CHAPTER 8.

Mechanical Actuation Systems

8.1 Mechanical systems

- Mechanism : The devices which can be considered to be motion converters in that they transform motion from one form to some other required form.

- Mechanical elements : linkages, cams, gears, rack and pinion, chains, belt drives, and etc.

- Many of the actions which previously were obtained by the use of mechanisms are, however, often nowadays being obtained, as a result of a mechatronics approach, by the use of microprocessor systems.

8.1 Mechanical systems

- Mechanisms might still be used to provide such functions as:

    1. Force amplification, e.g. that given by levers

    2. Change of speed, e.g. that given by gears.

    3. Transfer of rotation about one axis to rotation about another, e.g. a timing belt.

    4. Particular types of motion, e.g. that given by a quick-return mechanism

The term kinematics is used for the study of motion without regard to forces.

8.2 Types of motion

- Translation motion
- Rotational motion
- A complex motion may be a combination of translational and rotational motions.

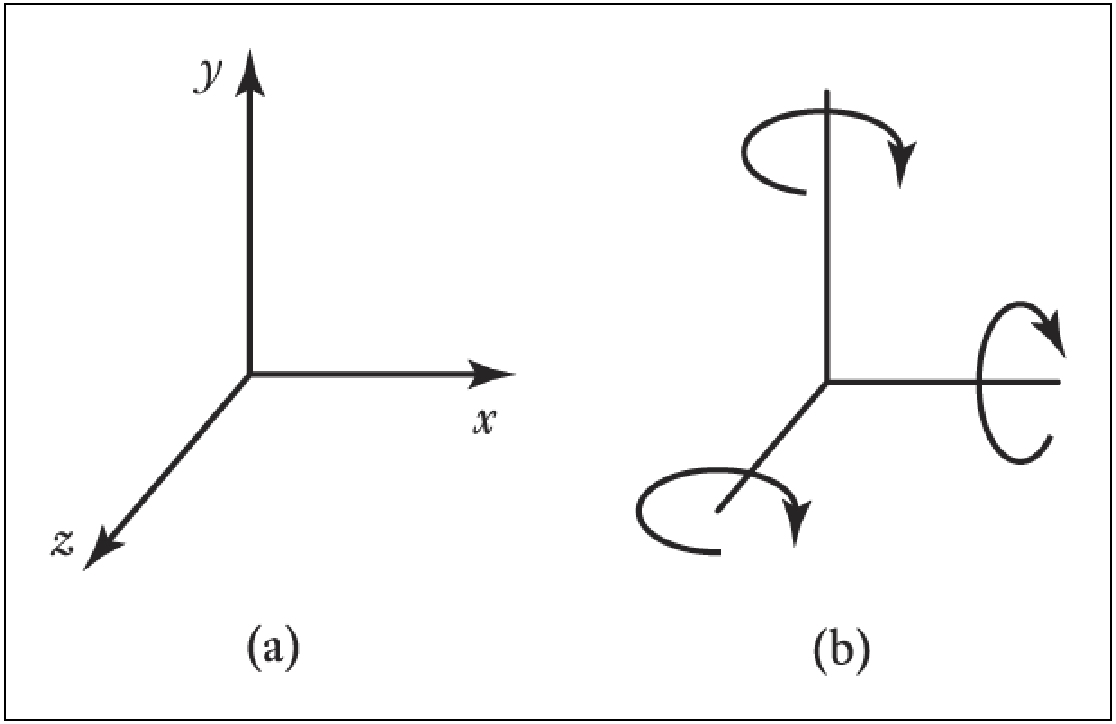


Figure 8.1 Types of motion: (a) translational, (b) rotational

8.2.1 Freedom and constraints

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

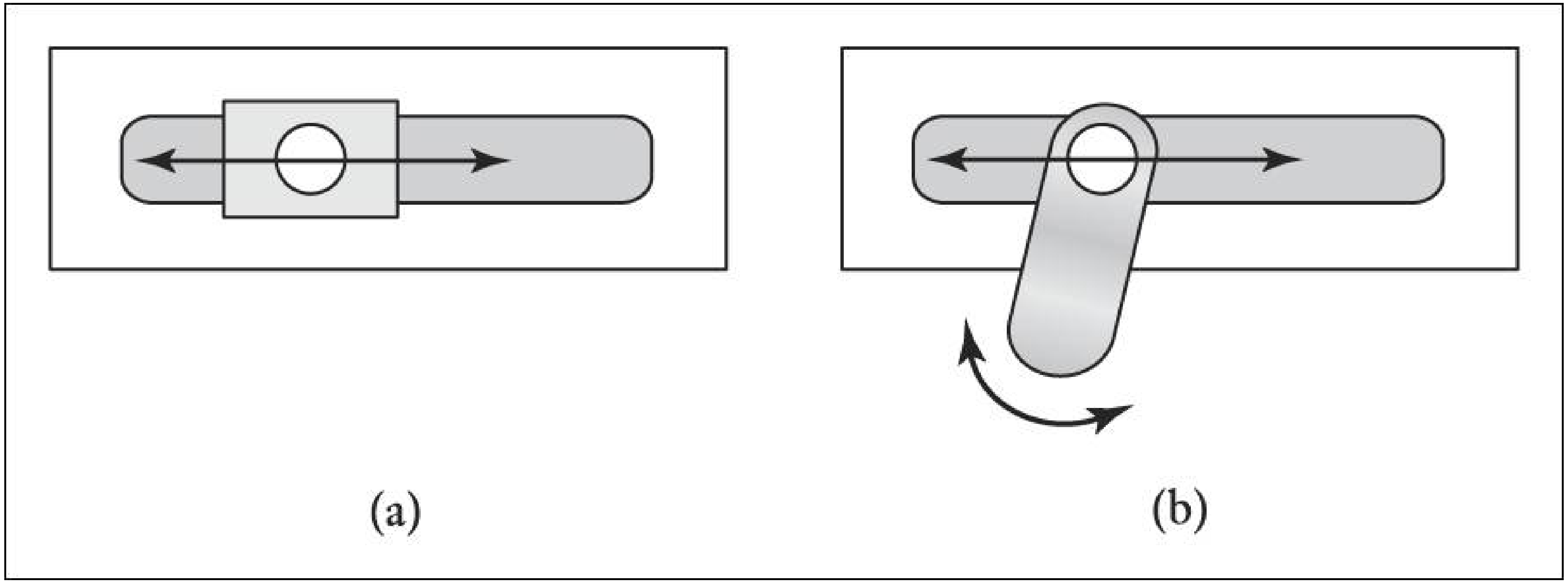


Figure 8.2 Joints with: (a) one degree, (b) two degrees of freedom

6 – number of constraints
= number of degrees of freedom
- number of redundancies

- The principle of least constraint : Kinematic design
  - In fixing a body or guiding it to a particular type of motion, the minimum number of constraints should be used, i.e. there should be no redundancies.

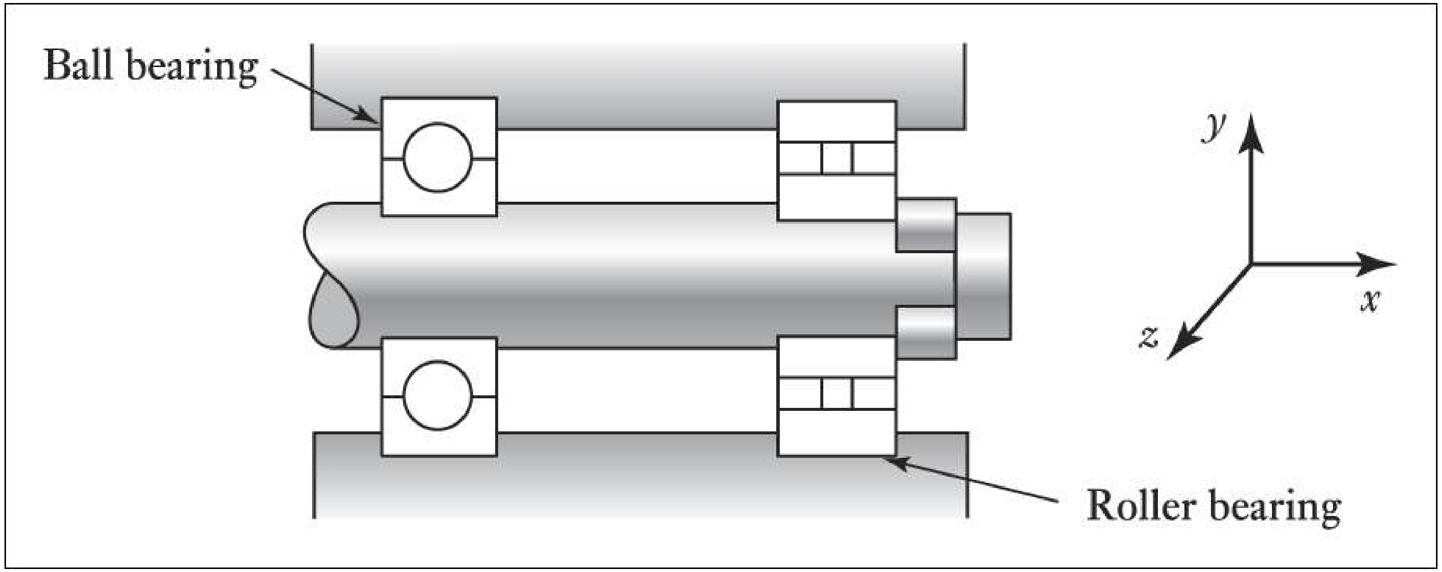


Figure 8.3 Shaft with no redundancies

8.2.2 Loading

- Mechanisms are structures and as such transmit and support loads.

- Analysis is thus necessary to determine the loads to be carried by individual elements.

- Then consideration can be given to dimensions of the element so that it might, for example, have sufficient strength and perhaps stiffness under such loading.

- Strength VS. Stiffness Design

8.3 Kinematic chains

- When we consider the movements of a mechanism without any reference to the forces involved, we can treat the mechanism as being composed of a series of individual links.

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

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

- A sequence of joints and links is known as a kinematic chain. For a kinematic chain to transmit motion, one link must be fixed.

- Movement of one link will then produce predictable relative movements of the others.

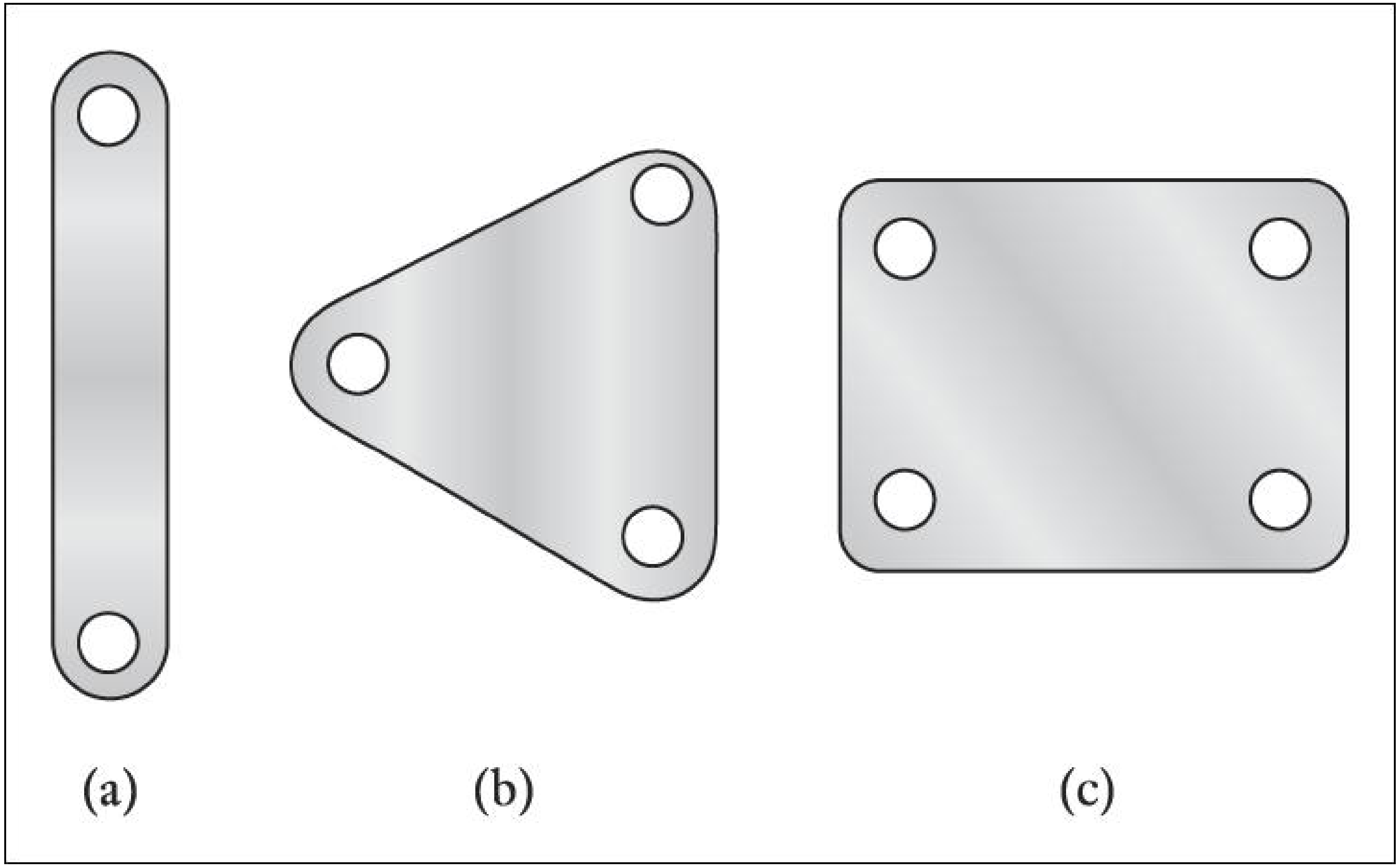


Figure 8.4 Links: (a) with two nodes, (b) with three nodes, (c) with four nodes

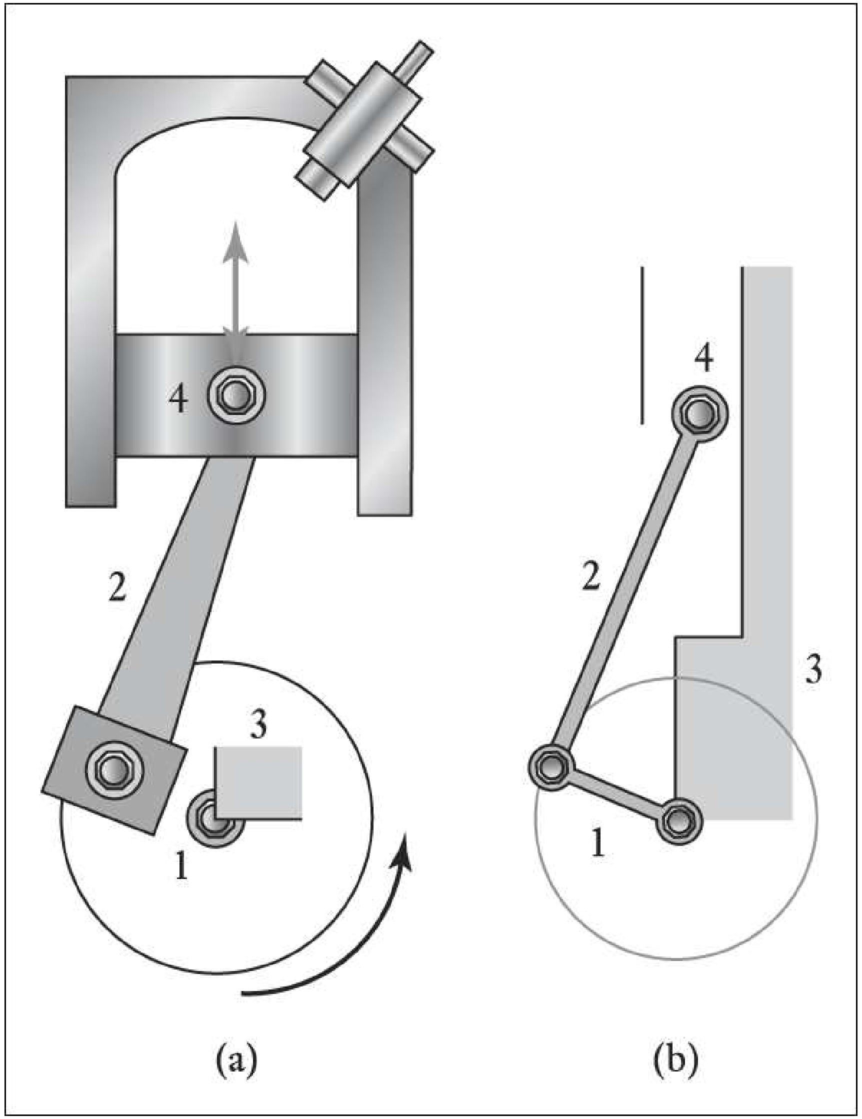


Figure 8.5 Simple engine mechanism

8.3.1 The four-bar chain

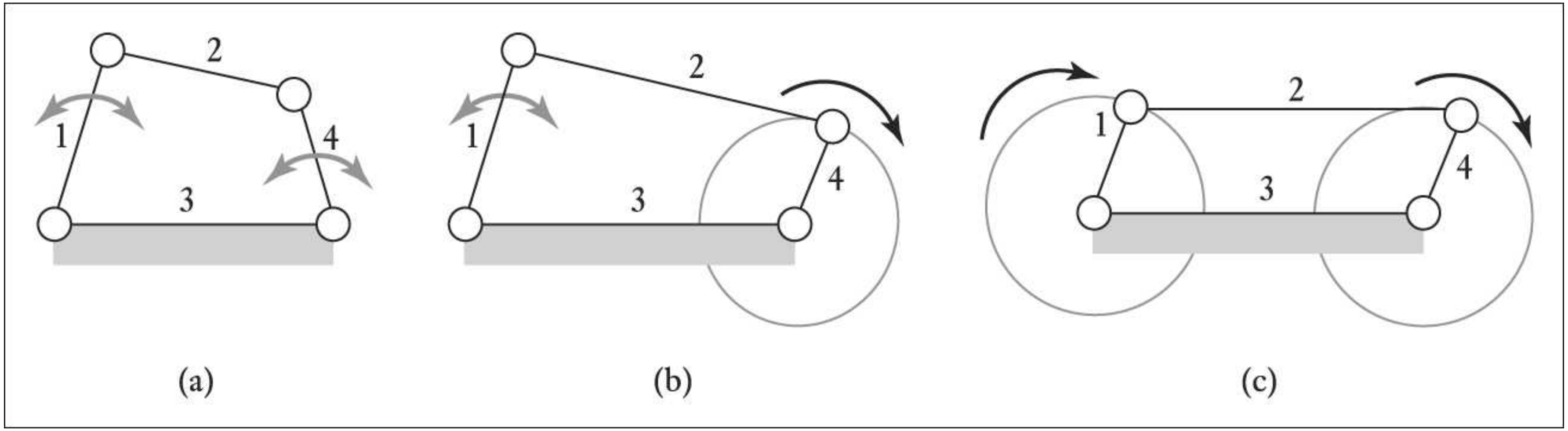


Figure 8.6 Examples of four-bar chains

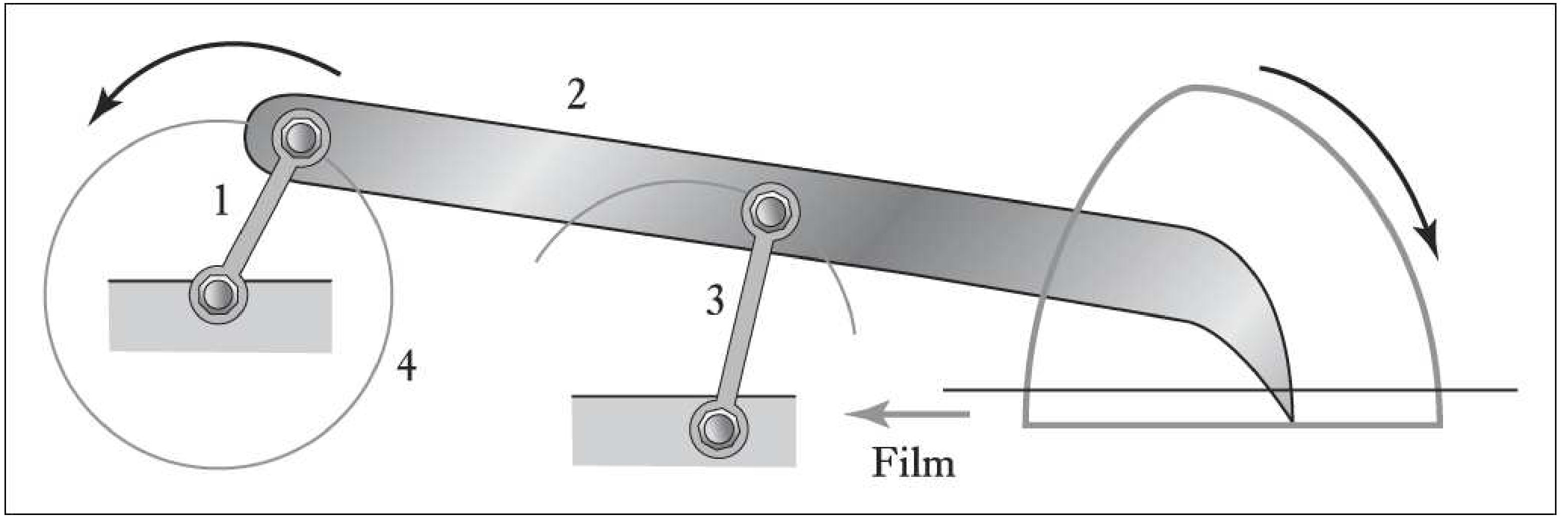


Figure 8.7 Cine film advance mechanism

8.3.1 The four-bar chain

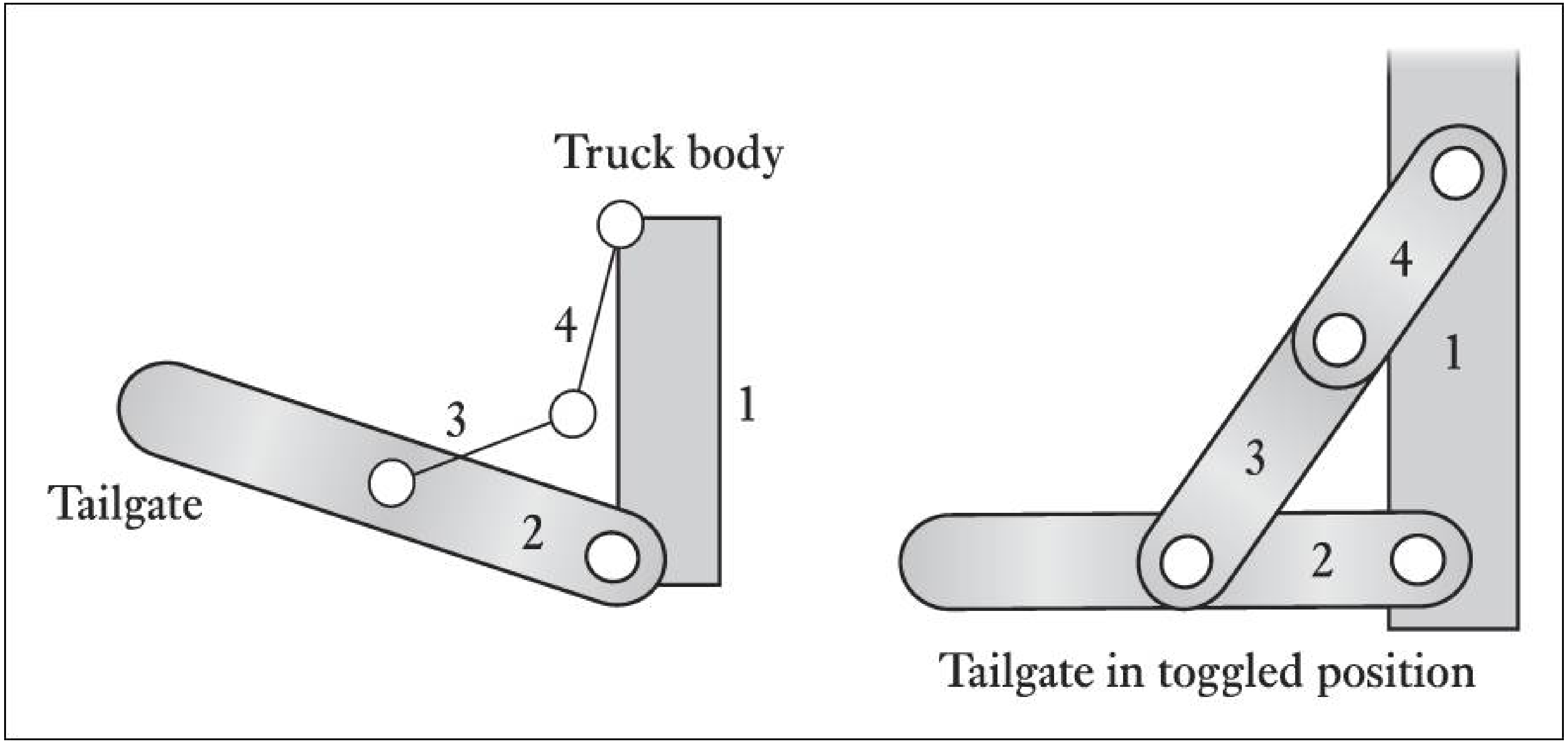


Figure 8.8 Toggle linkage

8.3.2 The slider-crank mechanism

- This form of mechanism consists of crank, a connecting rod and a slider and is the type of mechanism described simple engine mechanism
- Quick-return mechanism

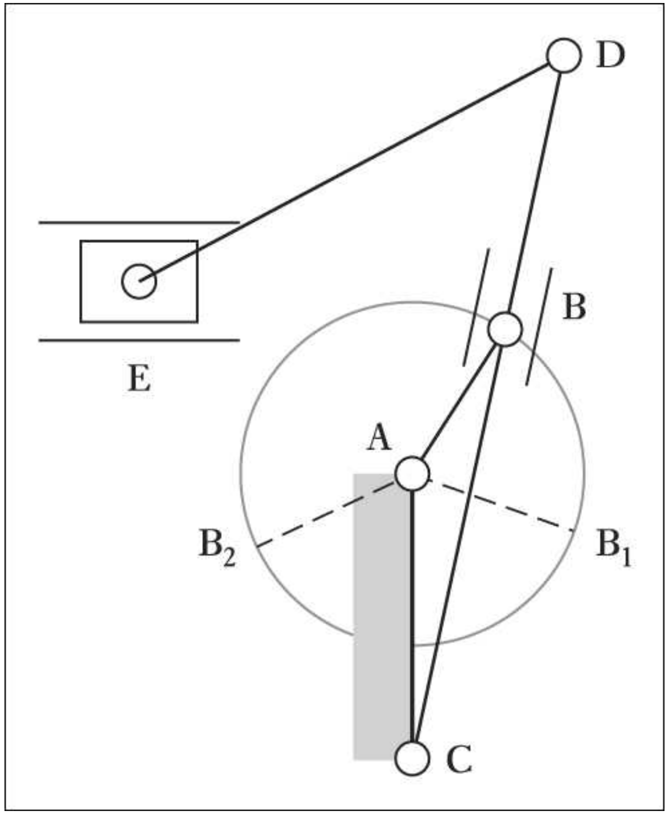


Figure 8.9 Quick-return mechanism

8.4 Cams

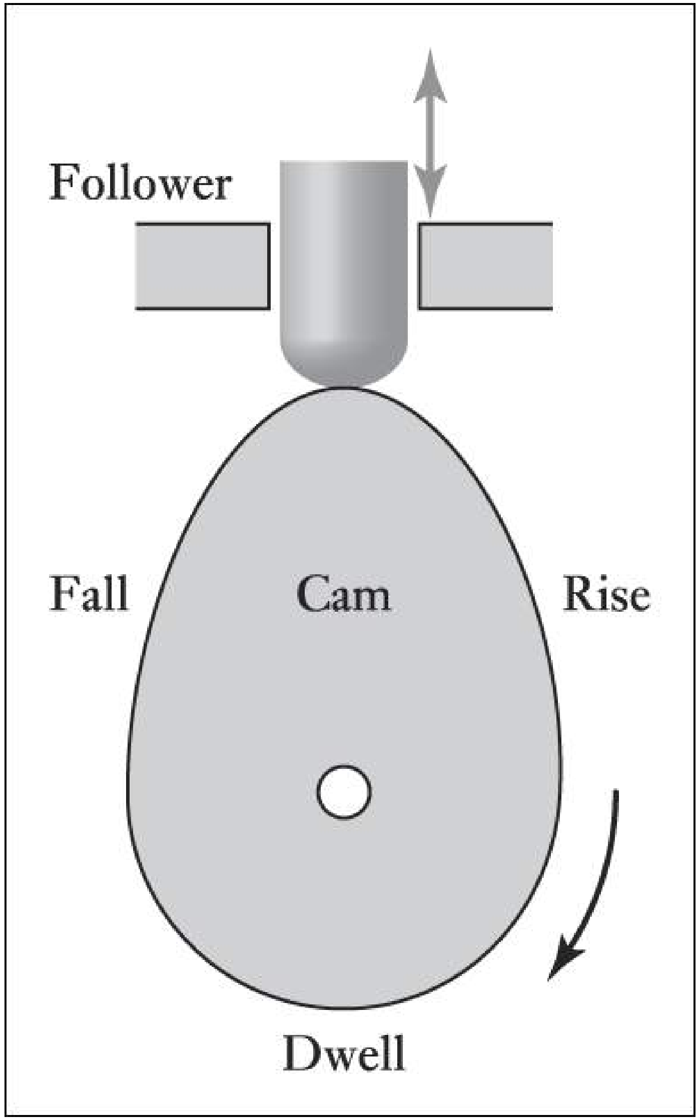


Figure 8.10 Cam and cam follower

8.4 Cams

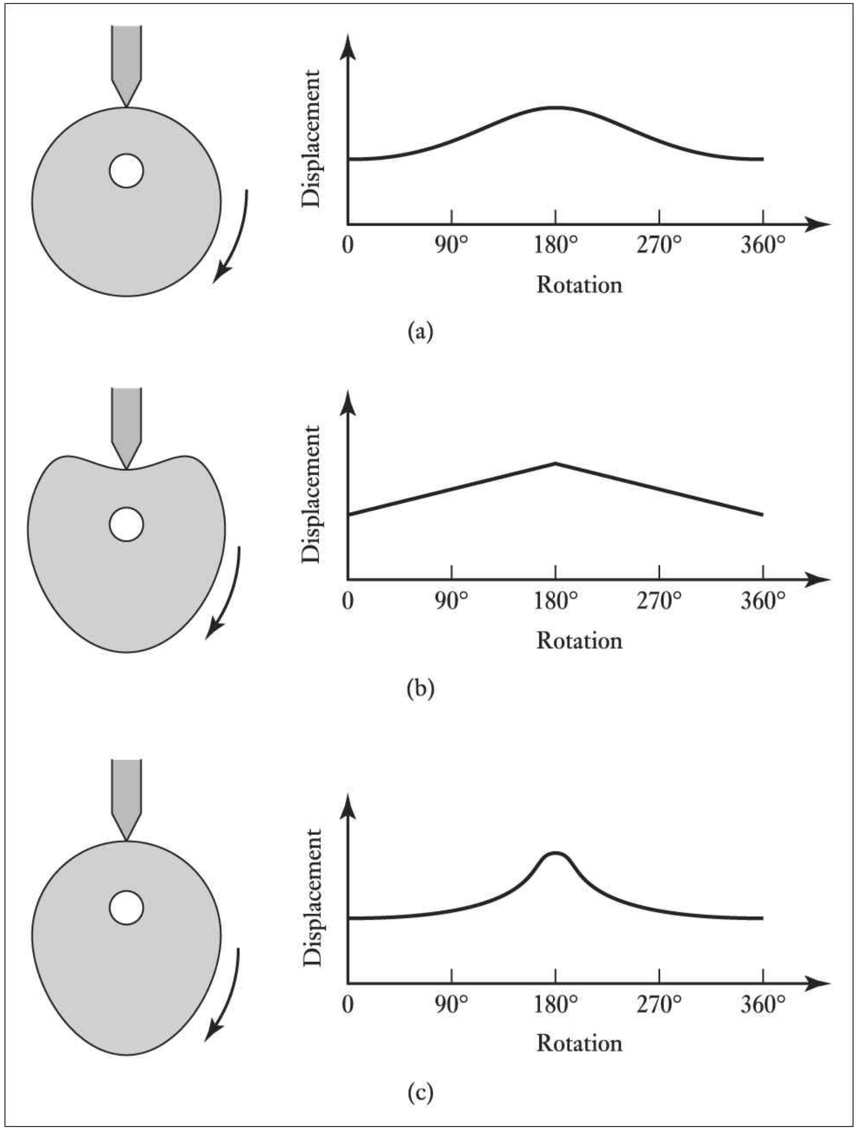


Figure 8.11 Cams: (a) eccentric, (b) heart-shaped, (c) pear-shaped

8.4 Cams

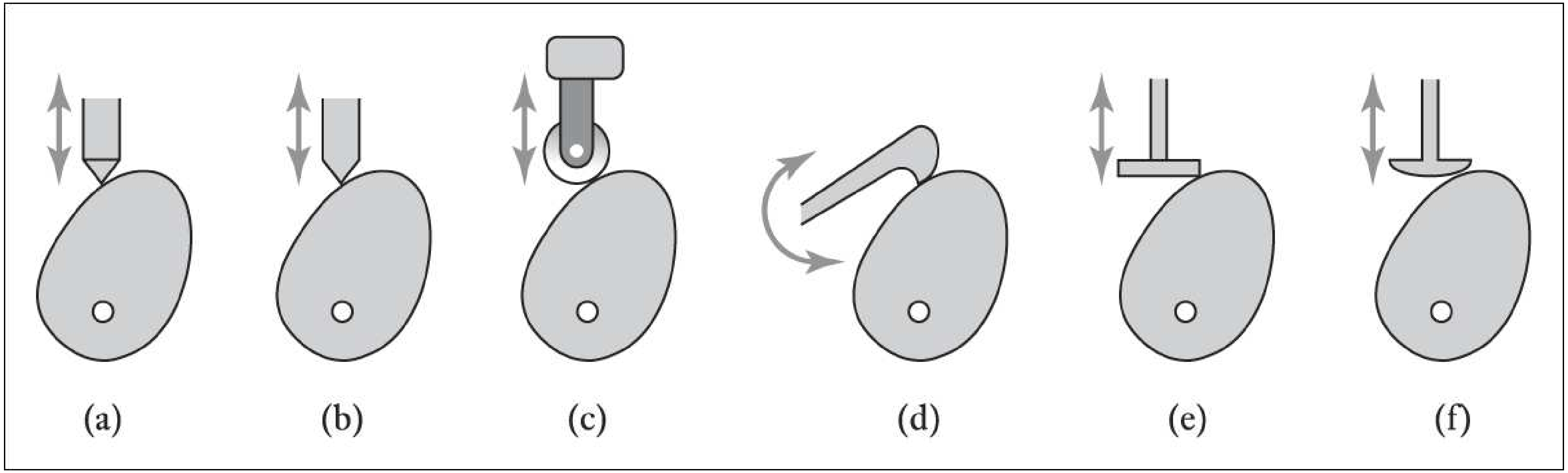


Figure 8.12 Cam followers: (a) point, (b) knife, (c) roller, (d) sliding and oscillating, (e) flat, (f) mushroom

8.5 Gears

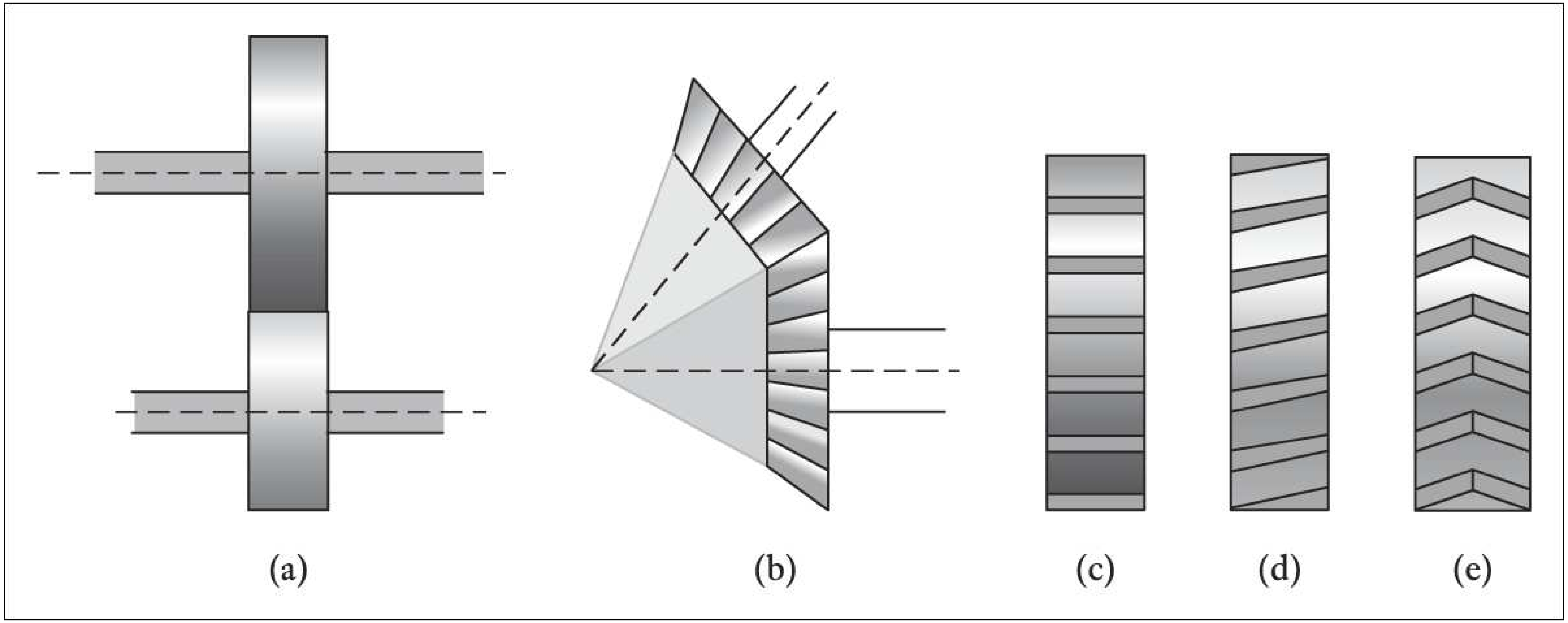


Figure 8.13 (a) Parallel gear axes, (b) axes inclined to one another, (c) axial teeth, (d) helical teeth, (e) double helical teeth

- Consider two meshed tear wheels A and B. If there are 40 teeth on wheel A and 80 teeth on wheel B, then wheel A must rotate through two revolutions in the same time as wheel B rotates through one.
- Since the number of teeth on a wheel is proportional to its pitch diameter, we can write

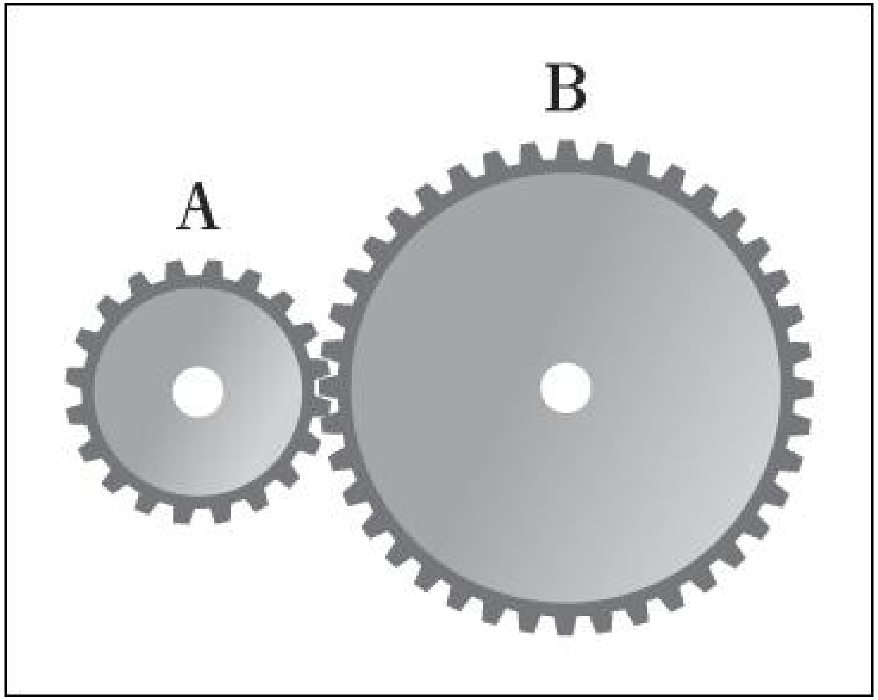


Figure 8.14 Two meshed gears

$$\frac{\omega_A}{\omega_B} = \frac{\text{number of teeth on B}}{\text{number of teeth on A}} = \frac{80}{40} = 2$$

$$\frac{\omega_A}{\omega_B} = \frac{\text{number of teeth on B}}{\text{number of teeth on A}} = \frac{d_B}{d_A}$$

8.5.1 Gear trains

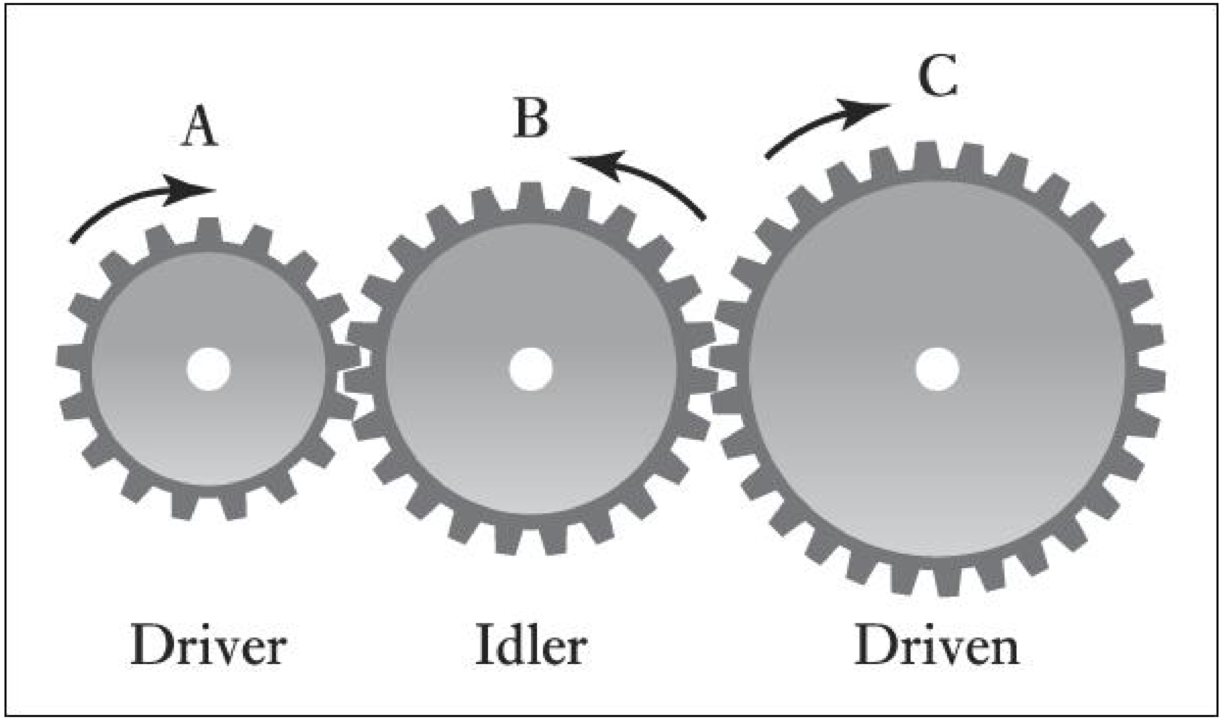


Figure 8.15 Simple gear train

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

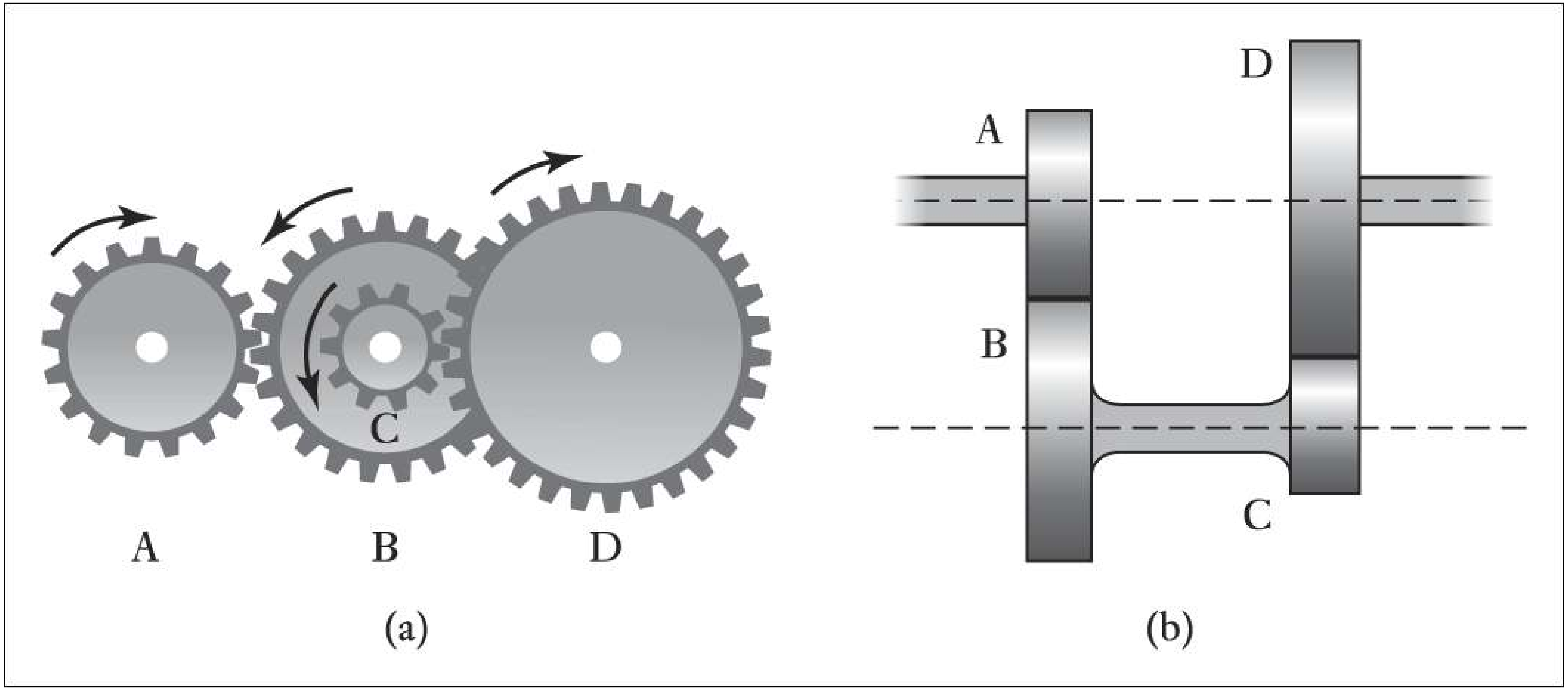


Figure 8.16 Compound gear trains

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

$$r_A + r_B = r_D + r_C$$

8.5.2 Rotational to translational motion

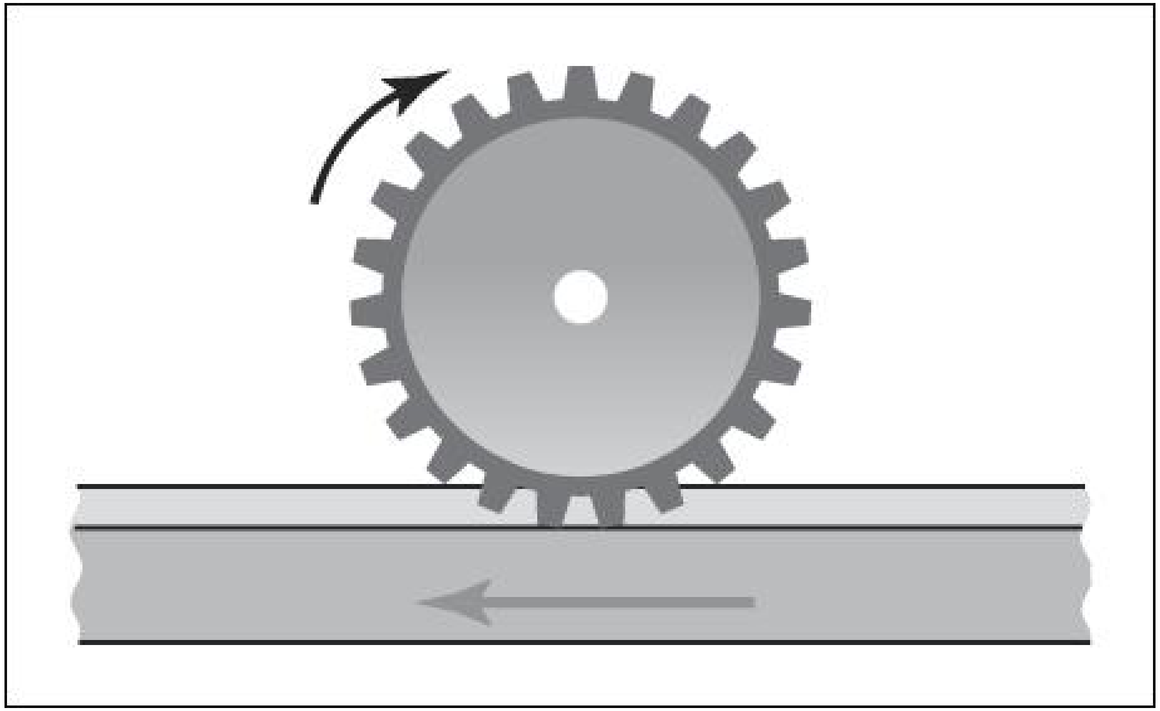


Figure 8.17 Rack-and-pinion

8.5.2 Rotational to translational motion

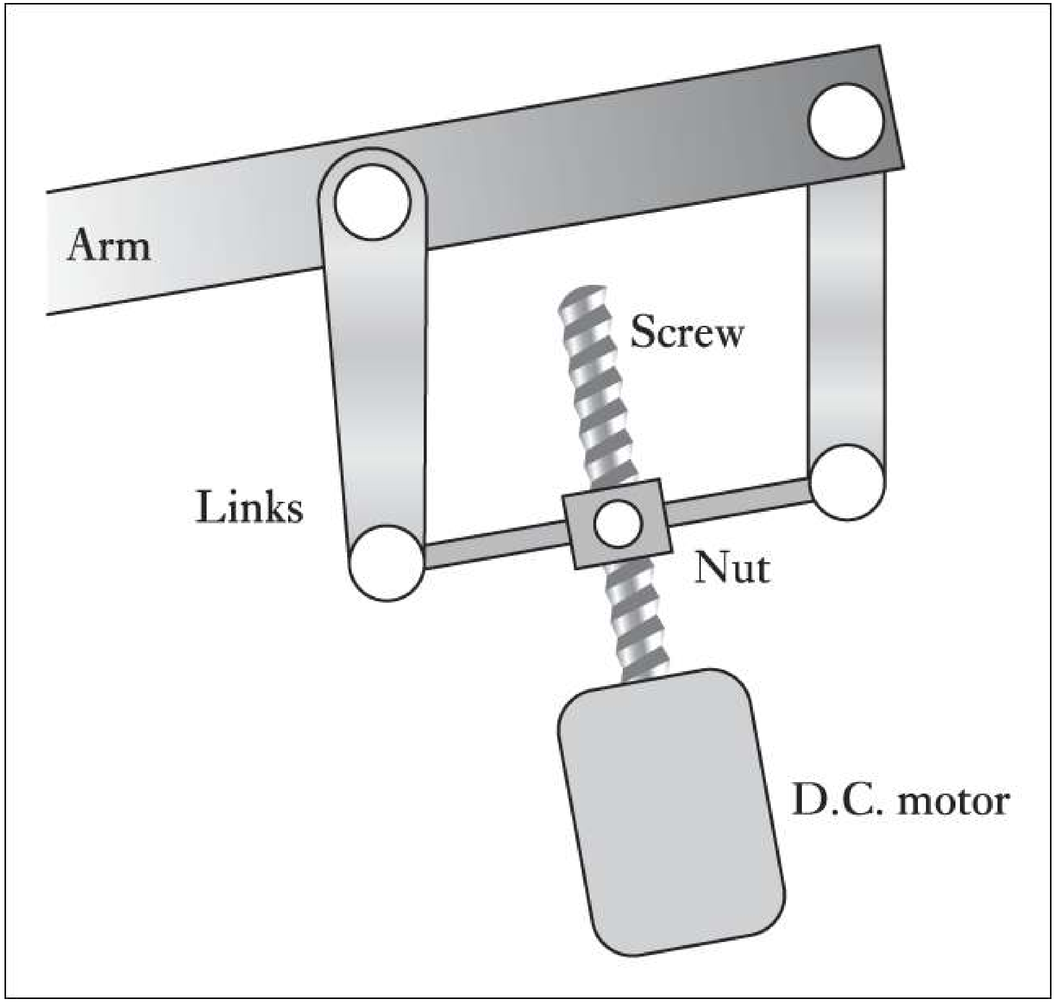


Figure 8.18 Ball screw and links used to move a robot arm

8.6 Ratchet and pawl

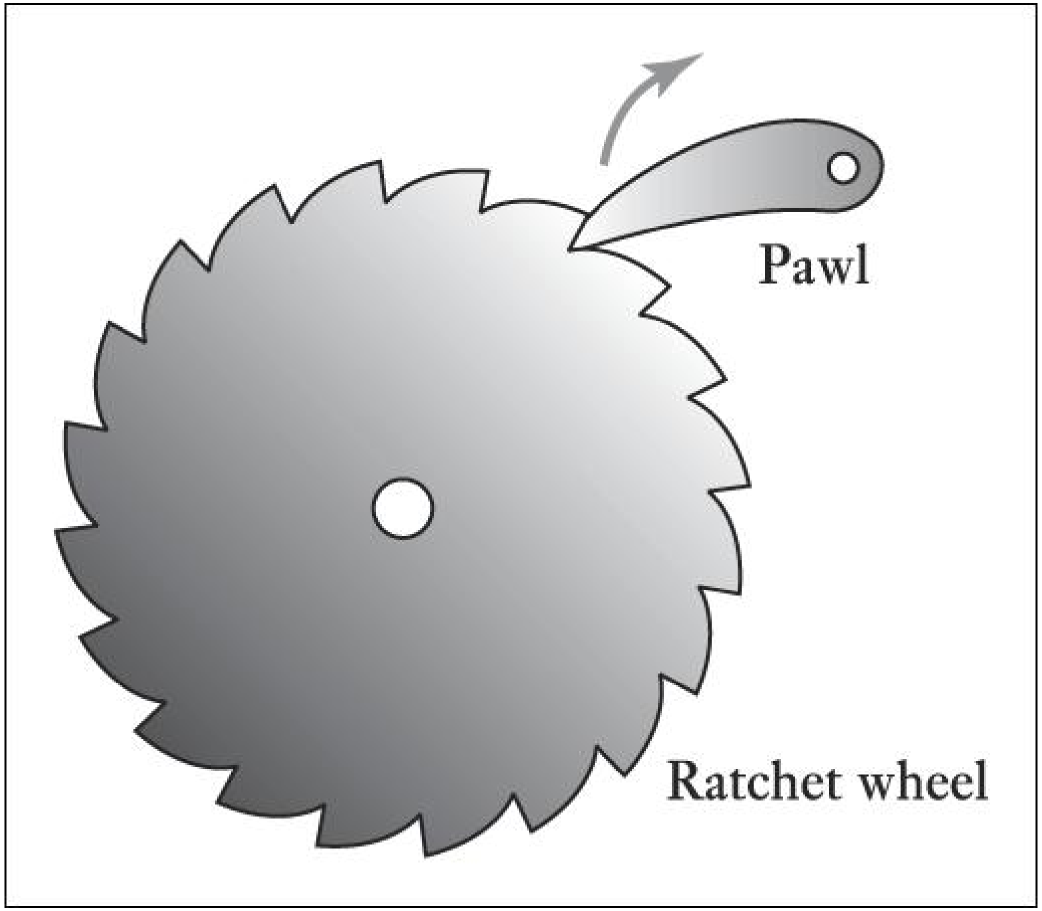
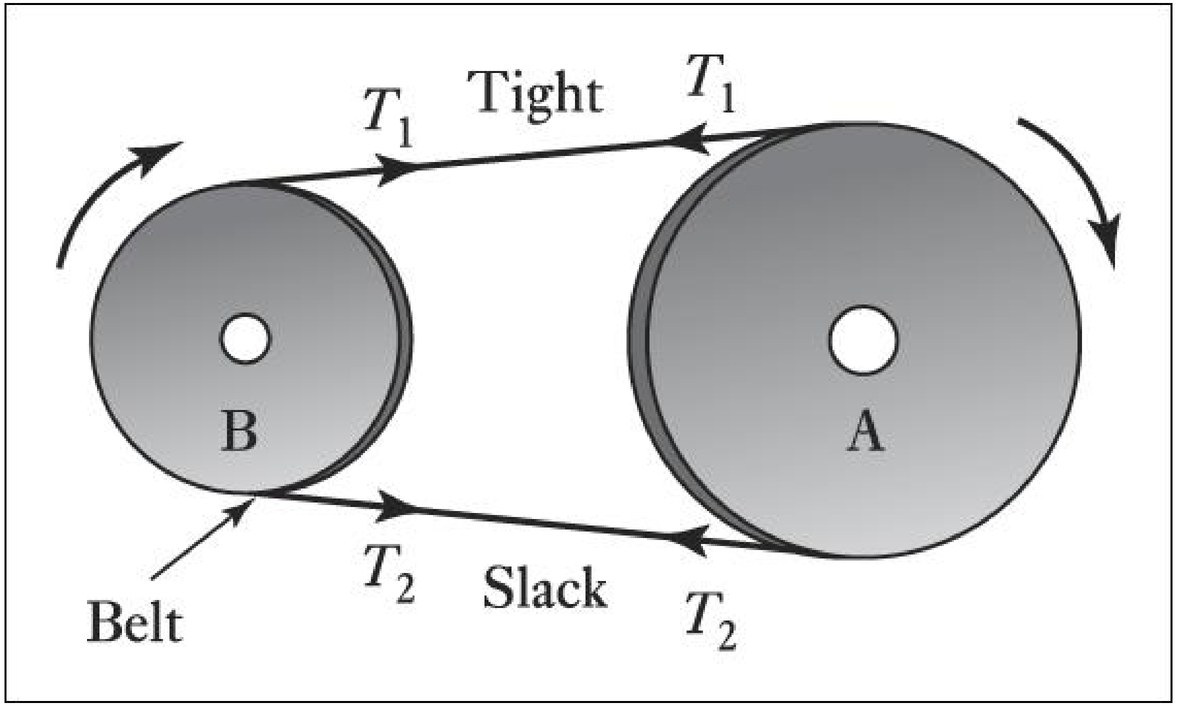


Figure 8.19 Ratchet and pawl

8.7 Belt and chain drives



$$\text{torque on A} = (T_1 - T_2)r_A$$

$$\text{torque on B} = (T_1 - T_2)r_B$$

$$\text{power} = (T_1 - T_2)v$$

Figure 8.20 Belt drive

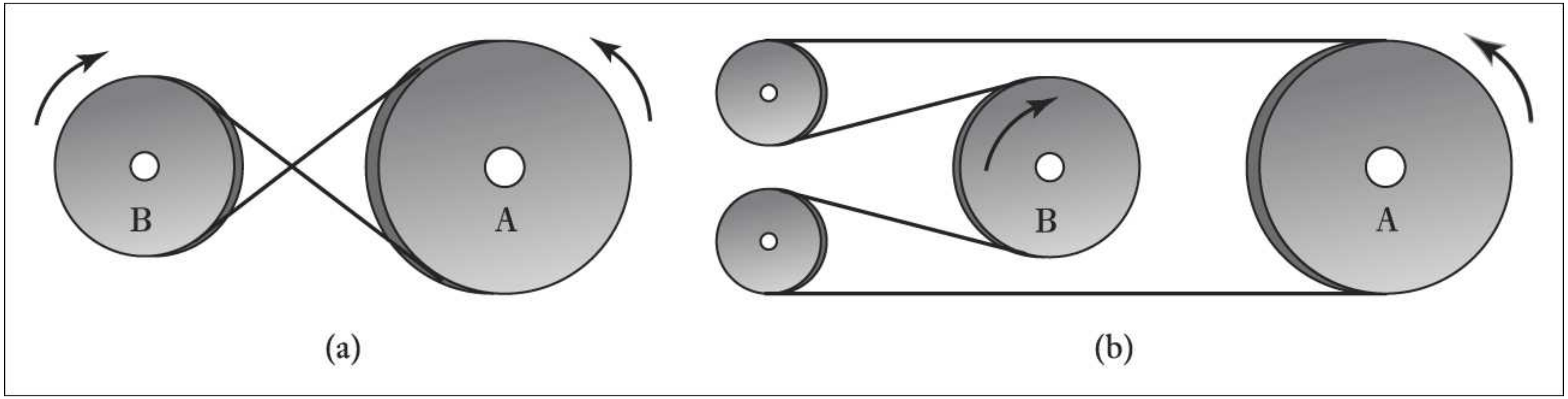


Figure 8.21 Reversed belt drives: (a) crossed belt, (b) open belt

8.7.1 Types of belts

- 1. Flat
    - The belt has a rectangular cross-section. Such a drive has an efficiency of about 98% and produces little noise. They can transmit power over long distances between pulley centers. Crowned pulleys are used to keep the belt from running off the pulleys.

- 2. Round
    - The belt has a circular cross-section and is used with grooved pulleys.

- 3. V
    - V-belts are used with grooved pulleys and are less efficient than flat belts but a number of them can be used on a single wheel and so give a multiple drive.

- 4. Timing
    - Timing belts are toothed wheels, having teeth which fit into the grooves on the wheels. The timing belt, unlike the other belts, does not stretch or slip and consequently transmits power at a constant angular velocity ratio. The teeth make it possible for the belt to be run at slow or fast speeds.

8.7.1 Types of belts

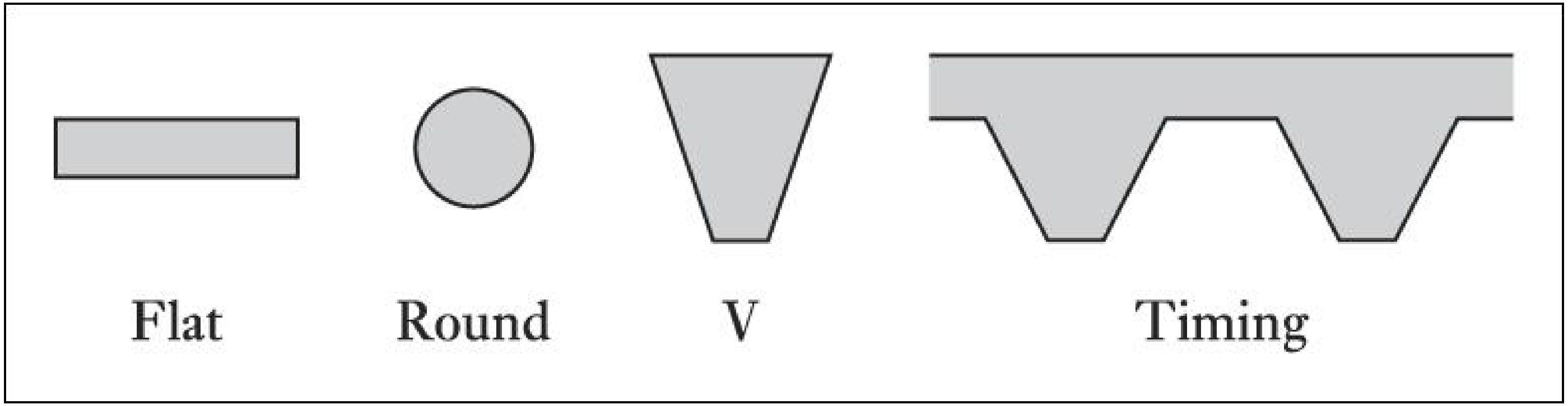


Figure 8.22 Types of belts

8.7.2 Chain

- Large torque but noisy

8.8 Bearings

8.8.1 Plain journal bearings

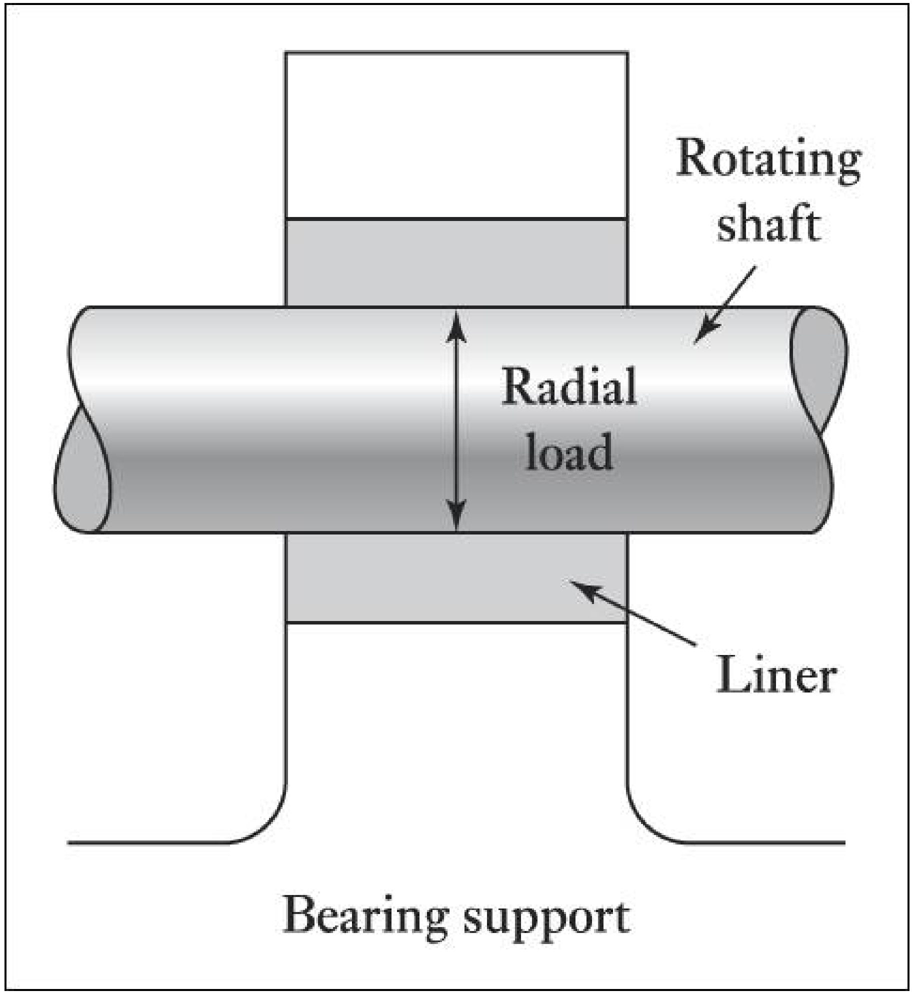


Figure 8.23 Plain journal bearing

- Lubrication
  1. hydrodynamic

  2. hydrostatic

  3. Solid-film

  4. Boundary layer

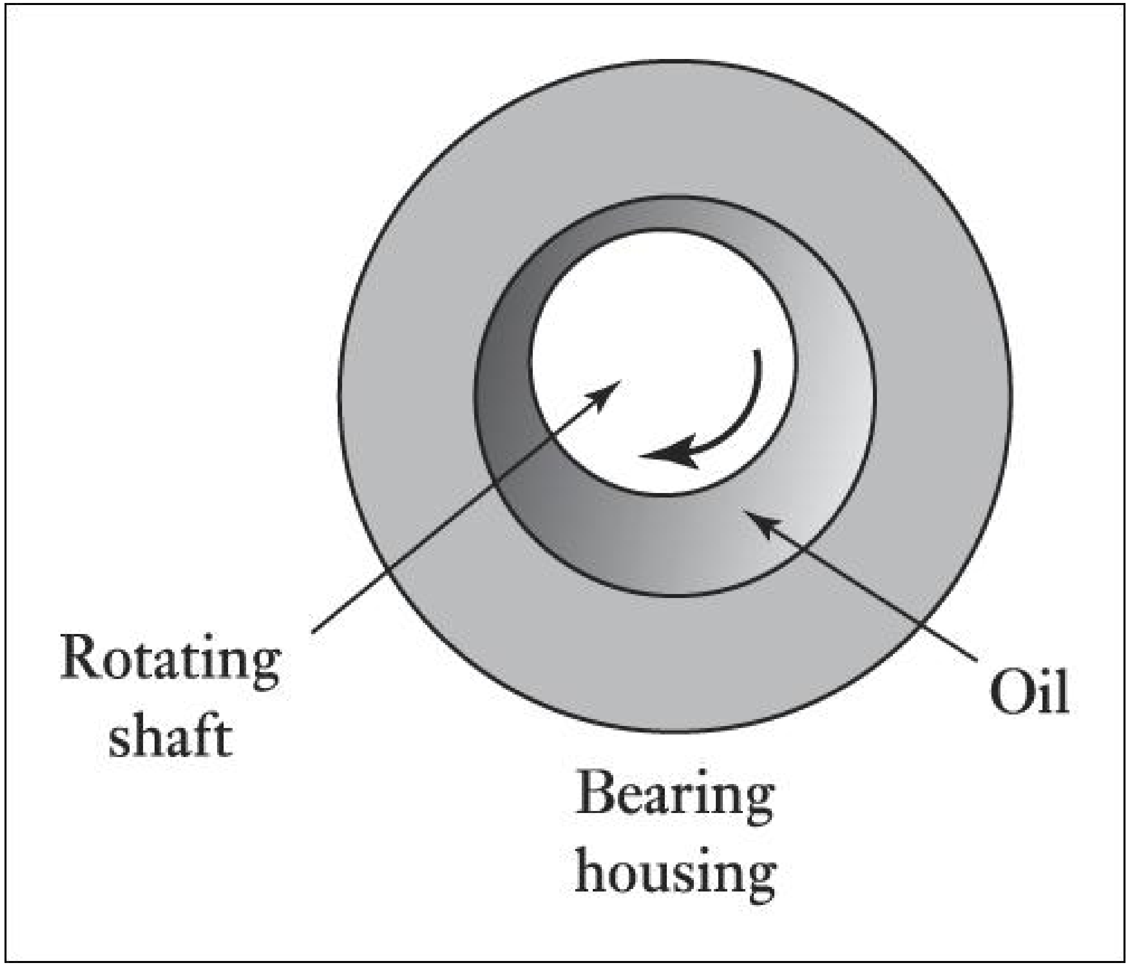


Figure 8.24 Hydrodynamic journal bearing

8.8.2 Ball and roller bearings

Ball Bearing

1. Deep-groove
2. Filling-slot
3. Angular contact
4. Double-row
5. Self-aligning
6. Thrust, grooved race

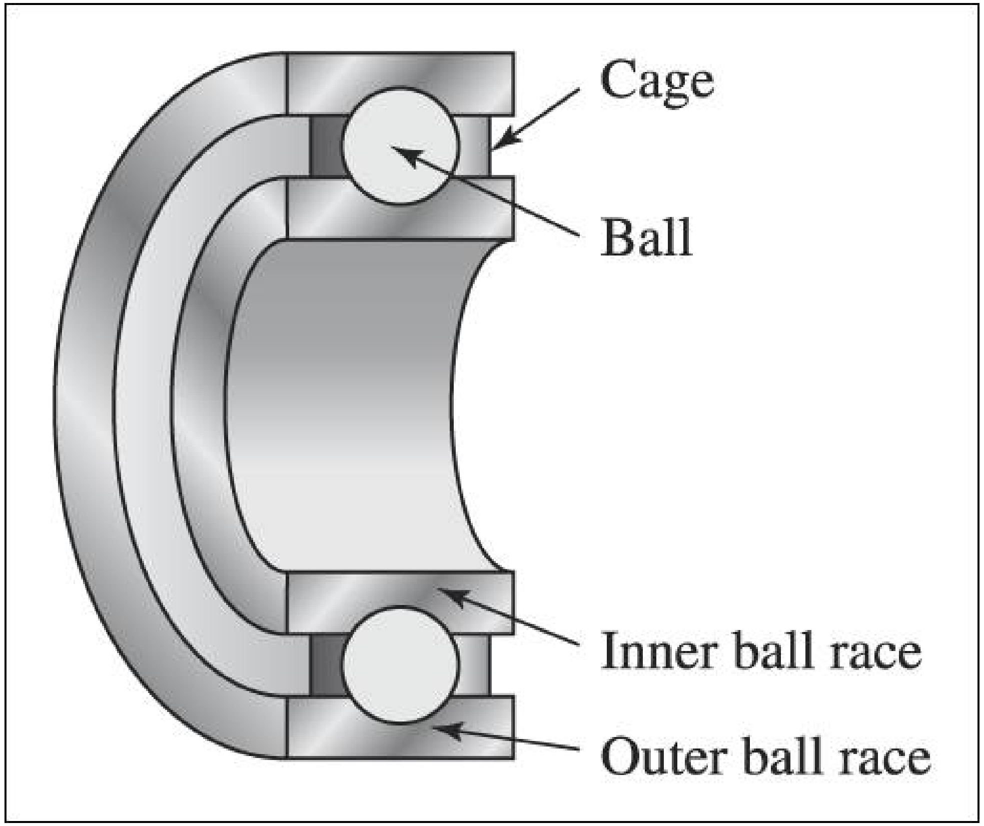
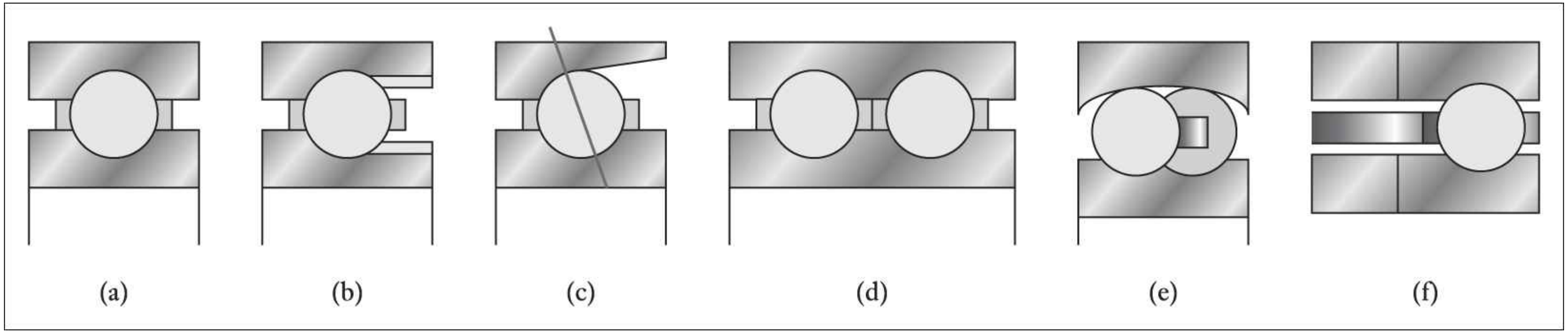


Figure 8.25 Basic elements of a ball bearing



(a) Deep-groove (b) Filling-slot (c) Angular contact

(d) Double-row (e) Self-aligning (f) Thrust, grooved race

Figure 8.26 Types of ball bearings

- **Roller Bearing**

1. Straight roller (a)

2. Taper roller (b)

3. Needle roller (c)

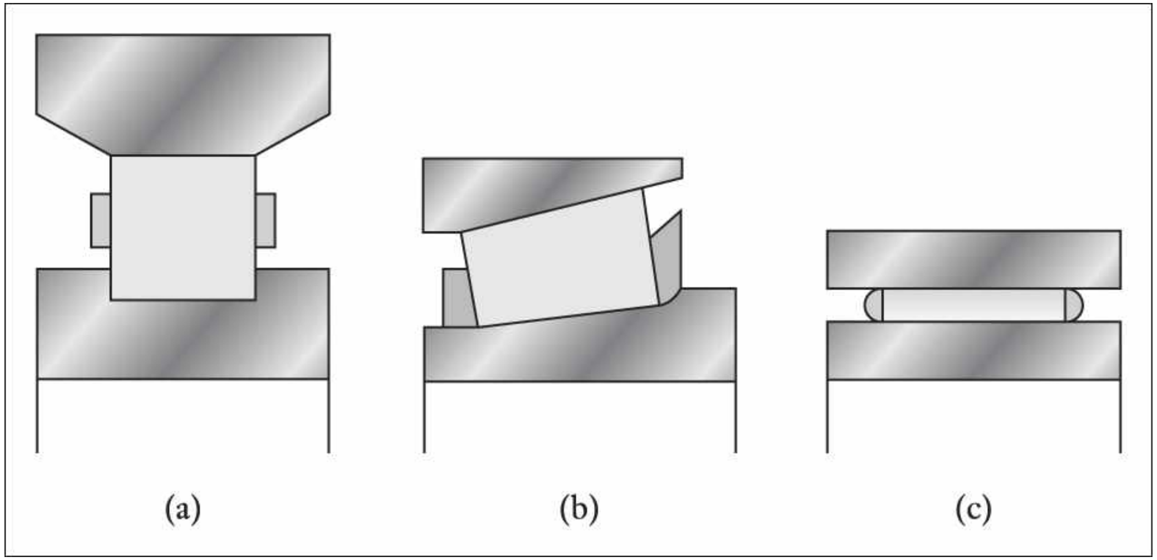


Figure 8.27 Roller bearings

8.8.3 Selection of bearing

- In general, dry sliding bearings tend to be used only for small-diameter shafts with low-load and low-speed situations, ball and roller bearings, i.e. bearings involving rolling with a much wider range of diameter shafts and higher load and higher speed, and hydrodynamic bearing for high load with large-diameter shafts.

8.9 Mechanical aspects of motor selection

8.9.1 Moment of inertia

- moment of inertia: I_L
- Angular acceleration: α
- Torque: $I_l\alpha$
- Motor Torque: $T_M=I_M\alpha_M$
- Load Torque: $T_L=I_L\alpha_L$
- Power for system driving: $(T_M+T_L)\omega$

$$\text{power} = (I_M + I_L)\alpha\omega$$

- The power is generated in motor:

$$T = \left(I_M + I_L\right)\alpha$$

- Rule of thumb : $I_M=I_L$

- Gear ratio: $G=\omega_L/\omega_M$
- Angular acceleration: $\alpha_L=G\alpha_M$
- Motor torque: $T_M=I_M\alpha_M$
- Load torque: $T_L=I_L\alpha_L$
- Total torque: $T_M\alpha_M+T_L\alpha_L$
- Power

$$\text{power} = \left(I_M + G^2 I_L\right)\alpha_M \omega_M$$

- Motor Torque

$$T_M = \left(I_M + G^2 I_L\right)\alpha_M$$

- Rule of thumb:

$$I_M=G^2I_L$$

8.9.2 Torque

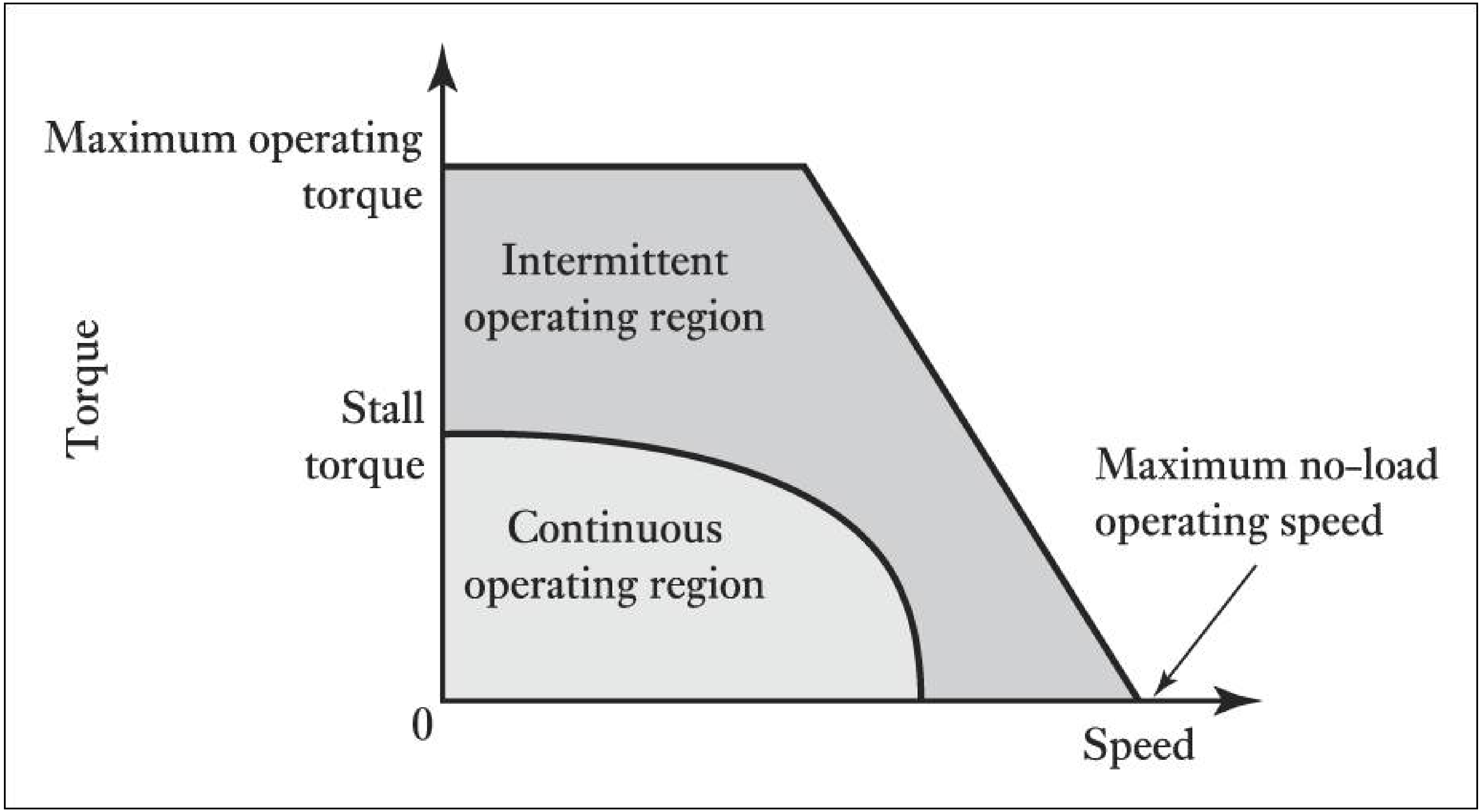


Figure 8.28 Torque-speed graph