Mechanical Actuators

Mechanical systems

Although now electronic systems are being used for many functions that previously were fulfilled by mechanism; mechanisms are still being used to provide the following functions:

1. **Force amplification e.g. levers**
2. **Change of speed e.g. gears**
3. **Transfer of rotation about one axis to rotation about another axis e.g. belt**
4. **Particular types of motion e.g. that given by a quick return mechanism**

This section introduce kinematics analysis of the mechanism i.e. consideration of motion without regard to forces

Types of Motion: Freedom & Constraints

The motion of any rigid body can be considered to be a combination of translation and rotational motions

Translation motion is a movement which can be resolved into components along one or more of the three axis x,y or z
A rotational motion is one which has components rotating about one or more of the axis

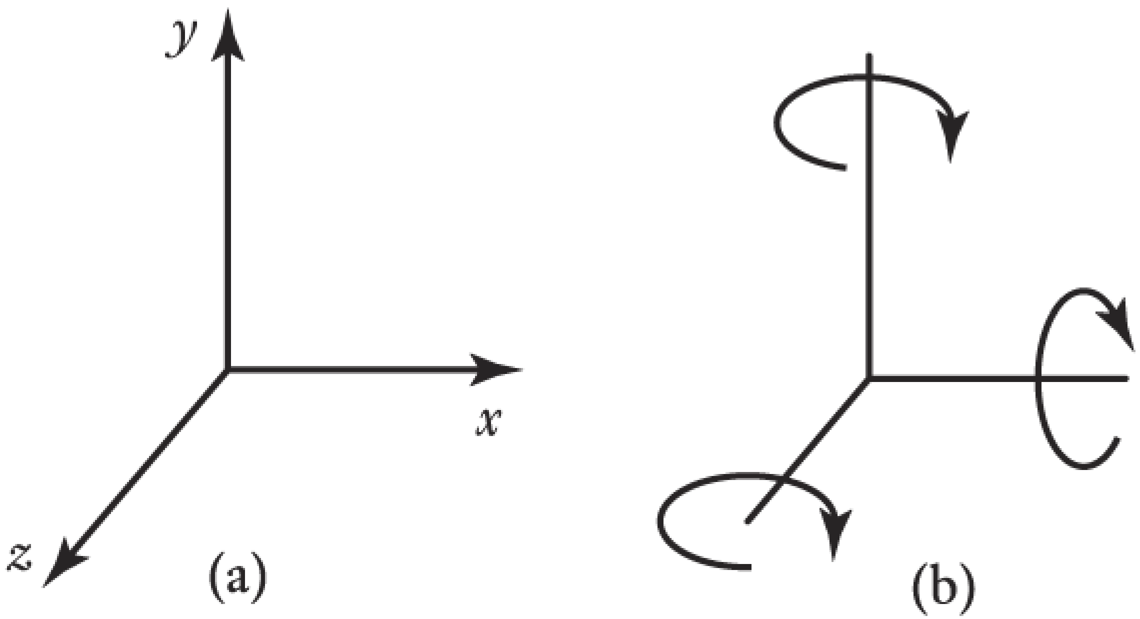


Figure 8.1 Types of motion: (a) translational, (b) rotational

Types of Motion:

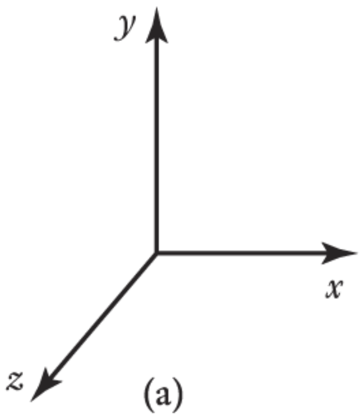
- A complex motion is the combination of the translation and rotation motions
- Example of complex motion:
- Instruct a robot to pickup a pencil from a table:

  you should breakup motion into small simple motion, e.g. instruct joint 1 to rotate by 20 degree then link 2 to be extended by 4 mm….etc

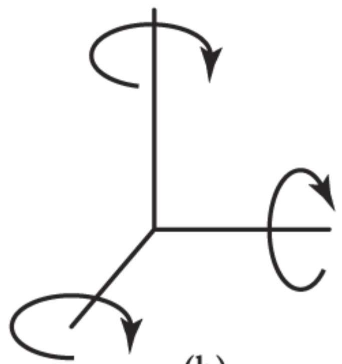
Freedom and constraints

A body that is free in space can move in three independent, mutually perpendicular directions and rotate in three ways about those directions. It is said to have **six degree of freedom**

- The number of degrees of freedom are the number of components of motion that are required in order to generate the motion



(a)


(b)

Freedom and constraints

If a joint is constrained to move along a line then it has one degree of freedom

If a joint is constraint to move on a plane then it has two degree of freedom

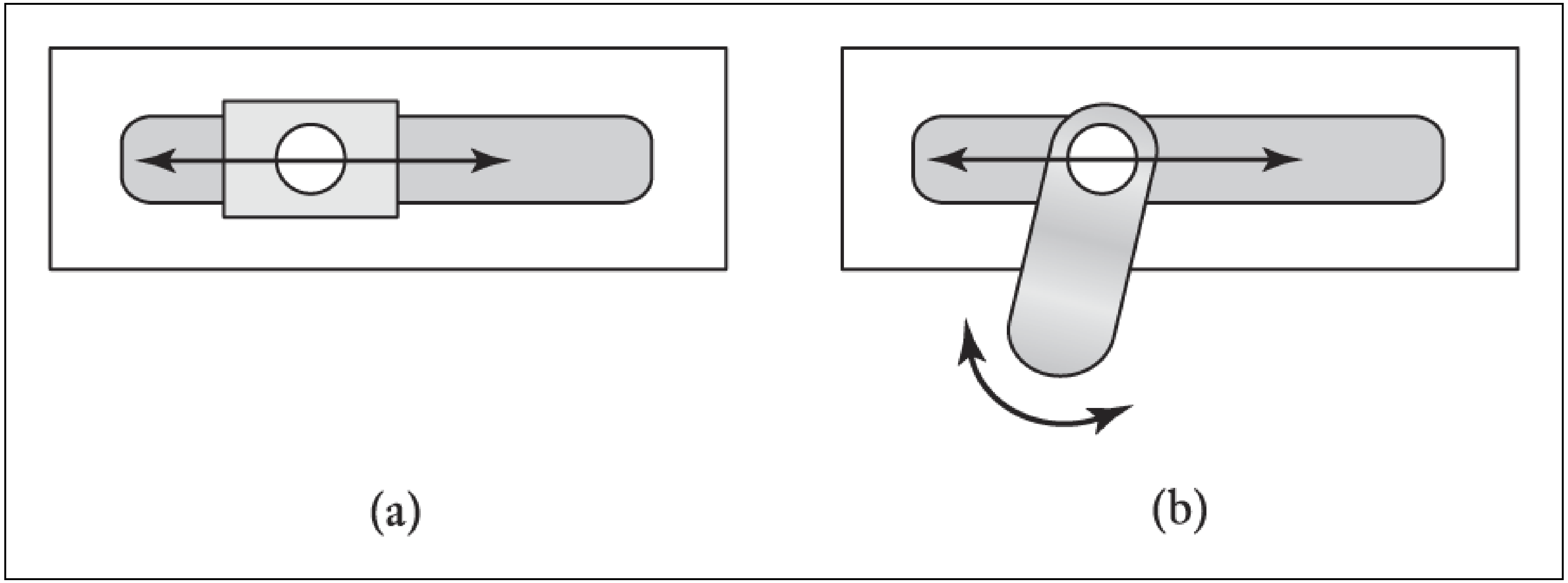


Figure 8.2 Joints with: (a) one degree, (b) two degrees of freedom

Freedom and constraints

- The problem in a design is to reduce the number of degrees of freedom which requires an appropriate number and orientation of constraint
- Fixed body implies zero degree of freedom implies 6 constraints
- Concept in design: In fixing a body or guiding it to a particular type of motion, the minimum number of constraints should be used "kinematics design"

Kinematics chains

Definitions:

Each part of a mechanism which has motion relative to some other part is termed a link

A link should be capable of transmitting the required force with negligible deformation

Fig 8.4 shows examples of links with two or more **nodes** “points of attachment to other links”

A joint is a connection between two or more links at their nodes and which allows some motion between the connected links

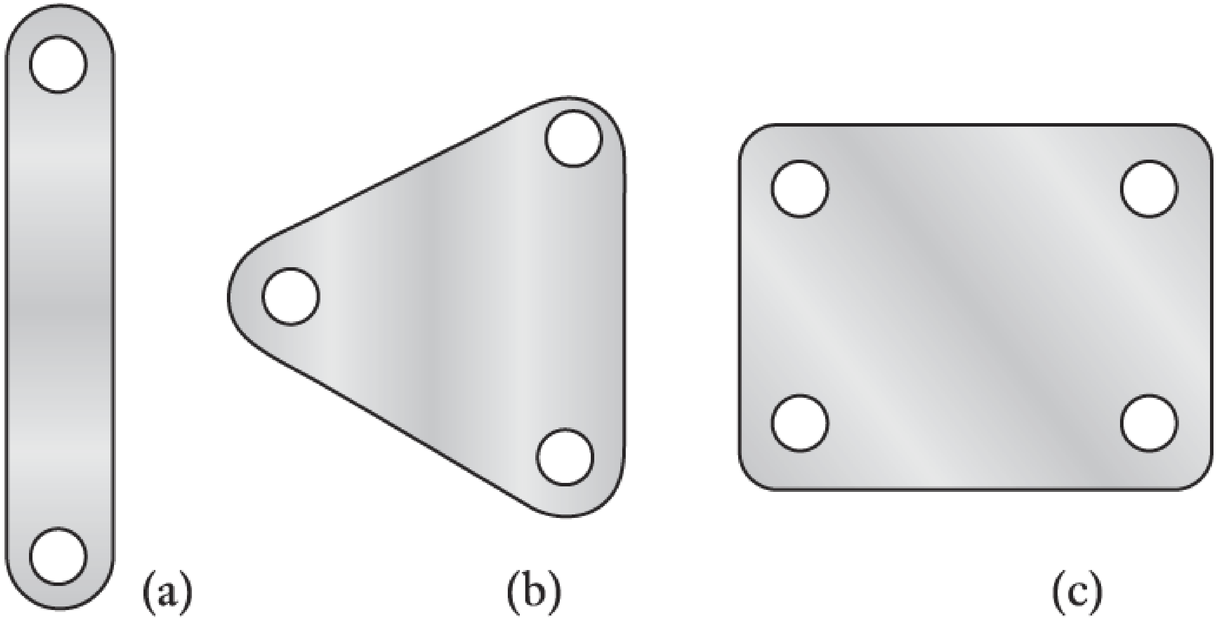


Figure 8.4 Links: (a) with two nodes, (b) with three nodes, (c) with four nodes

Kinematics chains

Examples of links: levers, cranks, connecting rods & pistons sliders, pulleys, belts and shafts

A sequence of joints and links is known as kinematics chain Fig8.5a

Consider motor car engine where the reciprocating motion of a piston is transformed into rotational motion of a crankshaft on bearings mounted in a fixed frame.:

Link 1 crankshaft, Link 2 the connecting rod, Link 3 the fixed frame, Link4 the slider i.e. the piston which move relative to the fixed frame

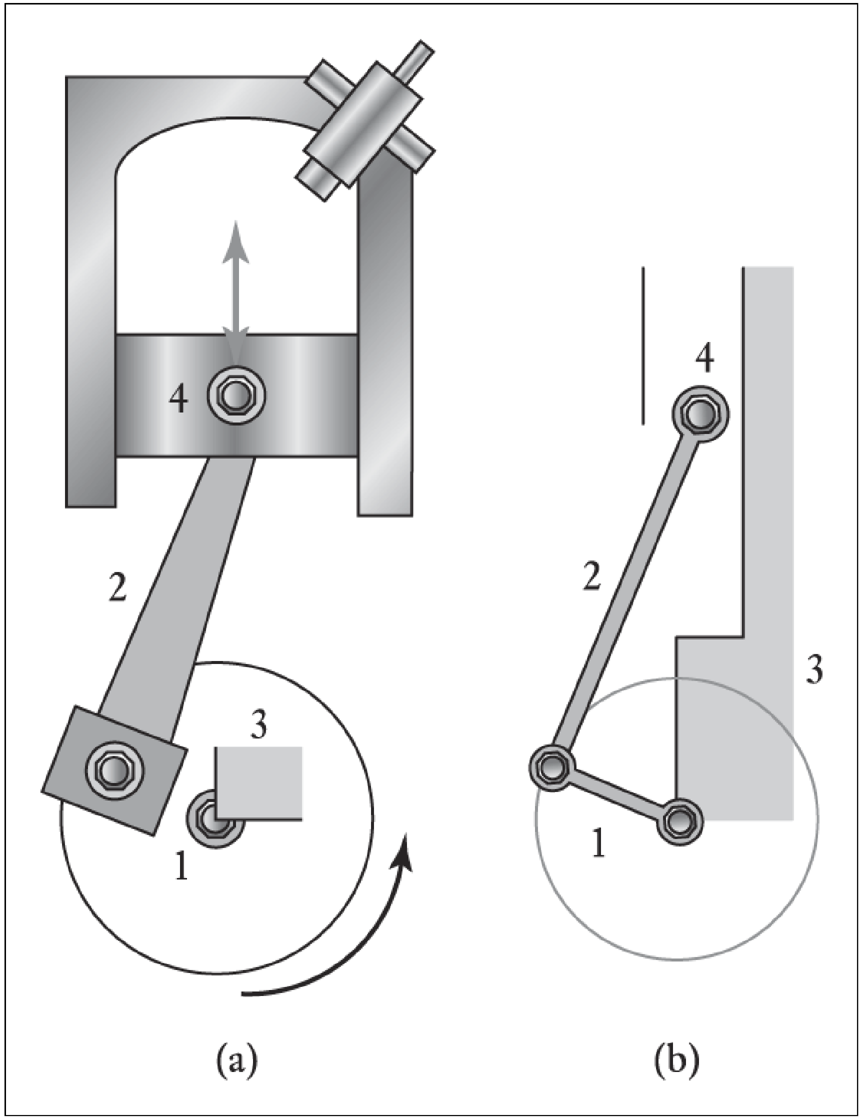
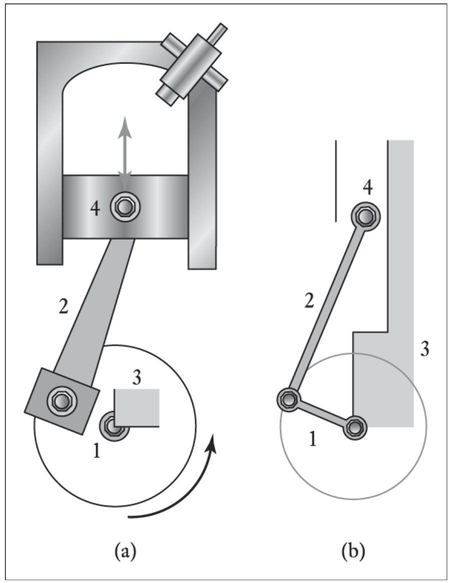


Figure 8.5 Simple engine mechanism

Kinematics chains

- The design of many mechanisms are based on two basic forms of kinematic chains:
- the four bar chain and
- the slider –crank chain

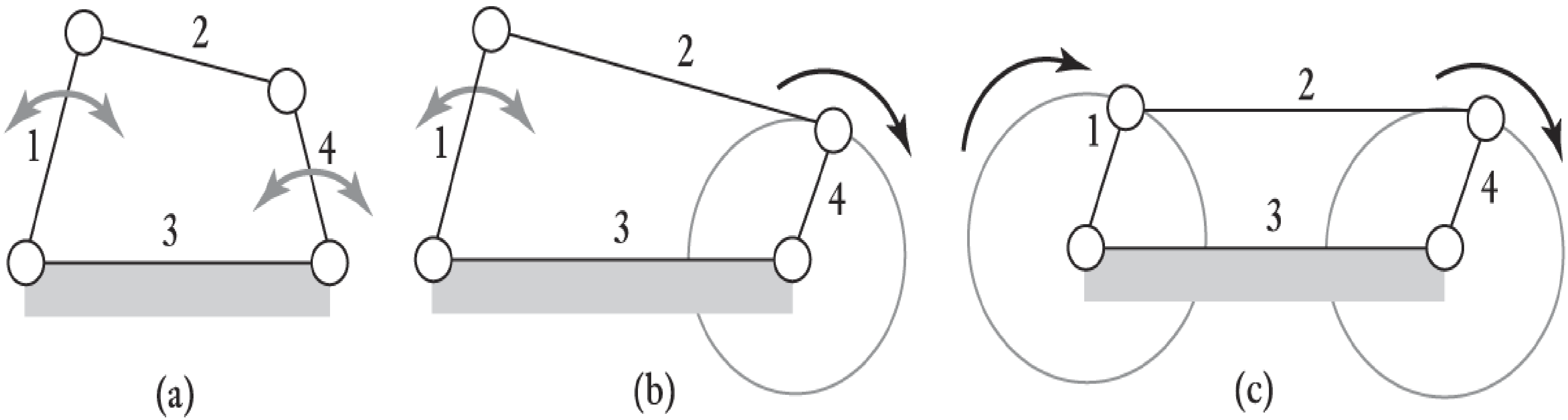


Kinematics chains: The four bar chain

It consists of four links connected to give four joints about which turning can occur. The No of forms of the four – bar chain is produced by altering the relative lengths of the links.

Grashof condition:

If (length of shortest + longest) is less than or equal to the sum of the two other links, then at least one link will be capable of making a full revolution w.r.t the fixed link



Double lever mechanism **lever crank mechanism** **double crank mechanism**

Figure 8.6 Examples of four-bar chains

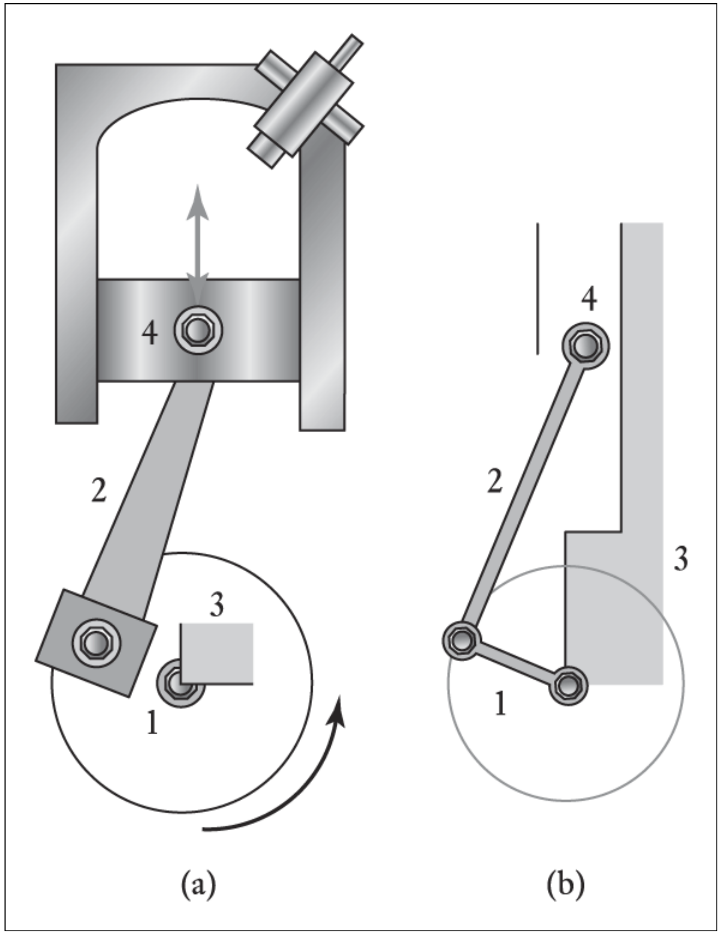
Kinematics chains:

Slider–crank mechanism

It consists of crank, connecting rod and a slider which show simple engine mechanism.

Link 3: is fixed i.e no relative movement between the centre of rotation of the crank and the housing in which the piston slides

- Link1: the crank that rotates
- Link2: connecting rod
- Link4: the slider which moves relative to the fixed link. So when the piston moves backwards and forwards, the crank (link1) is forced to rotate, hence the mechanism transforms an input of backwards and forwards motion into rotational motion.



CAMS

A cam is a body which rotates or oscillate and in doing so, imparts a reciprocating or oscillatory motion to a second body called the follower , with which it is in contact

As the cam rotates so the follower is made to rise, dwell and fall; the length of times spent at each of these positions depends on the shape of the cam

The rise section: is the one that drives the follower upwards,

The fall section: is the one that lowers the follower . **The dwell section** is the one that allows the follower to remain at the same level for a significant period of time. It is circular with a radius that does not change

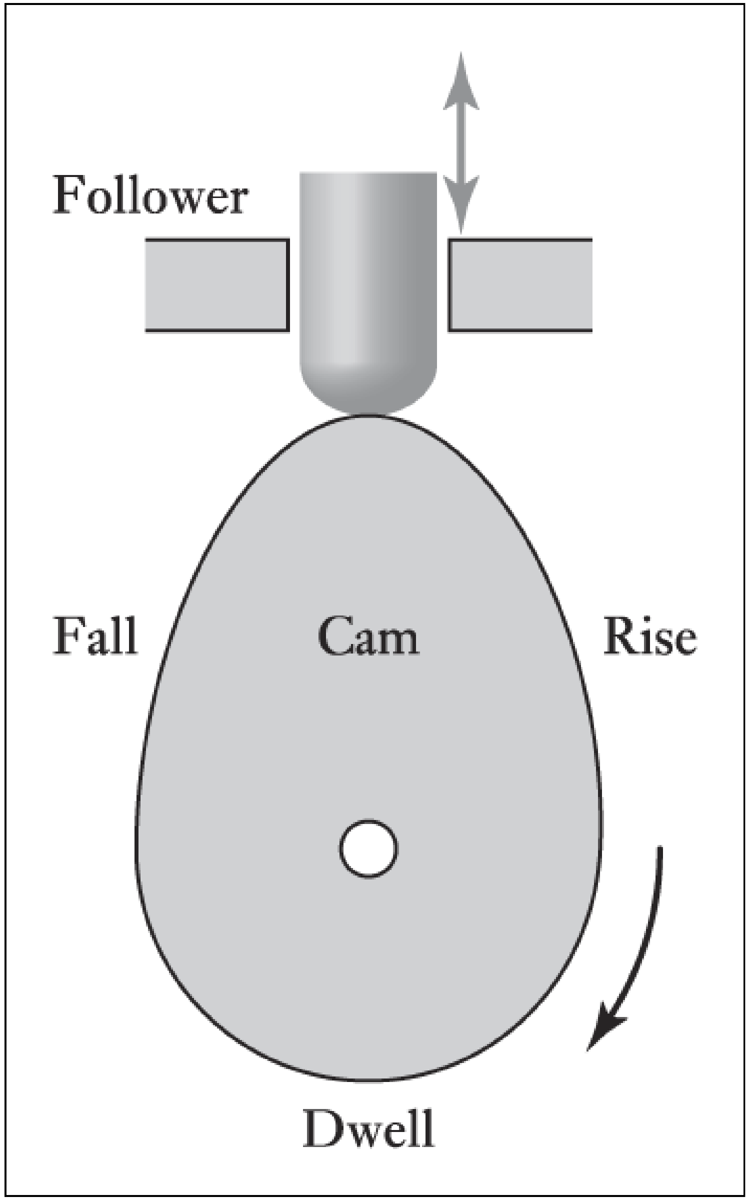


Figure 8.10 Cam and cam follower

CAMS

Fig.6.11: shows the types of follower displacement diagrams that can be produced with different shaped cams

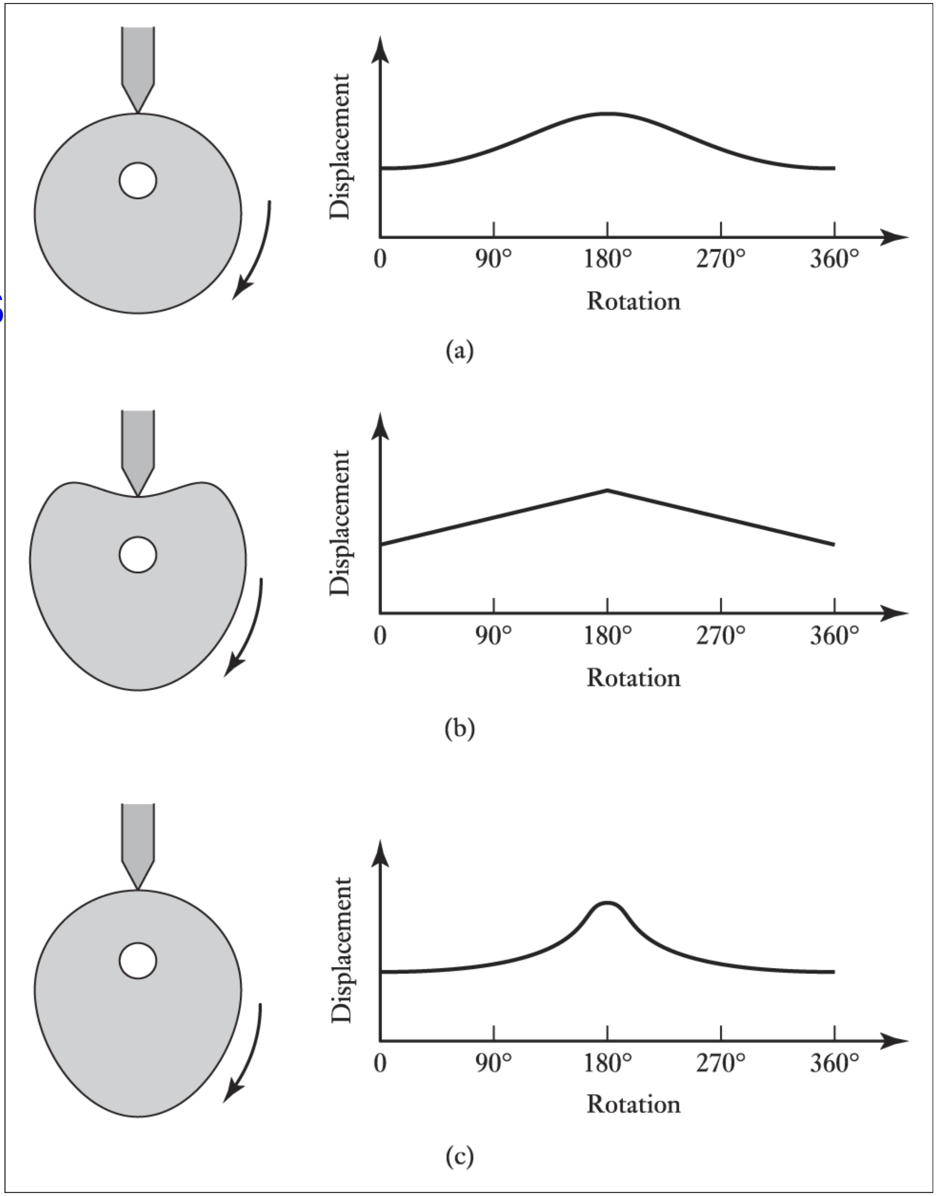


Figure 8.11 Cams: (a) eccentric, (b) heart-shaped, (c) pear-shaped

CAMS

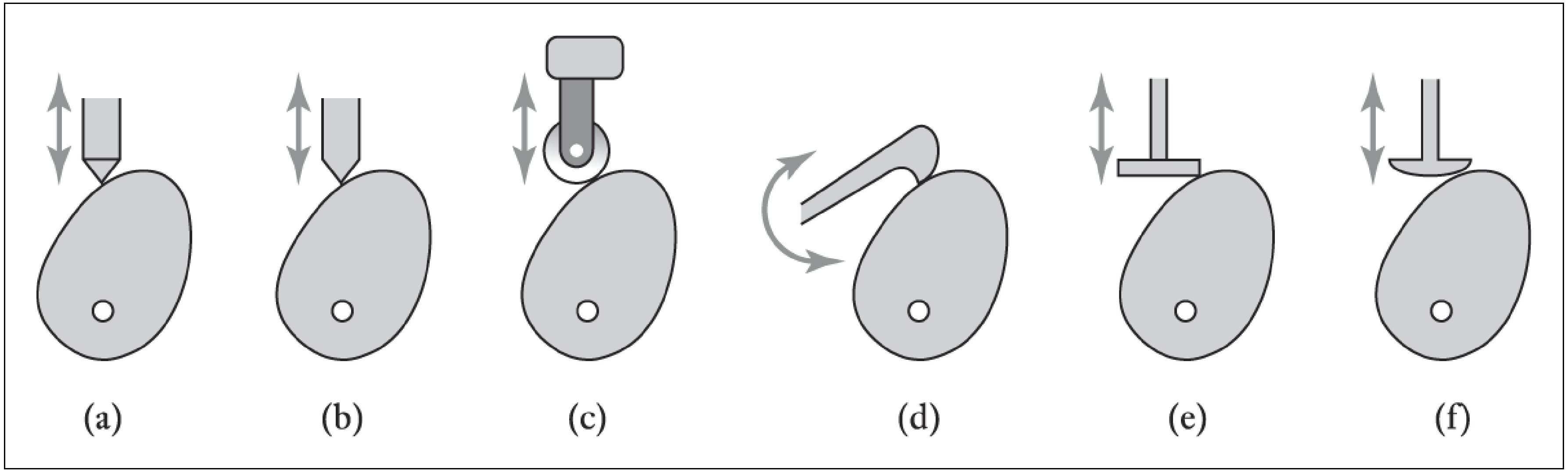


Figure 8.12 Cam followers: (a) point, (b) knife, (c) roller, (d) sliding and oscillating, (e) flat, (f) mushroom

Gears

Gear trains:

- Are used to transfer and transform rotational motion.
- They are used when a change in speed or torque of a rotating device is needed.
- e.g. the car gear box enables the driver to match the speed and torque requirements of the terrain with the engine power available

Gears

Rotary motion can be transferred from one shaft to another by a pair of rolling cylinders

The transfer of the motion between the two cylinders depends on the frictional forces between the two surfaces in contact . Slip can be prevented by the addition of meshing teeth to the two cylinders

Also gears can be used to transfer rotating motion for shafts which have axis inclined to one another, i.e. the two shafts intersect (bevel gears)

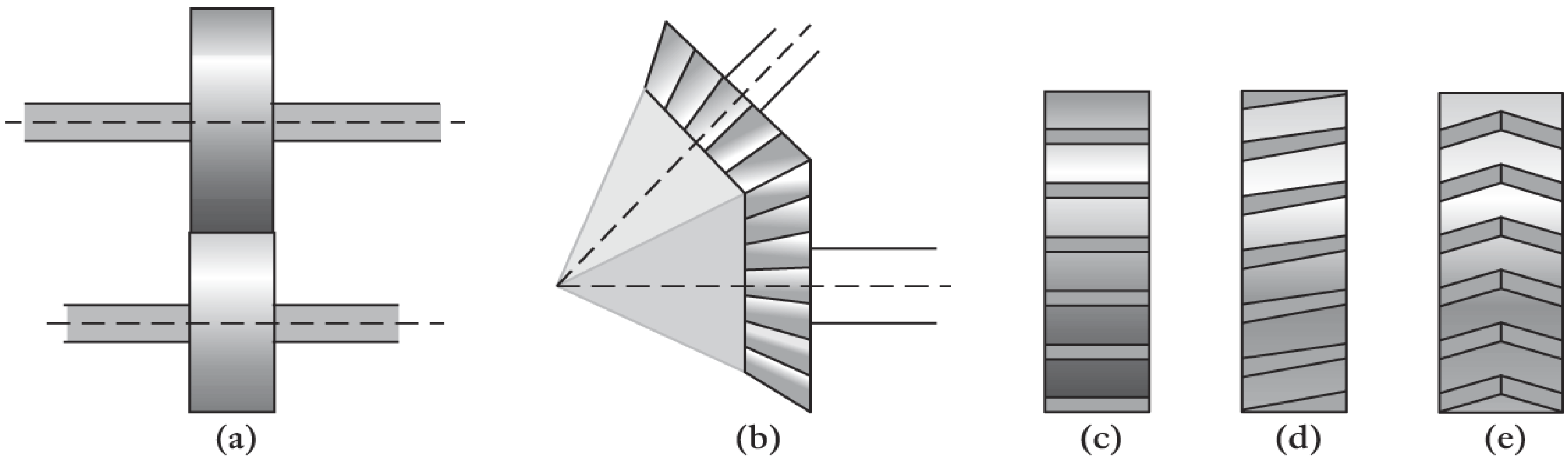


Figure 8.13 (a) Parallel gear axes, (b) axes inclined to one another, (c) axial teeth, (d) helical teeth, (e) double helical teeth

Gears

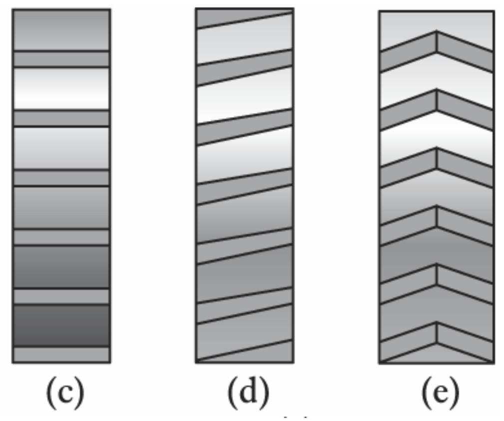
Forms of gears:

- parallel shaft gears:
- spur gears: have axial teeth with the teeth cut along axial lines parallel to the axis of the shaft
- helical gears: helical teeth with teeth being cut on helix

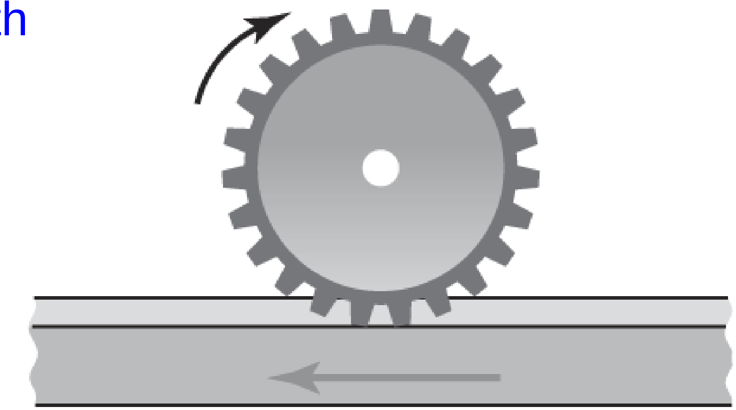
  helical gears have the advantage of smoother drive and prolonged life of gears, however, the inclination of the teeth results in an axial force component on the shaft bearing which can be overcome by using double helical teeth.
- Rack and pinion : are used to transfer linear to rotary motion

double helical teeth

spur gears



helical gears



Rack and pinion

Gears

Example of rotary to translational motion is screw and nut system

The motor powered by dc motor rotates the screw which moves the nut up or down its thread. The movement of the nut is conveyed to the arm by means of a linkage

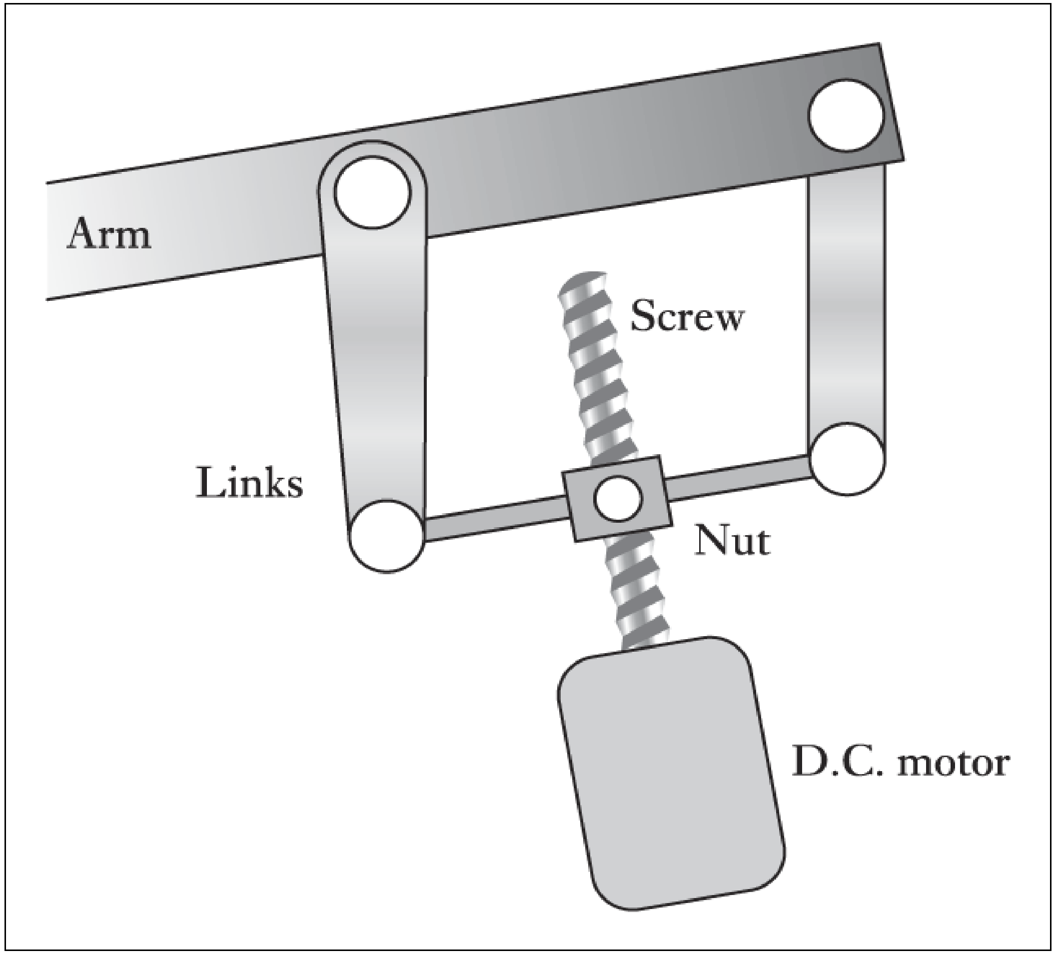


Figure 8.18 Ball screw and links used to move a robot arm

Gears

Slip can be prevented by the addition of meshing teeth to the two cylinders

When two gears in mesh; the larger gear wheel is called the spur (or crown wheel), the smaller is called the pinion

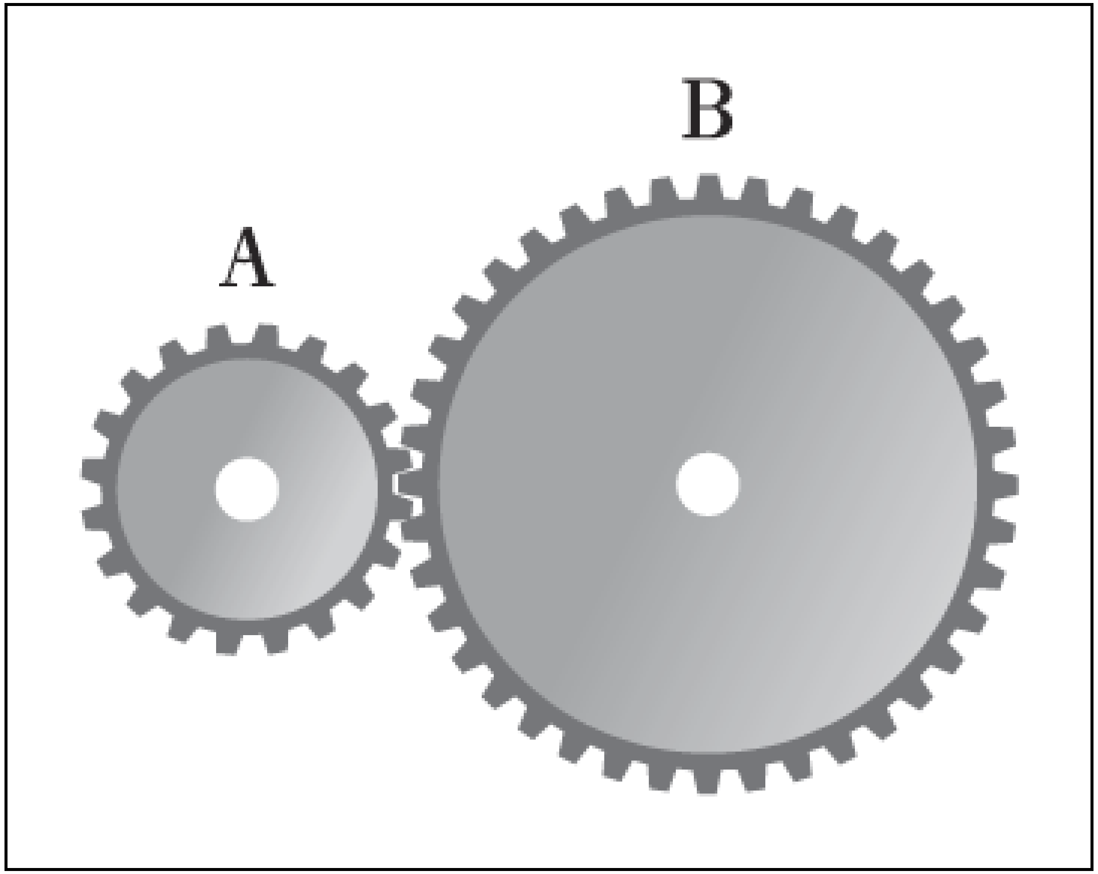


Figure 8.14 Two meshed gears

Gears: ratio

consider meshed wheels A & B . A with 40 teeth and B with 80 teeth.

$$\frac{\omega_A}{\omega_B} = \frac{No\ of\ \ teeth\ on\ B}{No\ of\ \ teeth\ on\ A} = \frac{80}{40} = 2$$

$$\omega_A = 2\omega_B$$

We can also write :

$$\frac{\omega_A}{\omega_B} = \frac{d_B}{d_A} = gear\ ratio = 2$$

Wheel B must have twice the diameter of wheel A.
Gear ratio is used for the ratio of the angular speeds of a pair of intermeshed gear wheels

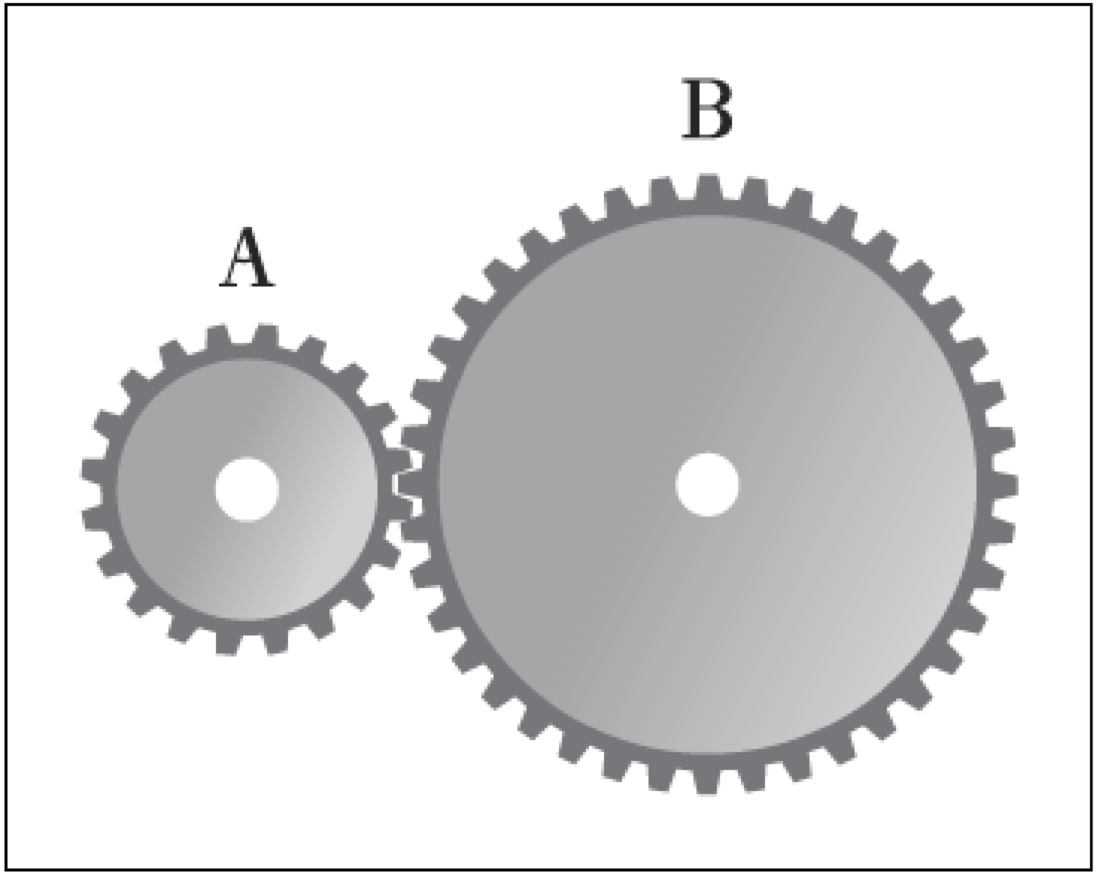


Figure 8.14 Two meshed gears

Gears: ratio

Types of gear trains:

1.simple gear train: this term is used for a system where each shaft carries only one gear wheel here we have

$$G = \frac{\omega_A}{\omega_C} = \frac{\omega_A}{\omega_B} \times \frac{\omega_B}{\omega_C}$$

the intermediate wheel B is termed the idler wheel, is used to change the direction of rotation of the output wheel

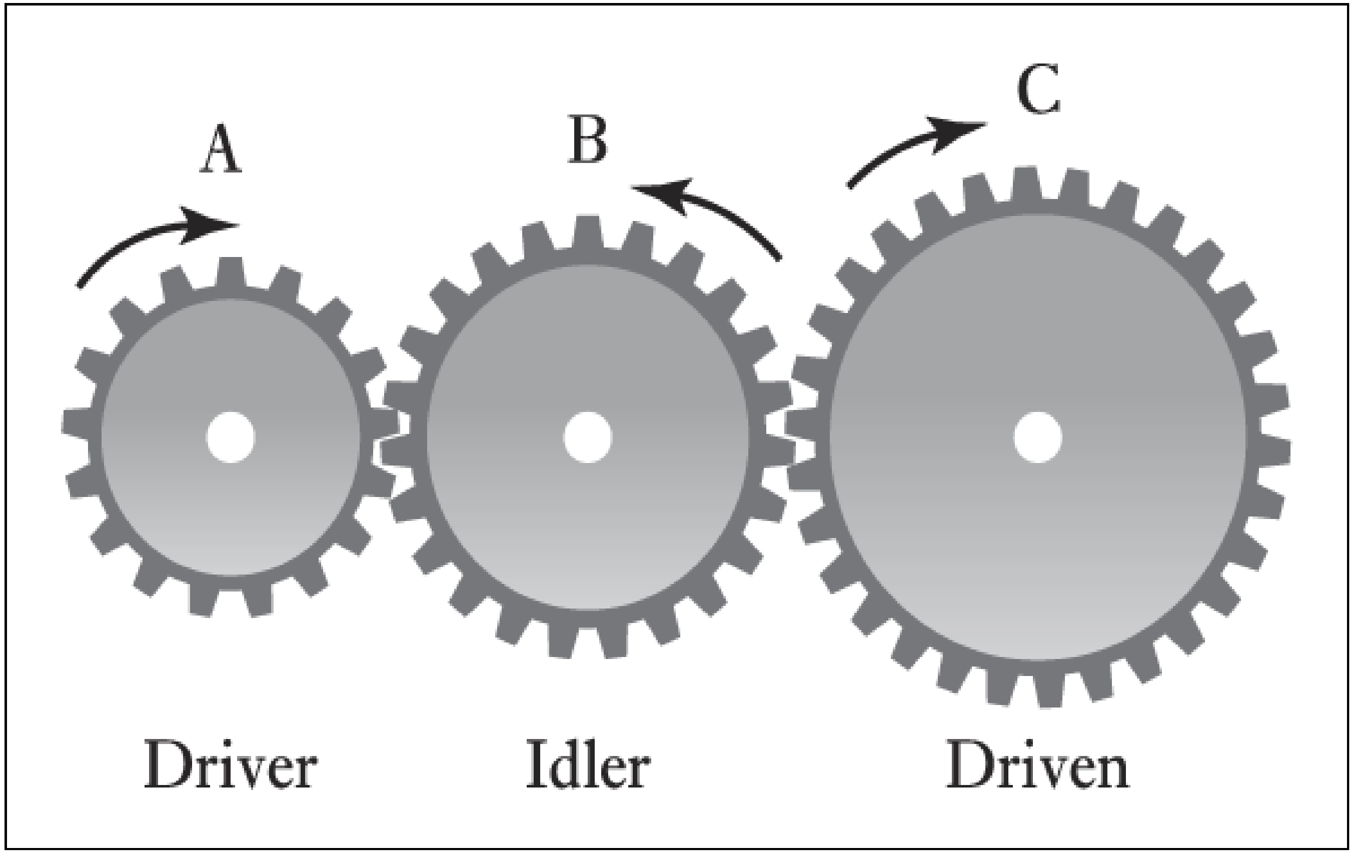


Figure 8.15 Simple gear train

Gears: ratio

1. The compound gear train:

This term is used to describe a gear train when two (or more) wheels are mounted on a common shaft.
When two wheels are mounted on the same shaft, they have the same angular velocity. Thus, for both of the compound gear trains in Fig.

$$\omega_B = \omega_C$$

The over all gear ratio

$$G = \frac{\omega_A}{\omega_D} = \frac{\omega_A}{\omega_B} \times \frac{\omega_B}{\omega_C} \times \frac{\omega_C}{\omega_D} = \frac{\omega_A}{\omega_B} \times \frac{\omega_C}{\omega_D}$$

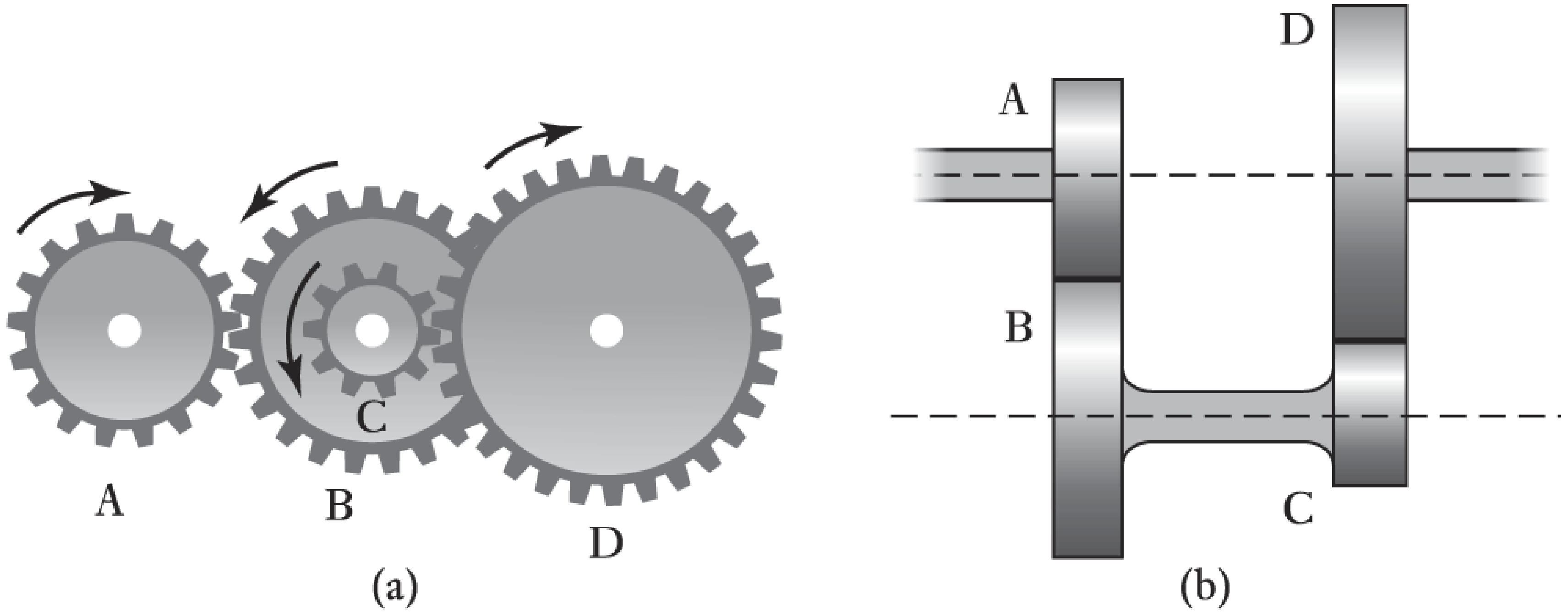


Figure 8.16 Compound gear trains

Gears: ratio

For the arrangement shown in Fig.8.16 for the input and output shafts to be in line we must have

$$r_A + r_B = r_D + r_C$$

e.g for Fig 8.16 if A has 15 teeth, B 30 teeth, C 18 teeth and D 36 Teeth. Find the angular speed of D if A speed is 160 rpm

Since the angular speed of a wheel is inversely proportional to the number of teeth on the wheel, the overall gear ratio is

$$G = \frac{30}{15} \times \frac{36}{18} = 4 = \frac{\omega_A}{\omega_D}$$

$$\omega_D = \frac{\omega_A}{4} = 160/4 = 40 \quad rpm$$

Ratchet & Pawl

It is used to lock a mechanism when it is holding a load.

It consist of a wheel, called a ratchet, with saw-shaped teeth which engage with an arm called Pawl. The arm is pivoted and can move back and forth to engage the wheel. The shape of the teeth is such that rotation can occur in only one direction. (used in winch to wind up a cable on drum)

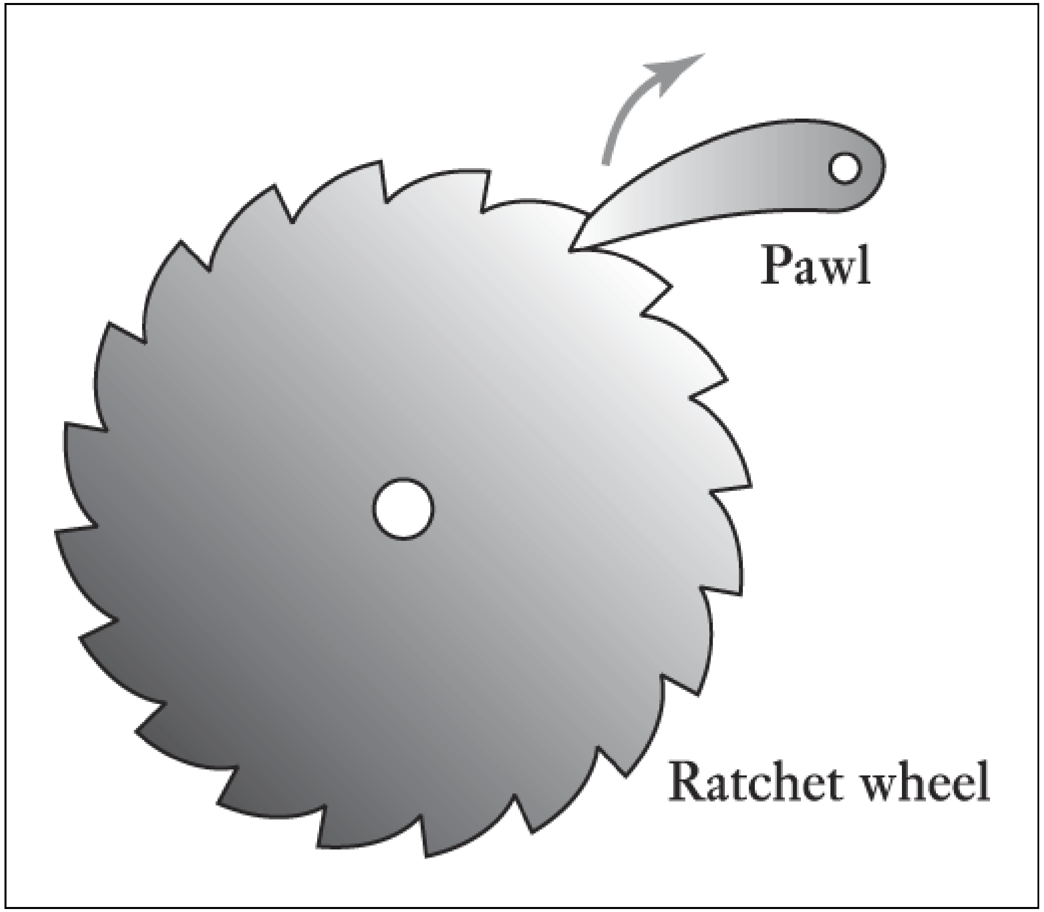


Figure 8.19 Ratchet and pawl

Belt & chain drives

Is essentially a pair of rolling cylinders with the motion of one cylinder being transferred to the other by a belt.

The transmitted torque is due to differences in tension that occur in the belt during operation. This difference results in a tight side and slack side for the belt.

If the tension on the tight side is T1 and that on the slack side is T2 then:

Torque on A =(T1-T2)r_A Torque on B=(T1-T2)r_B

r_A and r_B are the radius of A and B

If belt speed is v then angular speed for a and B are:

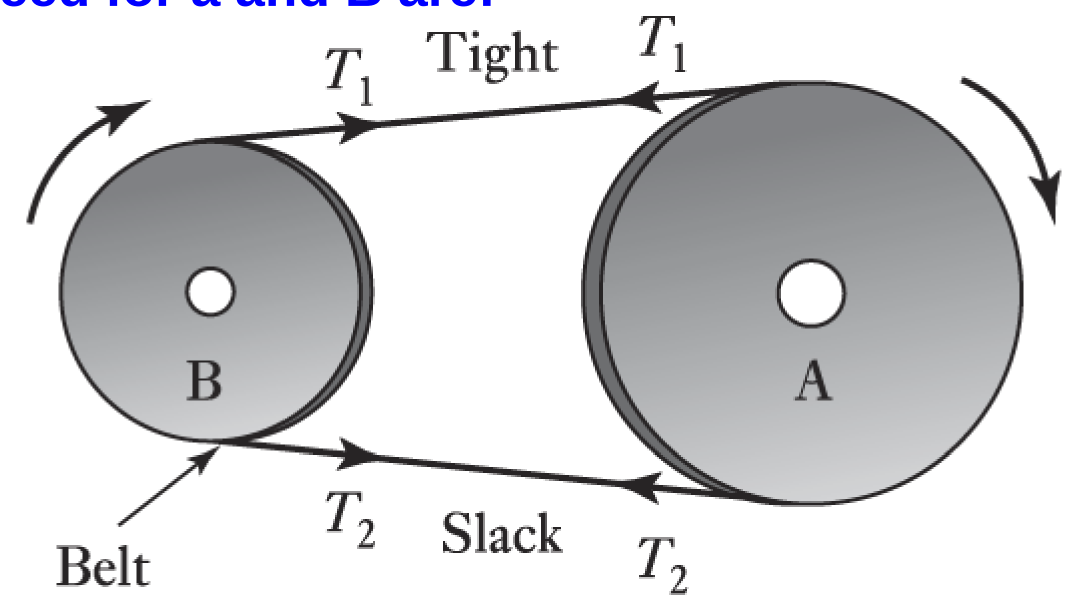
$$\omega_A = \frac{v}{r_A} \quad \& \quad \omega_B = \frac{v}{r_B}$$

Power on either pulley is :

$$P = T \bullet \omega$$

$$P = (T1 - T2)v$$

If distances between shafts are large then a belt drive is more suitable than gears



Belt & chain drives

Forms of reversing drives

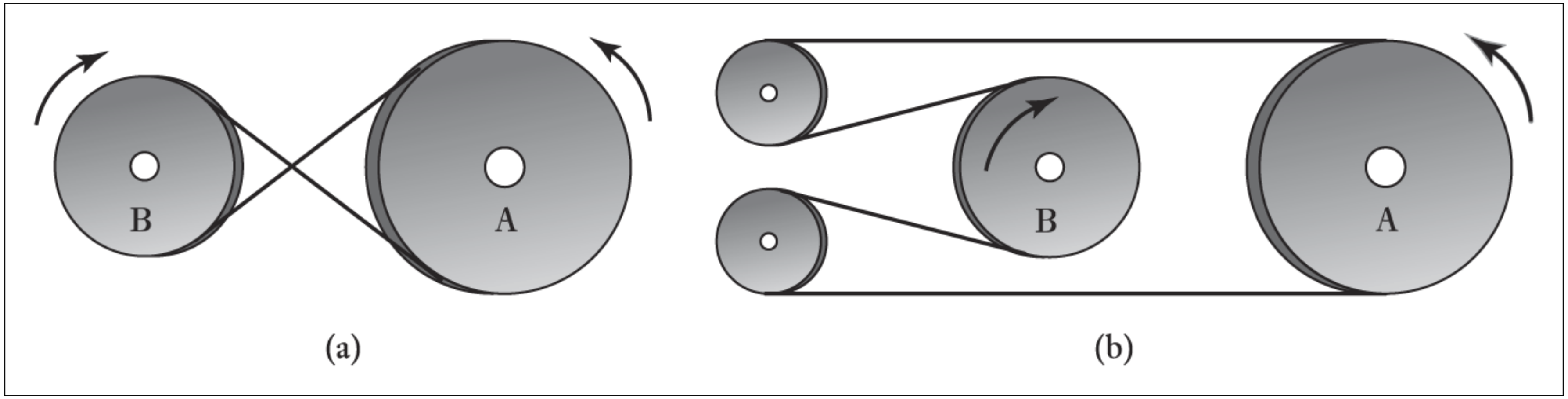


Figure 8.21 Reversed belt drives: (a) crossed belt, (b) open belt

Belt & chain drives: Types of belts

Flat: produces little noise, can transmit power over long distance. Crowned pulleys are used to keep the belts from running off the pulleys

Round: has circular cross section and is used with grooved pulleys

V belts: are used with grooved pulleys, less efficient than flat belts

Timing belts: required toothed wheels; it can run at slow or fast speed, does not stretch or slip

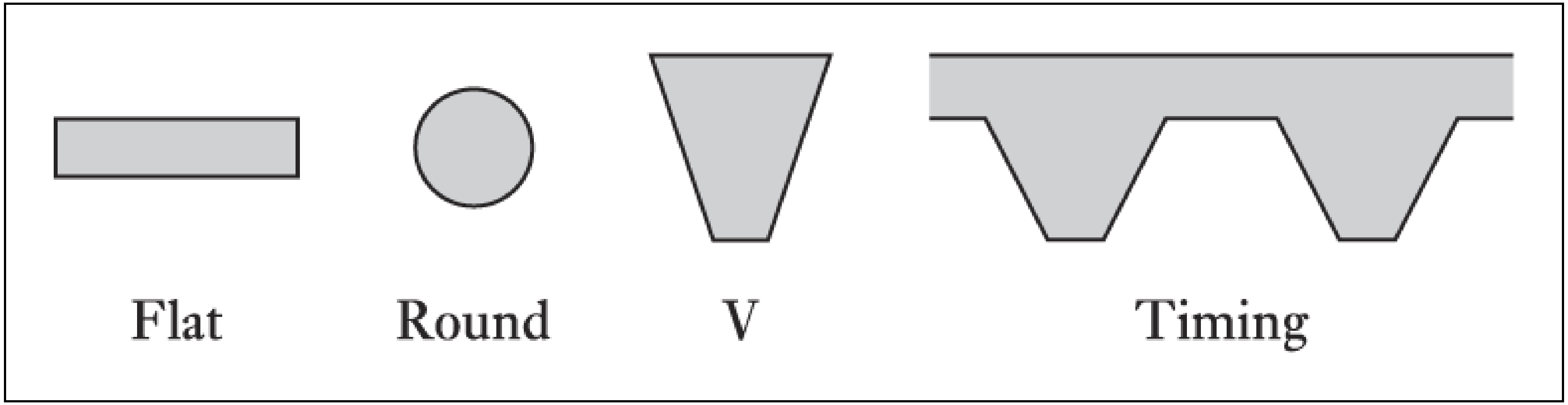


Figure 8.22 Types of belts

Chains

- Slip can be prevented by the use of chains which lock into teeth on the rotating cylinders.
- The drive mechanism used with bicycle is an example of a chain drive.
- It enables a number of shafts to be driven by single wheel and so give a multiple drive

Bearings

Is used mainly to prevent or reduce friction forces (which generate heat that wastes energy and result in wear) when two surface are in contact and one is moving with respect to other.

So the function of the bearing is to guide the movement of one part relative to another with minimum friction and maximum accuracy

Common types

Plain journal bearings

- Hydrodynamic
- Hydrostatic
- Solid- film
- Boundary layer

Ball and roller bearings

- Deep-groove
- Filling slot
- Angular contact
- Double row
- Self aligning
- Thrust grooved race

- Straight roller
- Taper roller
- Needle roller

Plain journal bearing

Journal bearings are used to support rotating shafts which are loaded in radial direction. The word journal is used for a shaft.

The bearing basically consist of an inserted of some suitable material which is fitted between the shaft and the support

The insert may be a white metal, aluminum alloy, copper alloy, bronze, etc..

The insert provides lower friction and less wear than if the shaft just rotated in a hole in the support

The bearing may be dry rubbing bearing or lubricated

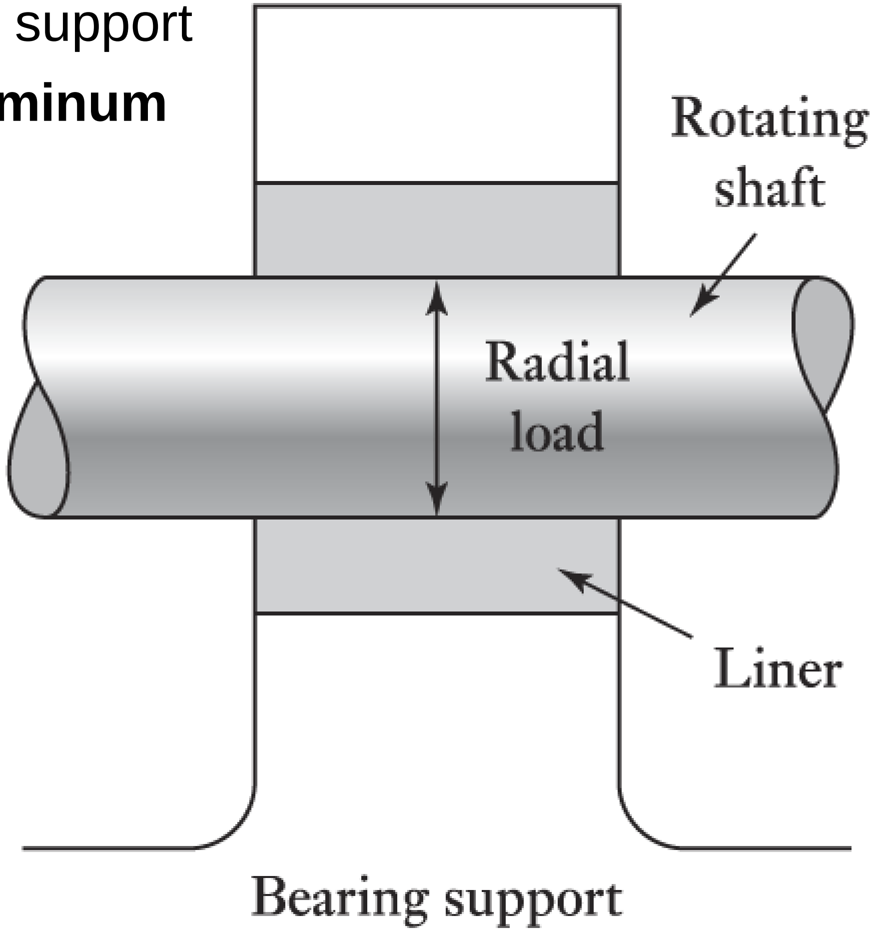


Figure 8.23 Plain journal bearing

Plain journal bearing

The bearing may be dry rubbing bearing or lubricated.

The lubrication may be:

Hydrodynamic: consists of shaft rotating continuously in oil. The load is carried by pressure degenerated in the oil as a result of the shaft rotating
Hydrostatic: is used to avoid excessive wear at start-up occurred in hydrodynamic types and when there is only a low load, oil is pumped into the load bearing area at a high-enough pressure to left the shaft off the metal when at rest.
Solid- film: is a coating of a solid material such as graphite or molybdenum disulphide
Boundary layer: is a thin layer of lubricant which adheres to the surface of the bearing.

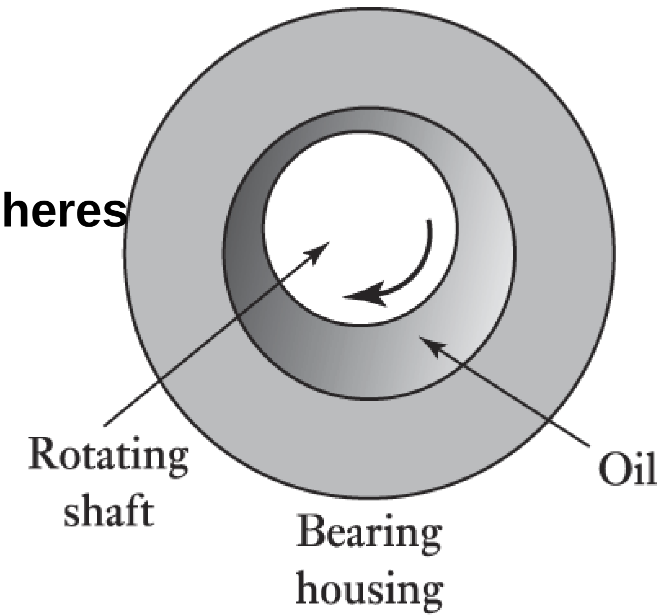


Figure 8.24 Hydrodynamic journal bearing

Ball and roller bearings

With this type the main load is transferred from the rotating shaft to its support by rolling contact rather than sliding contact.

A rolling element bearing consists of four main elements: an inner race, an outer race, the rolling element of either balls or rollers and a cage to keep the rolling elements apart

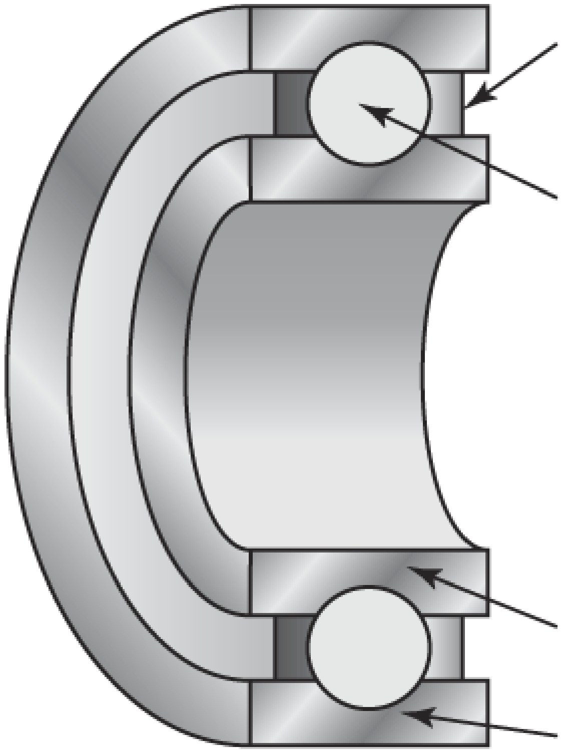


Figure 8.25 Basic elements of a ball bearing

Ball and roller bearings

There are a number of forms of ball bearings:

a- Deep-groove: can be used for a wide range of load and speed
b- Filling slot: can not be used when there are axial load
C- Angular contact: good for both axial and radial loads
d- Double row: it is able to withstand higher radial loads
e- Self aligning: can withstand shaft misalignment
f- Thrust grooved race: they are designed to withstand axial loads but are not suitable for radial loads

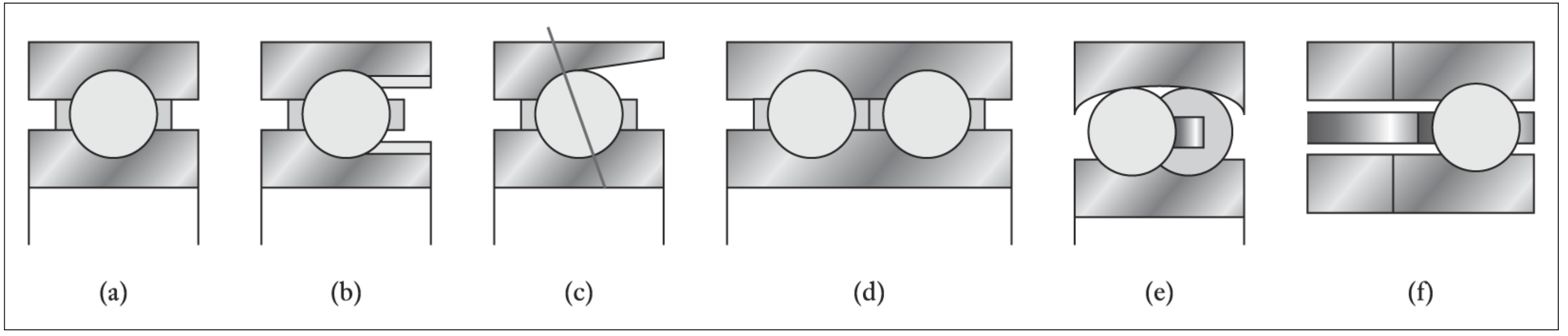


Figure 8.26 Types of ball bearings

Roller bearings

Common example of roller bearings:

a - Straight roller

b - Taper roller

C - Needle roller

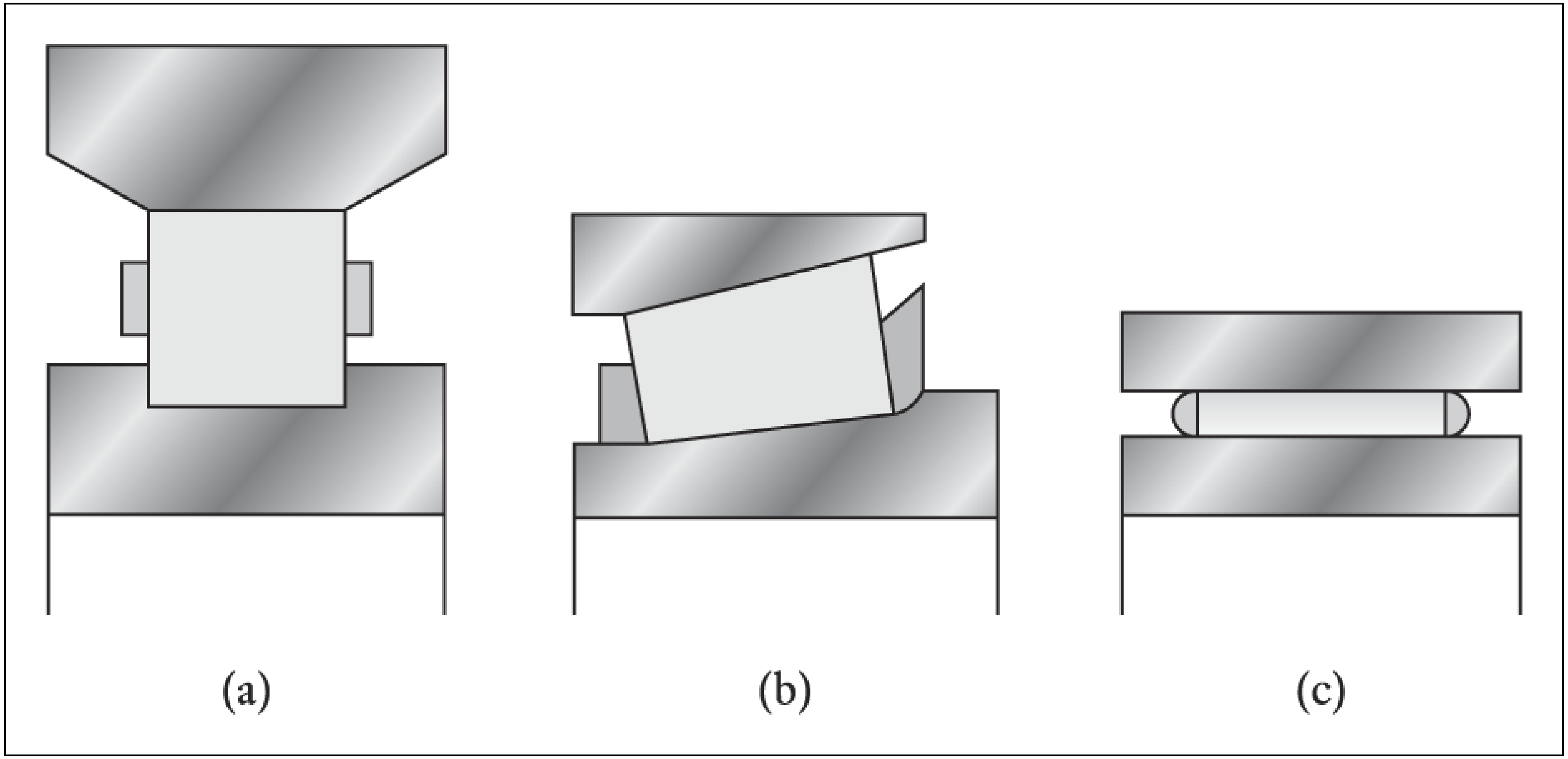


Figure 8.27 Roller bearings