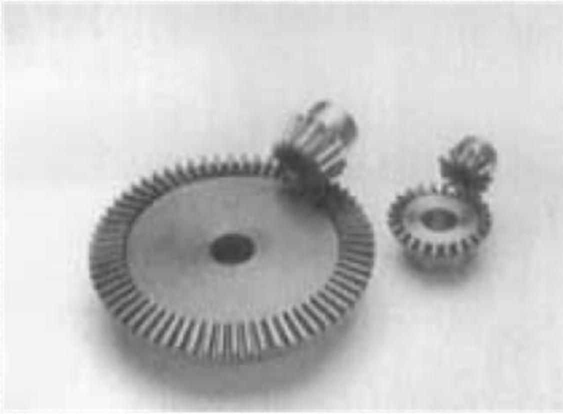
Gears

- Allow us to change the rotational velocity and the torque to suit the motor and load conditions
- Can be used to simply transport power from one shaft to a parallel shaft

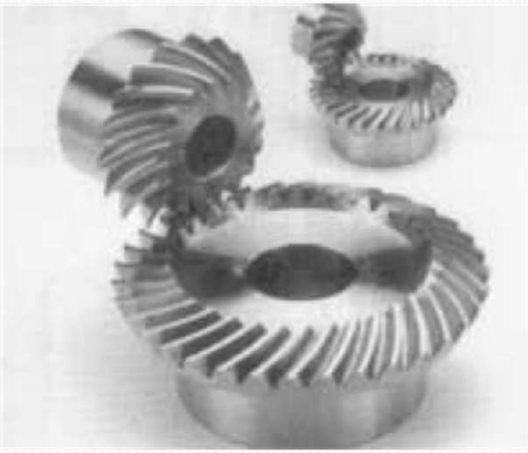


(a) Rack and pinion

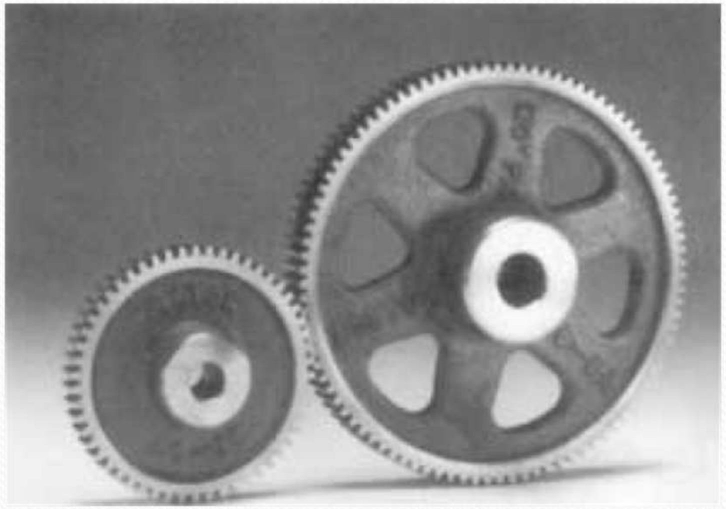
Gears



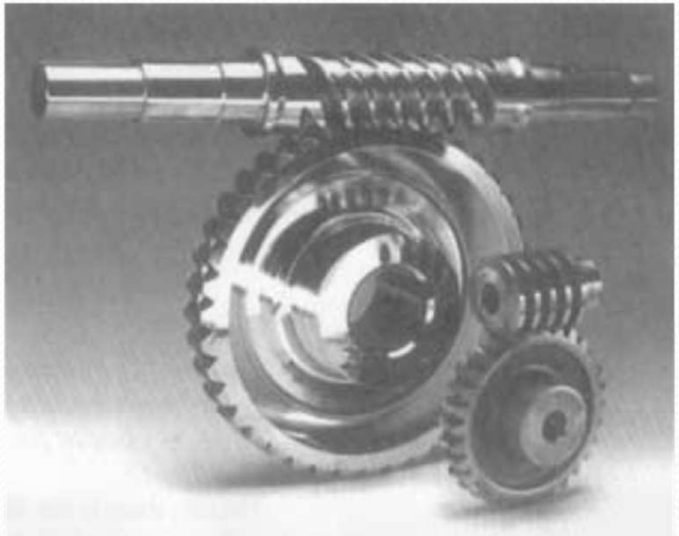
(b) Straight bevel gears



(e) Spiral bevel gears



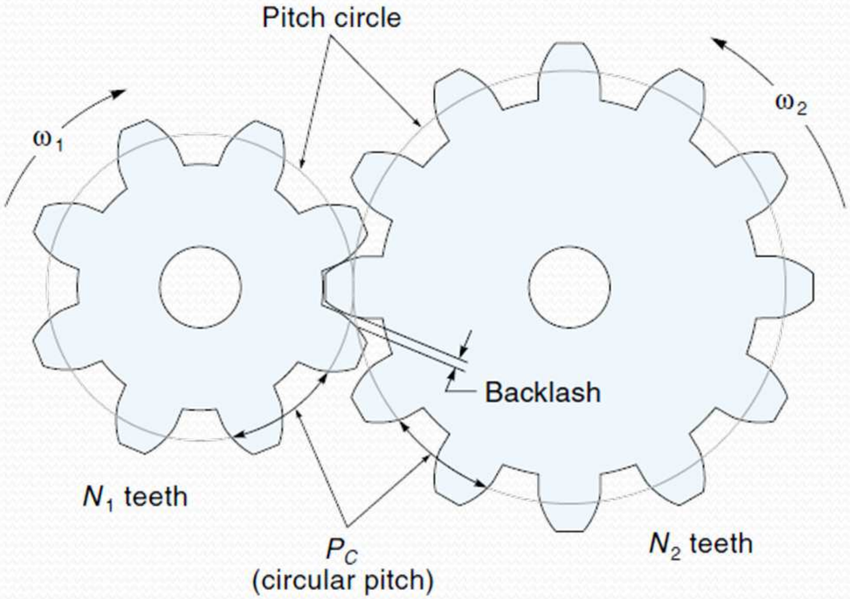
(c) Spur gears



(d) Worm and worm gears

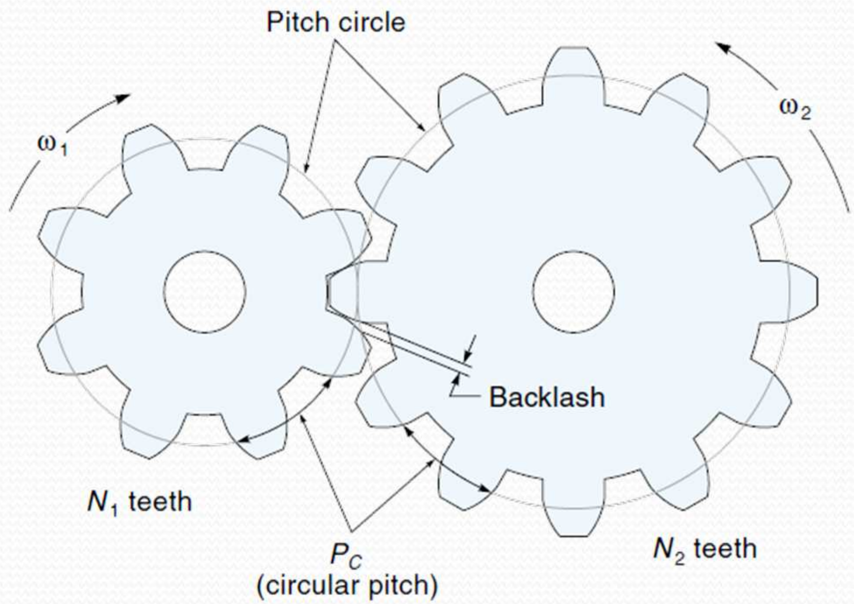
Spur Gears

- There is very little friction in a **gear pass**, which is one set of mating gears
- The size of each wheel is a theoretical circle called the **pitch circle**



Spur Gears

- The diameter of this pitch circle is called the **pitch diameter**
- The distance along the pitch circle of one tooth (and "valley") is called the **circular pitch**



Spur Gears

- The number of teeth on a gear can be calculated:

$$N = \frac{\text{circumference}}{\text{distance between teeth}} = \frac{\pi D}{P_C}$$

where

N = total number of teeth

D = pitch diameter

P_C = circular pitch

Spur Gears

- D**iametral pitch**, or simply *pitch*, is the ratio of the number of teeth per inch of pitch diameter:

$$\text{Diametrical pitch} = \text{pitch} = \frac{N}{D}$$

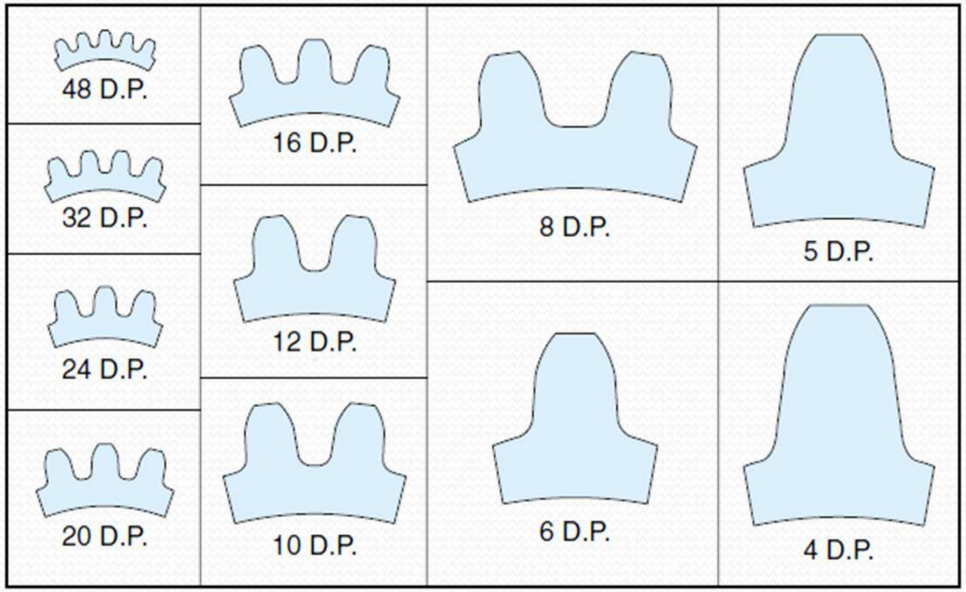
where

N = total number of teeth

D = pitch diameter (in inches)

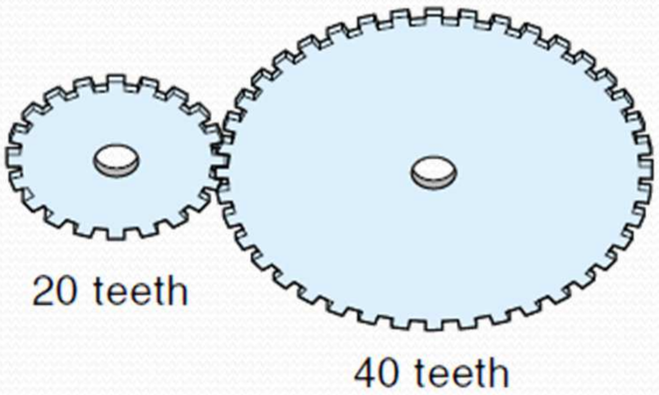
Spur Gears

- Diametral pitch is the parameter used to specify the tooth size in a gear
- A larger tooth has a smaller pitch.



Using Gears to Change Speed

- The **gear ratio** is a ratio of the number of teeth of two gears
- This two gears have 40 and 20 teeth respectively, so the gear ratio is 40/20 = 2



Using Gears to Change Speed

- The gear ratio can be calculated:

$$N_g = \frac{N_2}{N_1} = \frac{\mathrm{Cir}_2}{\mathrm{Cir}_1} = \frac{\pi D_2}{\pi D_1} = \frac{D_2}{D_1}$$

where

N_g = gear ratio between gears 1 and 2

N = number of teeth

Cir = circumference of the gear

D = diameter of the gear

Using Gears to Change Speed

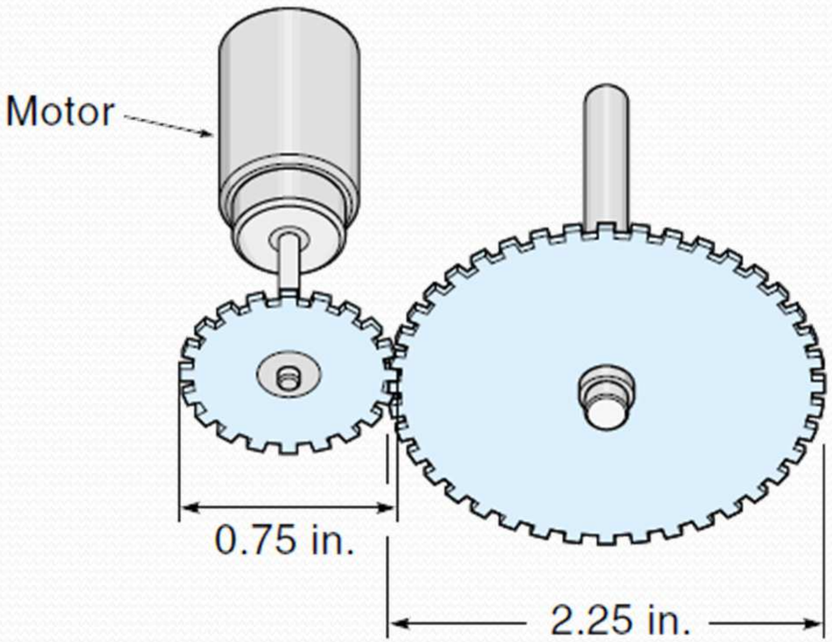
- The gear ratio can be calculated:

$$N_g = \frac{N_2}{N_1} = \frac{\mathrm{Cir}_2}{\mathrm{Cir}_1} = \frac{\pi D_2}{\pi D_1} = \frac{D_2}{D_1}$$

The assumption is that gear 1 is supplying the power (called the driver gear), and gear 2 is receiving the power (called the driven gear).

Example

- What is the gear ratio of the gear mesh?



Example

Solution

The driver gear has a diameter of 0,75 inch and the driven gear has a diameter of 2,25 inch. Find the ratio by dividing the diameters:

$$N_g = \frac{\text{Dia}_2}{\text{Dia}_1} = \frac{2{,}25\,\text{inch}}{0{,}75\,\text{inch}} = 3$$

Using Gears to Change Speed

- Looking at the 3 : 1 gear mesh before, the small gear (pinion) makes three revolutions in the same time it takes the big gear to make one revolution (the small gear must rotate three times faster than the big gear)
- This leads us to conclude that the ratio of position, velocity, and acceleration are inversely proportional to the gear ratio N_g

Using Gears to Change Speed

- The gear ratio can be calculated:

$$N_g = \frac{N_2}{N_1} = \frac{\theta_2}{\theta_1} = \frac{\omega_2}{\omega_1} = \frac{\alpha_2}{\alpha_1}$$

where

N_g = gear ratio

N = number of teeth

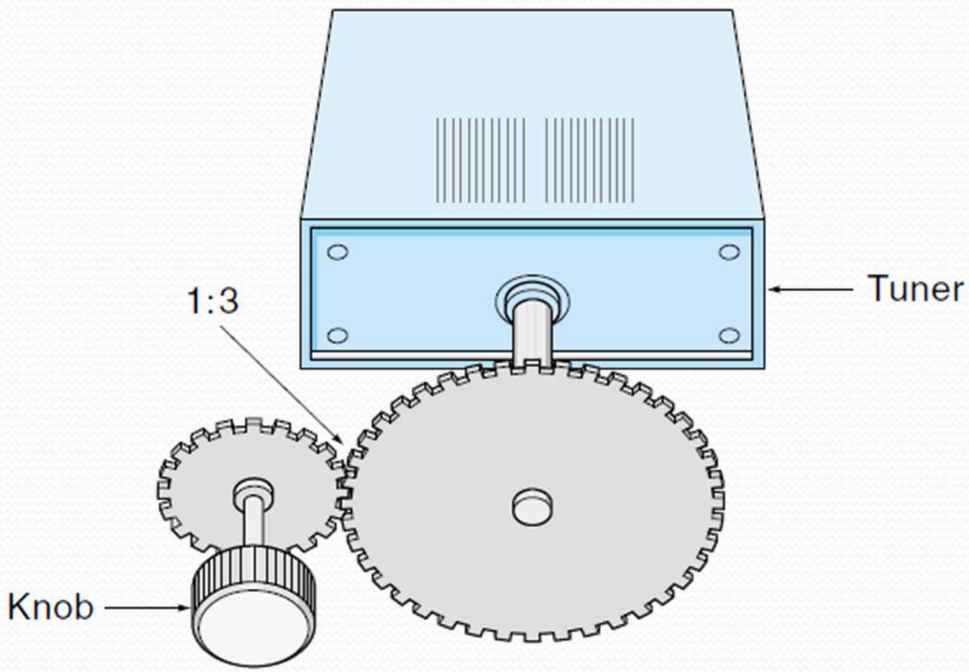
θ = gear position (angle in degrees)

ω = angular velocity of the gear

α = angular acceleration

Example

- A radio tuner is connected to the tuning knob through a 3 : 1 gear mesh. If the knob is turned 70°, how many degrees does the tuner rotate?



Example

Solution

The gear attached to the tuner is the bigger, therefore it must turn less than 70°. We can calculate for the angle of the tuner gear, θ_2:

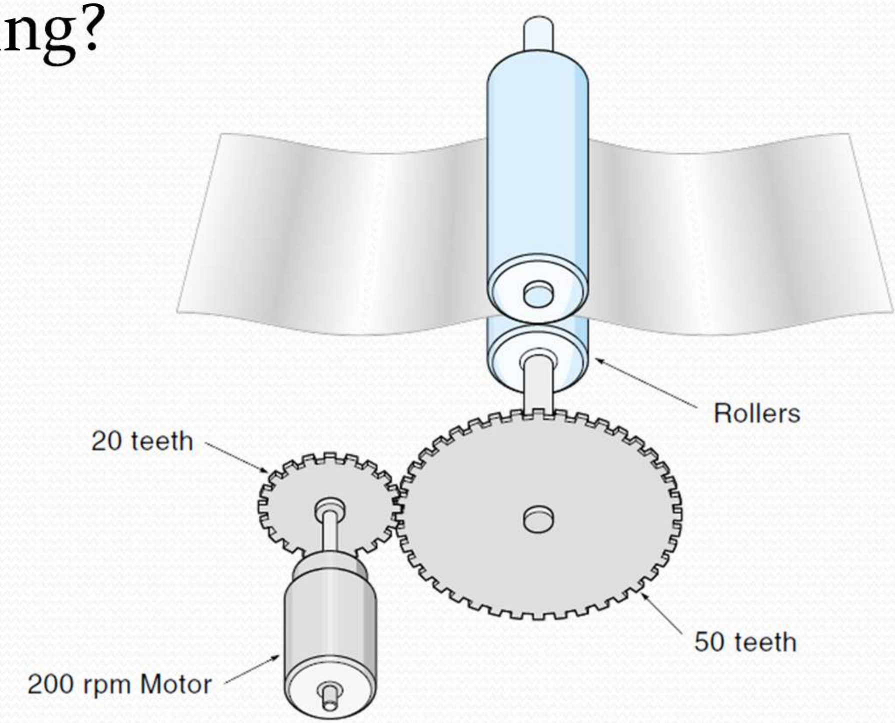
$$N_g = \frac{3}{1} = \frac{70°}{\theta_2}$$

$$\theta_2 = \frac{70°}{3} = 23{,}33°$$

The tuner will rotate 23.33° when the knob rotates 70°

Example

- A small motor running at 200 rpm drives a paper roller in a machine. The gear on the motor has 20 teeth, and the gear on the roller has 50 teeth. How fast is the roller turning?



Example

Solution

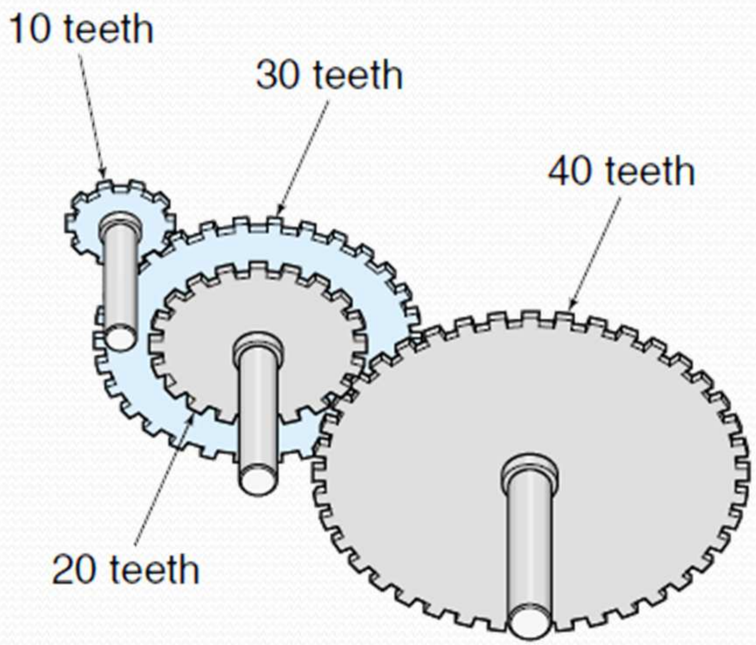
First, note that the roller gear is larger than the motor gear, so it will be turning slower than the motor. To calculate the speed:

$$\frac{50\text{ teeth}}{20\text{ teeth}} = \frac{200\text{ rpm}}{\omega_2}$$

$$\omega_2 = \frac{200\text{ rpm} \times 20\text{ teeth}}{50\text{ teeth}} = 80\text{ rpm}$$

Gear Train

- A **gear train** consists of more than a single gear pass
- In figure, notice that the middle gear is actually two gears fastened together



Gear Train

- The gear ratio of the total system is the product of the individual gear ratios:

$$N_g = N_{g1} N_{g2} N_{g3} \ldots$$

where

N_g = overall gear ratio

N_{g1} = gear ratio of first pass

N_{g2} = gear ratio of second pass, and so on

Using Gears to Transfer Power

- For precision-made spur gears, the assumption is that power is conserved across the gear pass
- Except for a small loss through friction, the gear pass can neither create nor destroy power:

Power in, gear 1 = Power out, gear 2

Using Gears to Transfer Power

- Therefore, because power = torque × angular velocity, we rewrite the equation as follows:

$$T_1\omega_1 = T_2\omega_2$$

where

T = torque (such as ft · lb or Nm)

ω = angular velocity (such as deg/s)

Using Gears to Transfer Power

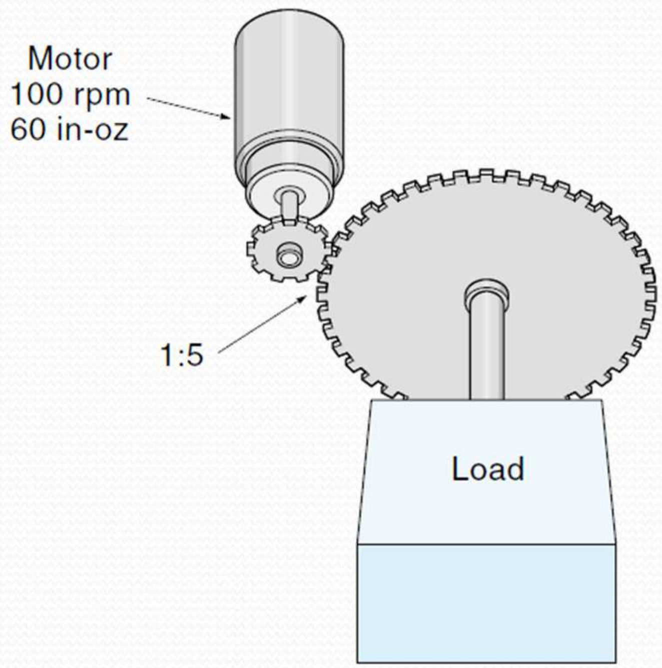
- Rearranging the equation, we get:

$$\frac{T_2}{T_1} = \frac{\omega_1}{\omega_2} = N_g$$

This means that the faster turning gear has less torque, and the gear that is turning slower has more torque

Example

- An electric motor supplies 60 inch · oz of torque while running at 100 rpm and it is driving a load through 1 : 5 gear ratio. Find the output torque and velocity?



Example

Solution

Solving first for torque on the driven (or load) gear, we have $T_2/T_1 = N_g$, so

$$T_2 = T_1 N_g = 60 \text{ inch} \cdot \text{oz} \times 5 = 300 \text{ inch} \cdot \text{oz}$$

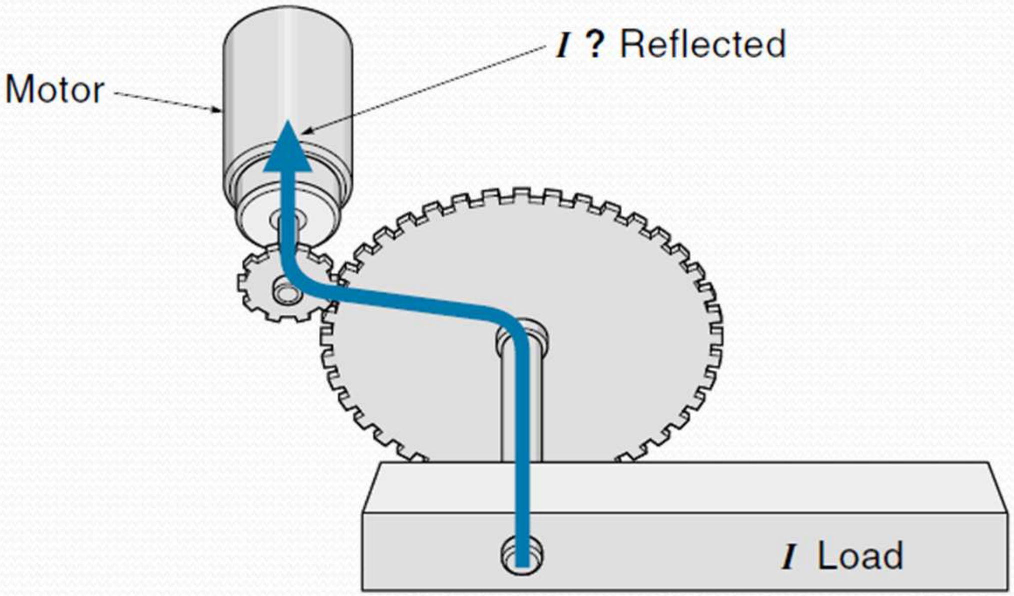
Solving for the velocity of the load gear we have

$\omega_1/\omega_2 = N_g$, so

$$\omega_2 = \frac{\omega_1}{N_g} = \frac{100 \text{ rpm}}{5} = 20 \text{ rpm}$$

Reflected Moment of Inertia

- Recall that every load rotating on an axis has a moment of inertia (I)
- What moment of inertia does the motor "see" if the load is driven through a set of gears?



Reflected Moment of Inertia

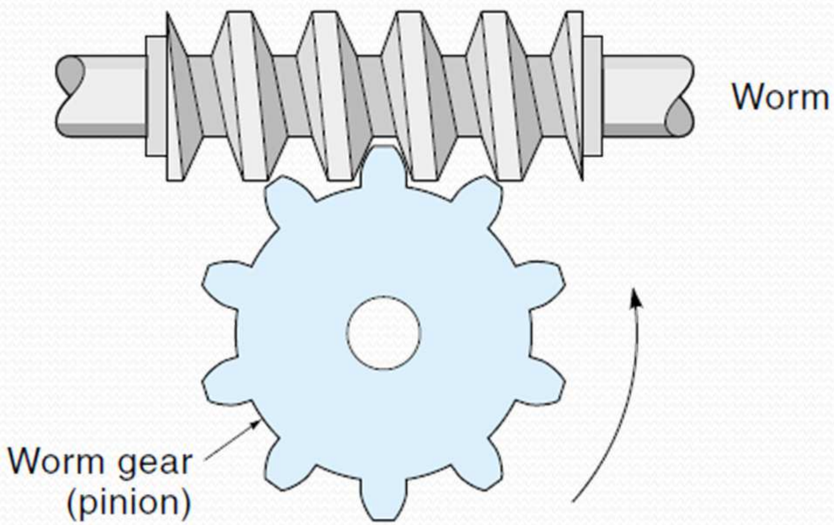
- The reflected moment of inertia is inversely proportional to the gear ratio squared:

$$I \text{ reflected} = \frac{I_{\text{load}}}{N_g^{\ 2}}$$

This means that in most cases the motor "sees" a much lower inertia than the load actually has

Worm Gears

- Worm gears yield very high gear ratios on a single pass, but they can be highly inefficient
- Each worm revolution, the pinion advances one tooth (a pinion with 50 teeth would yield a gear ratio of 50)

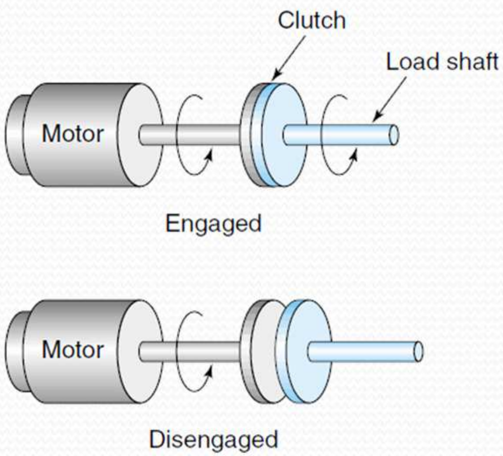


Worm Gears

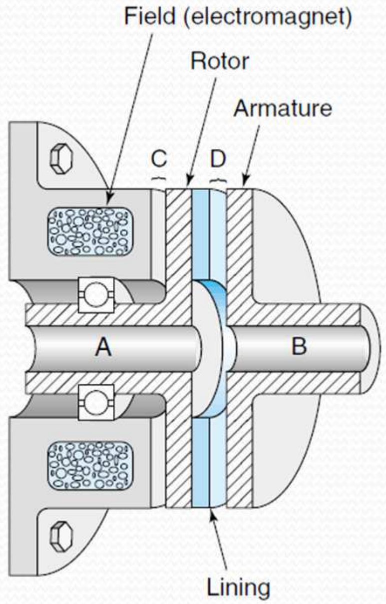
- As the worm rotates and sliding across the pinion's teeth, the friction from this sliding is the cause of the inefficiency, which is typically in the 50-80% range
- An advantage of worm gearing is the **lockup property**
- Lockup occurs in higher-ratio worm gears, it means that power flows only one way from the worm to the pinion (example: tighten guitar string)

Clutches

- Clutch is used to connect or disconnect one rotating shaft from another "on the fly"
- One side of the clutch is connected to the motor and the other side to the load



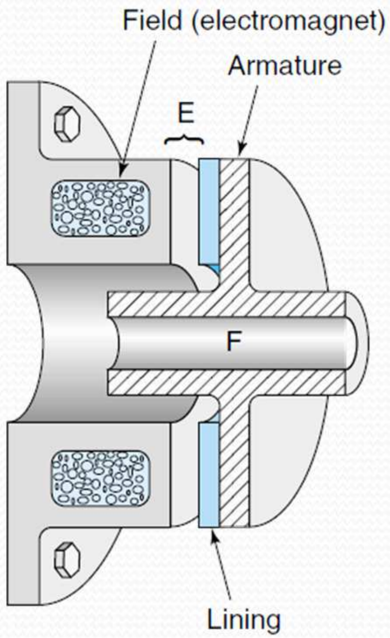
(a) Clutch action



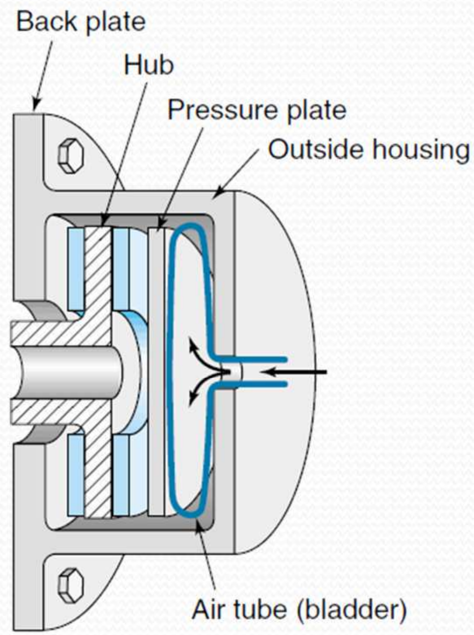
(b) Cut away diagram of an electromagnetic clutch

Brakes

- Brake is used to slow down or stop a rotating shaft
- To prevent a shaft from turning when the power has been turned off



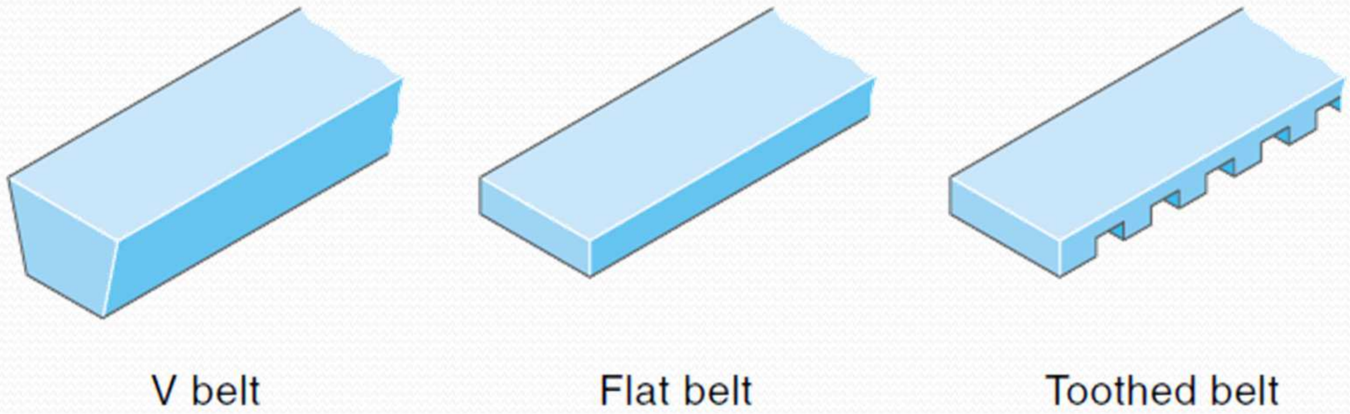
(a) Cut-away diagram of electromagnetic brake



(b) Cut-away diagram of pneumatic brake

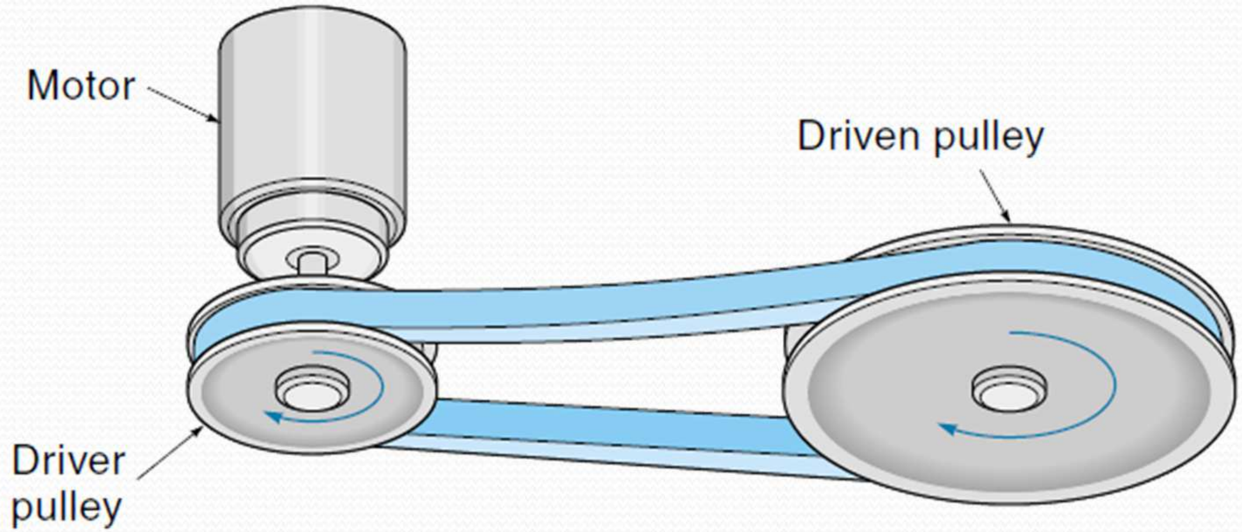
Belts

- Belts are a good means of transmitting power, usually made of rubber and very flexible
- Advantages of belts include low cost, quiet running, low maintenance (no lubrication), shock absorbtion, tolerance of nonparallel shafts, and they allow for "gearing" by having one pulley larger than the other



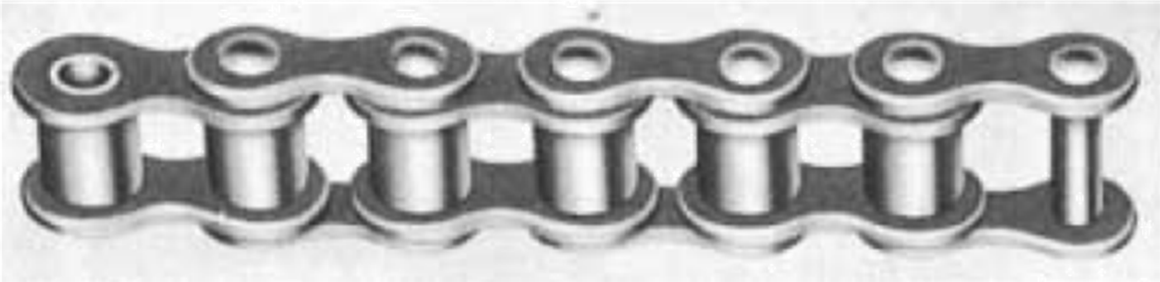
Belts

- Standard belt setup includes a driver pulley and a driven pulley
- Not like meshed gears that rotate in opposite directions, both pulleys in a belt system rotate in the <u>same direction</u>



Roller Chain

- Consists of a series of links connected by pins, with a roller around each pin (used on bicycles)
- The rollers engage teeth on the sprocket, so unlike belts, there is no slippage
- "Gear ratio" is a function of the number of teeth on each sprocket



Objectives Completed

- ✓ Understand the use of the various gear types and their terminology and perform gear train calculations
- ✓ Know the characteristics of belts and roller chains used for power transfer