Mechanics

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1. Features of machines

Human beings have limited physical strength. Machines therefore are needed to increase force or speed or to facilitate the application of force. There are various types of machines. For example, a car jack (Fig. 1a) can be used to save our energy, so that we can use a smaller effort to raise a heavy car.

Fig. 1 (a) Car jack to multiply force (b) Machines for increasing speed (bicycle)

Another typical example is the bicycle (Fig. 1b). We can move more quickly on a bicycle than on foot. There are also other types of machines, which do not save energy or increase velocity, but are used to change directions of the applied forces conveniently. A fixed pulley is one of the typical examples.

A machine is composed of different components called machine elements. Simple machines comprise a few machine elements and can operate individually, for example, bottle openers, scissors, pulleys and screw jacks. Machines composed of two or more simple machines are called compound machines. Examples are linkage, chain and sprocket of the bicycle, car engines etc.

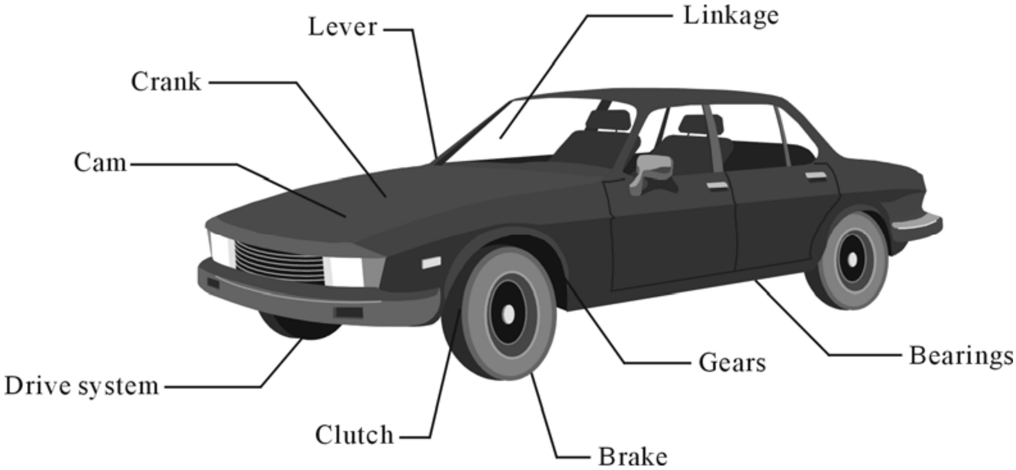
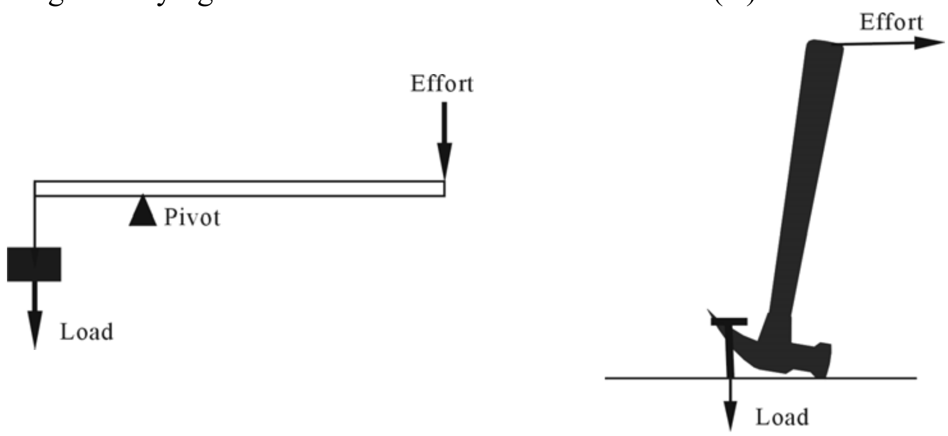


Fig. 2 Structure of a car

Nowadays, people use more and more machine elements to increase the efficiency of machines. Take a car as an example. It is composed of many machine elements like lever, linkage, drive system, belts, bearings, clutch, gears, crank, cam, brake and ratchets. Furthermore, a screw jack can be used to raise the car for changing the tyres. Pulleys are often used in repairing the engines. To know the applications of technologies, we must understand the principles for the working of the machine elements.

(a) Load and effort

With appropriate machines such as levers, we can use a smaller force to raise a heavy weight. A load is the weight the machines need to move or lift. An effort is the force applied to the machines for lifting or carrying a load. Both are measured in Newton (N).



(a) Lever (b) Claw hammer

Fig. 3 Some examples of load-effort relationships.

(b) Mechanical Advantage

If the applied force can raise a heavier load through a machine, the machine can save effort. Mechanical Advantage (MA) is the ratio of load to effort, and does not have any unit.

$$\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}}$$

OR

$$\text{MA} = \frac{L}{E}$$

If MA>1, then L>E, meaning that a heavier load can be moved by the effort. The larger the MA is, the smaller the effort to be applied to the machine will be. However, in practice, friction and the weight of the machine also affect the weight to be lifted as well as the Mechanical Advantage.

Example 1:

If the effort is 250 N and the load is 1000 N. What is the Mechanical Advantage of the block and tackle system as shown in the diagram below?

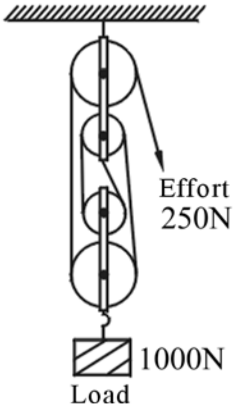


Fig. 4 Block and tackle system

Solution:

Mechanical Advantage = $= \dfrac{Load}{Effort} = \dfrac{1000\,\text{N}}{250\,\text{N}} = 4$

(c) Velocity Ratio

Refer to the block and tackle system in Fig. 4, if the load needs to be raised by 1 m, the effort has to be pulled 4 m downwards. Therefore, the moving velocity for both load and effort is not the same. Velocity Ratio (VR) is the ratio of the distance moved by effort (d_E) to the distance moved by load (d_L). It does not have any unit.

$$\text{Velocity Ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

OR

$$VR = \frac{d_E}{d_L}$$

For instance, in Fig. 4, when the load is raised by 1 m, the effort has to pulled the string by 4 m downwards. Therefore, the velocity ratio for the block and tackle system is:

$$\frac{4\,\text{m}}{1\,\text{m}} = 4$$

The velocity ratio of machines is governed by their design. It depends on the weight of the machines and the friction.

If the velocity ratio of a machine is less than one (VR < 1), then $d_E < d_L$, indicating that the machine can be used to increase velocity. For example, the velocity ratio of a bicycle is less than 1.

Example 2 :

When a lever is used to raise a load by 2 m, the effort has to move 5 m. Find the VR of the machine.

Solution:

Velocity Ratio of the lever = $VR = \frac{5\text{ m}}{2\text{ m}} = 2.5$

(d) Work done

The work done by a force on an object is equal to the force applied to such object multiplied by the distance moved along the direction of force by the object. Work done also refers to the energy required to move the object. Therefore, the unit is Joule (J).

Work done = Force × Distance moved

OR

$$W = F \times s$$

Example 3 :

A pulley system is used to lift a load. When the applied effort of 250 N moves downwards by 4 m, the load of 900 N is raised by 1 m.

Find

(a) The work done by the effort.

(b) The work done by the load.

(c) Why is the work done by the effort larger than the work done by the load?

Solution:

(a) The work done by effort = effort × the distance moved

$= F \times s$

$= 250 \times 4$

$= 1000$ J

(b) The work done by load = 900 × 1 = 900 J

(c) Part of the work done by effort (energy) is dissipated to overcome friction and to raise the pulley system.

(e) Efficiency

When the effort of the machine moves, the work done will be changed into mechanical energy called input energy. This input energy will be converted into output energy to move the load. The remaining energy will be used to overcome friction or to move the machine. The energy is said to be lost as shown in Fig. 5.

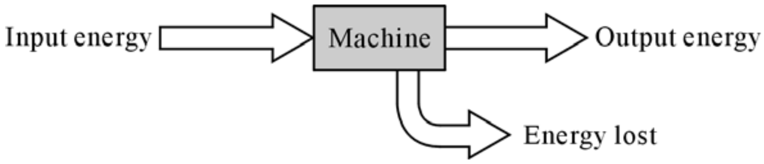


Fig. 5 Conversion of energy in machines

The efficiency of a machine refers to the ratio of output energy to the total input energy. It is expressed in a percentage.

Efficiency = (Output Energy / Input Energy) × 100 %

If all input energy is converted into output energy, the efficiency of the machine is 100%. As part of the energy input is used to overcome friction and part converted to the kinetic energy of the moving parts, the efficiency of all machines must be less then 100%.

If work done is used to represent the input and output energy, efficiency can be represented by:

$$Efficiency = \frac{Output\ energy}{Input\ energy} = \frac{L \times d_L}{E \times d_E} = (\frac{L}{E}) \times (\frac{d_L}{d_E}) = MA \times (\frac{1}{VR})$$

Efficiency = (Mechanical Advantage / Velocity Ratio) × 100%

Considering the time taken for energy conversion, efficiency can be represented by:

Efficiency = (Output power / Input power) × 100%

The common way to increase the efficiency of a machine is to reduce friction as well as the weight of the moving part so as to reduce energy loss.

Example 4 :

In a machine an effort of 500 N is applied to move up a load of 2000 N. When the load is raised by 0.6 m, the effort moves a distance of 6 m. Find (i) the input energy, (ii) the output energy, and (iii) the efficiency of the machine.

Solution:

(i) Input energy = work done by the effort = 500 × 6 = 3000 J

(ii) Output energy = work done by the load = 2000 ×0.6 = 1200 J

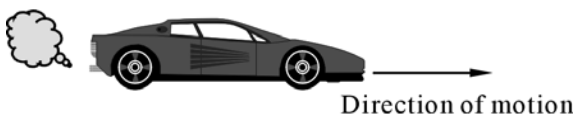
(iii) Efficiency = Output energy / Input energy = 1200/3000 × 100% = 40%

2. Classifications of motions

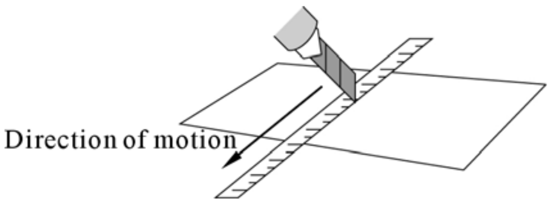
When a machine is operating, some parts of it will undergo motion in various forms. Typical motions include linear motions, rotary motions, oscillating motions and reciprocating motions.

(a) Linear motions

If an object moves along a straight line, its motion is called a linear motion. Linear motions are very common, for example, the motion of the saw blade in cutting wood, the motion of a car moving forwards and the motion of a cutter in paper cutting along a straight rule (Fig. 6).



(a) A car moving forwards

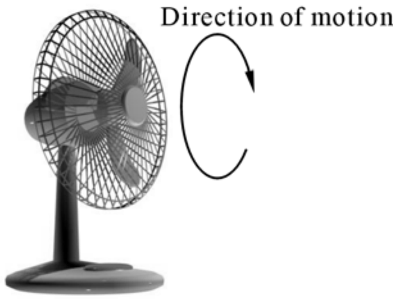


(b) Motion of paper cutting under the coordination of a ruler

Fig. 6 Examples of linear motion

(b) Rotary motion

If an object rotates along a fixed point as centre in a clockwise or anti-clockwise direction, its motions is called a rotary motion. For instance, the motion of the blades in a mixer, the motion of the blades in an electric fan and the motion of the bit of a hand drill (Fig. 7).



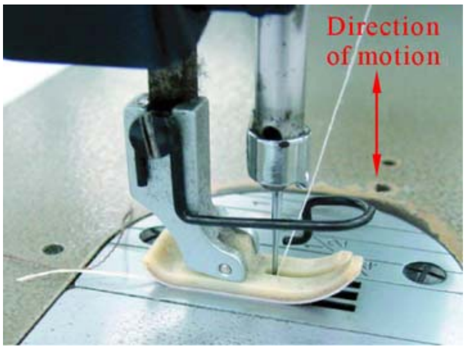
(a) The motion of blades in an electric fan

(b) The motion of the bit of a hand drill

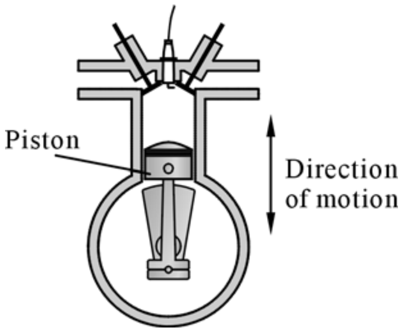
Fig. 7 Examples of rotary motion

(c) Reciprocating motion

If an object moves to and fro in a straight line continuously within a fixed region, its motion is called a reciprocating motion. For example, the upward and downward motions of the needle of a sewing machine, the saw-blades of a jigsaw and the piston in engines are reciprocating motions (Fig. 8).



(a) Motion of the needle in the sewing machine

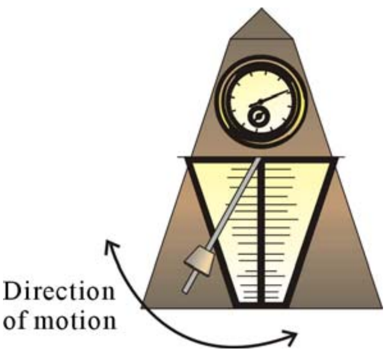


(b) The motion of the piston in the engine

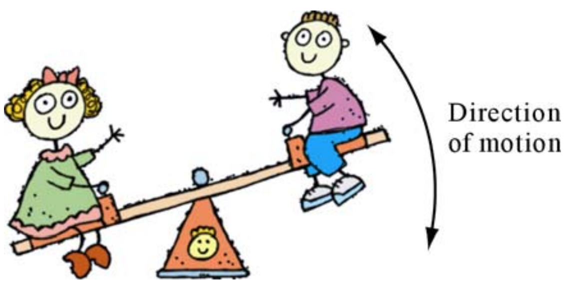
Fig. 8 Examples of reciprocating motion.

(d) Oscillating motion

If an object moves along an arc at a distance from a fixed point as centre, its motion is called an oscillating motion. The motion of a pendulum, a seesaw and the Pirate Boat in Ocean Park are all examples of oscillating motions (Fig. 9).



(a) The motion of swinging pendulum



(b) The motion of seesaw

Fig. 9 Examples of oscillating motion.

3. Applications of mechanical components

(a) Pulley

Pulleys and the block and tackle system are common machines to raise heavy objects (Fig. 10). Pulleys can be classified as fixed pulley and movable pulley.

Fig. 10 Block and tackle system in the cranes

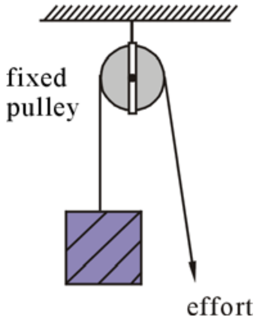


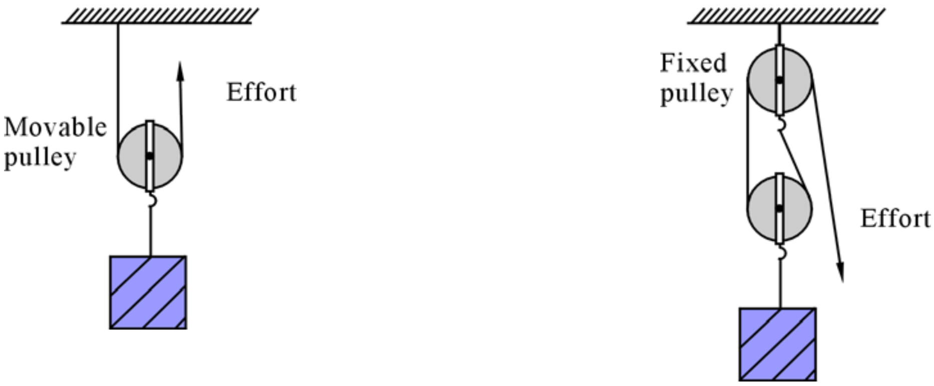
Fig. 11 Fixed pulley

(i) Fixed pulley

Fig. 11 shows a fixed pulley. It does not save effort. Its main function is to change the direction of the effort for easy application of the force.

(ii) Movable pulley

The movable pulley in Fig. 12a can be used to lift a heavier load. To change the direction of the effort, a fixed pulley can be added (as shown in Fig. 12b). However, the fixed pulley will not change the velocity ratio but to make the application of the effort in a downward direction easier.

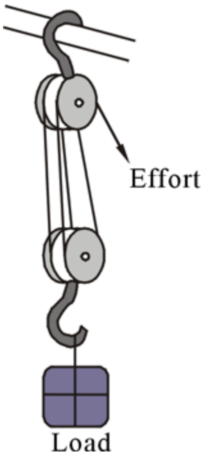


(a) (b)

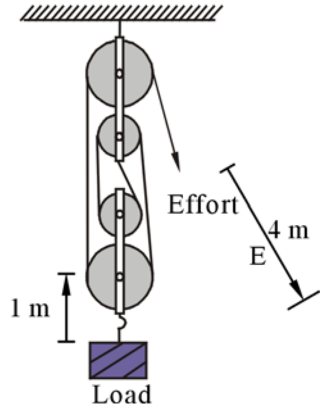
Fig. 12 Movable Pulley

(iii) Block and tackle system

The block and tackle system is a combination of several pulleys. A common block and tackle system includes a rope linking both fixed and movable pulleys. In practice, the pulleys are linked with the symmetric axes (Fig. 13a). However, in order to show the structure of the system clearly, we often separate the pulleys as shown (Fig. 13b).



(a)



(b)

Fig. 13 Block and Tackle System

The velocity ratio of the block and tackle system can be determined by the number of sections of the rope. In general, the velocity ratio of the block and tackle system is:

> Velocity Ratio (VR)
> = Number of sections in the rope of the movable pulleys in the block and tackle system.

Therefore, the velocity ratio in the block and tackle system in Fig. 13b is 4.

When designing the block and tackle system, a lighter pulley should be used because the weight of the movable pulleys will affect the efficiency. Furthermore, the rope or steel wire should not be twisted together. When using the block and tackle system, the tensile strength of the rope should be noted, in order to calculate the upper limit of the load. This is to avoid the breaking of the rope in raising heavy load. Furthermore, every section of the steel wire should be checked regularly to avoid breaking.

Example 5

If the block and tackle system in Fig. 13b is used to lift a load of 300 N, the effort required is 100 N.

(a) Find the Mechanical Advantage of the system.

(b) Find the efficiency of the system.

(c) Why is the efficiency less than 100%? Give two reasons.

Solution

(a) $MA = \frac{L}{E} = \frac{300}{100} = 3$

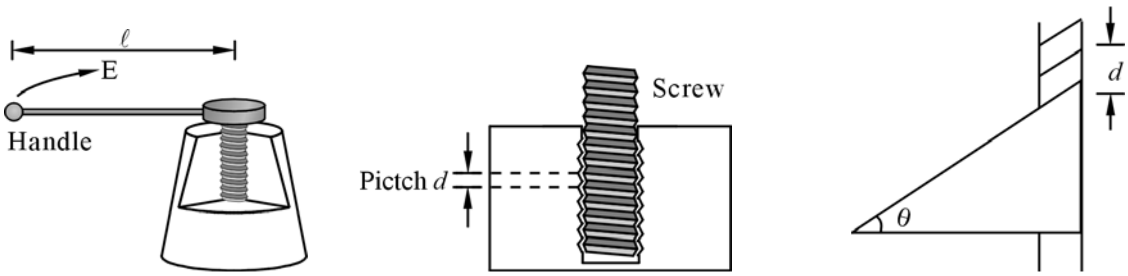
(b) Velocity Ratio (VR) = Number of sections in the rope of the system = 4

$$\text{Efficiency} = \frac{MA}{VR} = \frac{3}{4} \times 100\,\% = 75\,\%$$

(c) It is because part of the energy is being used to

1. overcome friction;
2. raise the movable system.

(b) Screw mechanism



(a) Screw jack (b) Pitch (c) Inclined plane on the screw

Fig. 14

Machines using screw are called screw threads mechanism. For example, a screw jack is a common screw mechanism. These mechanisms have very large velocity ratio and mechanical advantage. Therefore, they can be used to lift a large load. Its working principle is shown in Fig. 14a. When the handle has moved a complete revolution, the screw will move up a pitch. The threads of screw can be viewed as compressing of inclined planes wrapping around the screw (Fig 14c).

(a) G-shaped pliers

(b) Golden vice

Fig 15

Fig. 15 shows some examples of screw mechanisms. There are various types of screw threads. Table 1 shows some common characteristics and their applications

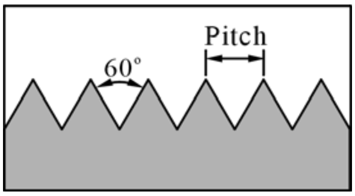
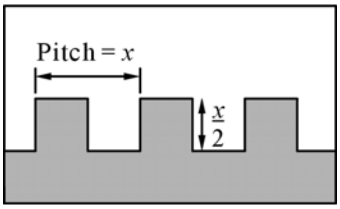
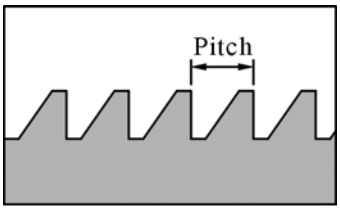
Screw Thread	**Cross-section**	**Characteristics**	**Applications**
V-shaped thread (triangular thread)		• Most commonly used • Slightly different between International standard and British standard • Often used in clamping tools	To fix screw, bolt, stud, screw cap, etc.
Square screw thread		• Most effective transmission of force • Commonly used in movable parts in a machine	Machine vice, screw jack, etc.
Saw-teeth thread		• Often used in unidirectional transmission of force • Often used in clamping tools	Wooden vice, speedy open-close mechanism

Table 1

The friction of screw mechanism is very large. Therefore, its efficiency is very low. However, friction is very useful. For instance, when the load is raised by the screw jack, friction can prevent the load from falling down even after the applying force has stopped. Lubricating oil can be added to reduce the friction of the screw mechanism.

(c) Lever

Lever is a simple machine. It consists of a tough and straight rod pivoted at a fulcrum (Fig. 16). The main function of the lever is to change the direction and magnitude of the force applied. Its applications include: crowbar, scissors, staplers and bottle openers (Fig. 17).

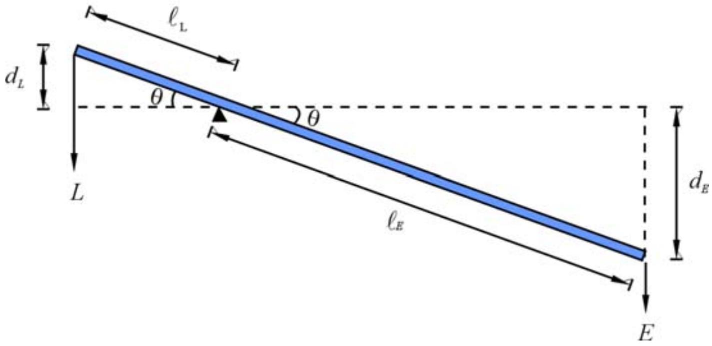


Fig. 16 Simple lever

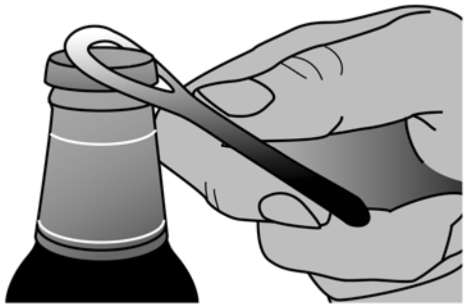


Fig. 17 Bottle opener

Using the ratio of the edges of the similar triangles in Fig. 16, we can find the velocity ratio of the lever.

$$VR = \frac{d_E}{d_L} = \frac{\ell_E}{\ell_L} = \frac{\text{distance between effort and pivot}}{\text{distance between load and pivot}}$$

If the distance between the load and pivot is shorter than the distance between the effort and pivot, the distance moved by the effort is larger than the distance moved by the load, i.e. VR>1.

Example 6:

In Fig. 18, the length of the crowbar is 0.8 m. The distance between the load and pivot is 0.2 m. An effort of 200 N has to be applied to move the load of 600 N.

(a) Find the Velocity Ratio of the crowbar.

(b) Find its efficiency.

(c) Why is its efficiency smaller than 1? Explain briefly.

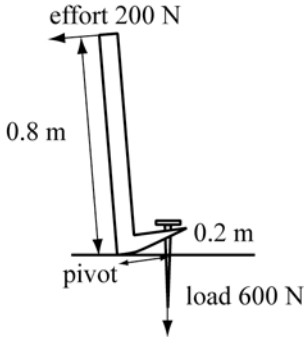


Fig. 18

Solution:

(a) Velocity Ratio (VR) $= \dfrac{l_E}{l_l} = \dfrac{0.8}{0.2} = 4$

(b) Mechanical Advantage (MA) $= \dfrac{L}{E} = \dfrac{600}{200} = 3$

$$Efficiency = \frac{\text{MA}}{\text{VR}} = \frac{3}{4} \times 100\% = 75\%$$

(c) Some energy is dissipated to overcome friction and to move the crowbar.

There are various applications for levers. Levers are classified into three main types according to the positions of pivot, load and effort. Table 2 lists the features, functions and the examples of these three types of levers.

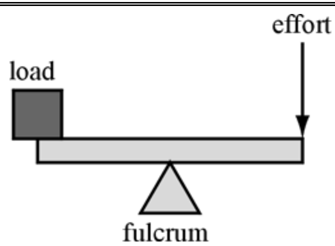
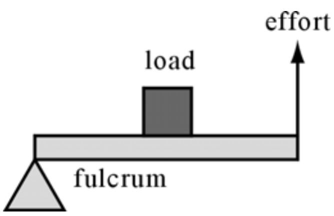
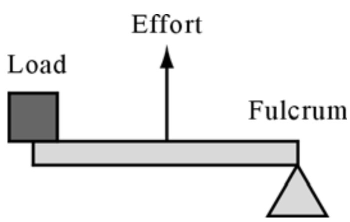
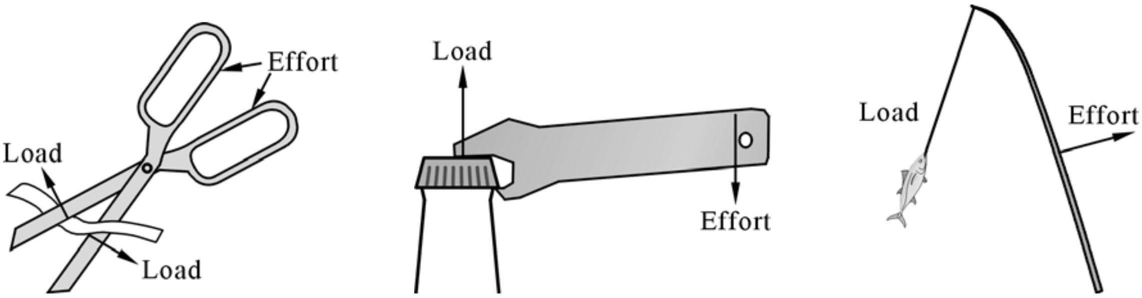
Type of Lever	Type 1	Type 2	Type 3
Diagram			
Features	Pivot lies between the load and effort.	Load lies between the pivot and effort.	Effort lies between the load and pivot
Functions	Change the magnitude and direction of effort	Save effort to move a larger load	Easier to apply force
Examples	Scissors, crowbar	Bottle opener, nutcracker	Fishing rod, bread tongs

Table 2



(a) Type 1 lever (b) Type 2 lever (c) Type 3 lever

Fig. 19 Examples of levers

When designing the levers, note the limit of the load and select appropriate materials of the levers. For example, if aluminium is used to make a bottle opener, the part where the load lies will bend easily. Therefore, a thicker aluminium should be selected. Similarly, crowbar, nutcracker and spanner should be able to bear a larger load. Furthermore, several sets of levers can be combined together to form tools that save more effort. For instance, nail cutter uses two sets of levers to increase its shearing force.

(d) Linkage

Linkage is made up of a set of levers. It is mainly used to change the direction of motions and to transmit motions. Motions in linkage can be classified as parallel, reverse, perpendicular and rotary. There are numerous applications for linkages, such as the limbs of robots and walking mechanisms.

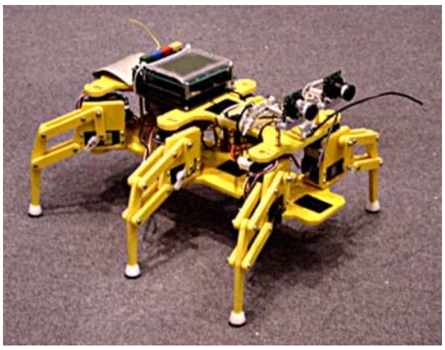
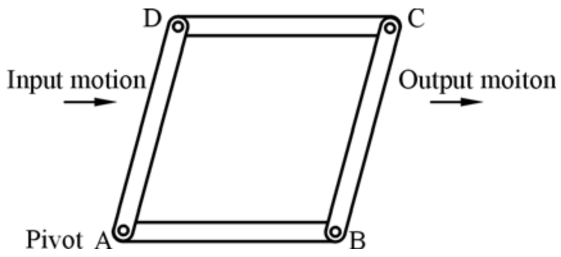


Fig. 20 (a) Robot (b) Walking mechanisms

(i) Parallel motion of linkage mechanism

In parallel motion of linkage mechanism, the input motion is converted into parallel output motion as shown in Fig. 21a. Fig. 21b shows an application of parallel motion in a tools box. Other examples are windscreen wipers, parallel rulers and magnifying drawing tools.



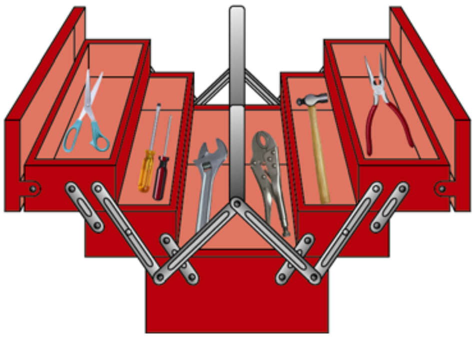
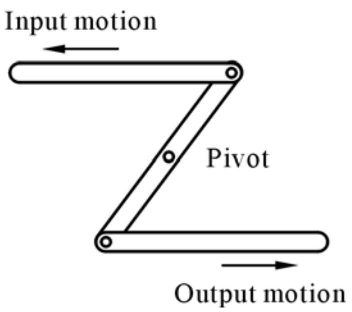


Fig. 21 (a) Parallel motion of linkage mechanism (b) Tools box

(ii) Reverse motion of linkage mechanism

In reverse motion of linkage mechanism, the input motion is converted into output motion in a reversed direction, as shown in Fig. 22a. An application of the reverse motion is the fire tongs in Fig. 22b.



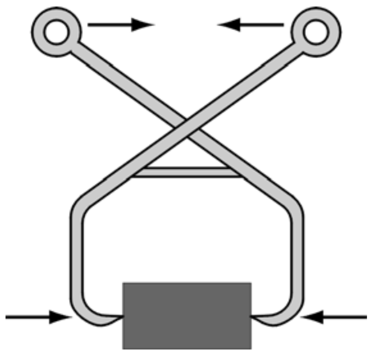


Fig. 22 (a) Linkage mechanism of reverse motion (b) Fire tongs

(iii) Perpendicular motion of linkage mechanism

In the perpendicular motion of linkage mechanism, the input motion is converted to a perpendicular output motion as shown in Fig. 23a. This can be applied to the aluminium can compressor as shown in Fig. 23b.

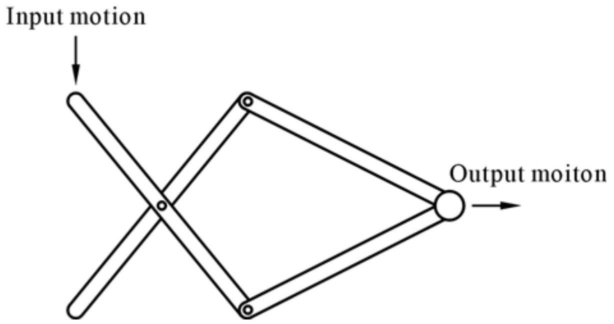
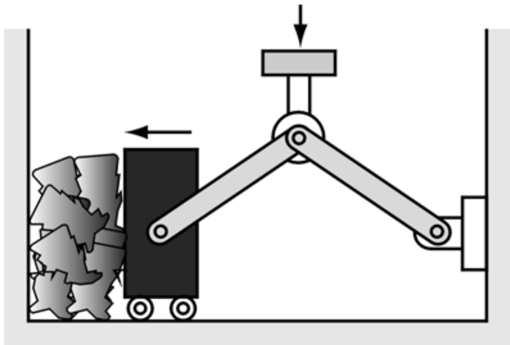


Fig. 23 (a) Perpendicular motion of linkage Mechanism



(b) Aluminium can compressor

(iv) Rotary motion of linkage mechanism

In rotary motion of linkage mechanism, the linear input motion is converted into rotary output motion. One typical example is the crankshaft and linkage mechanism in car engines. (Fig. 24b)

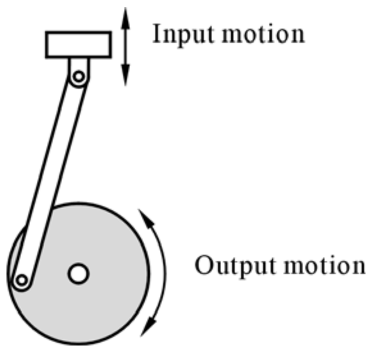
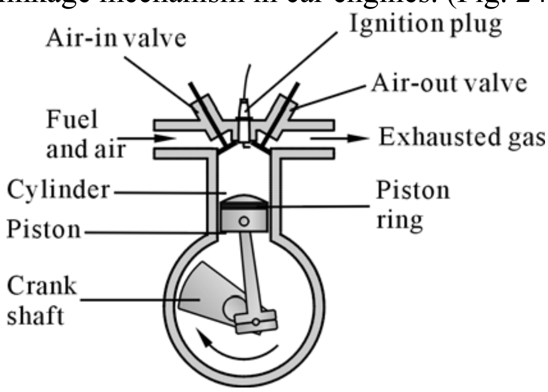


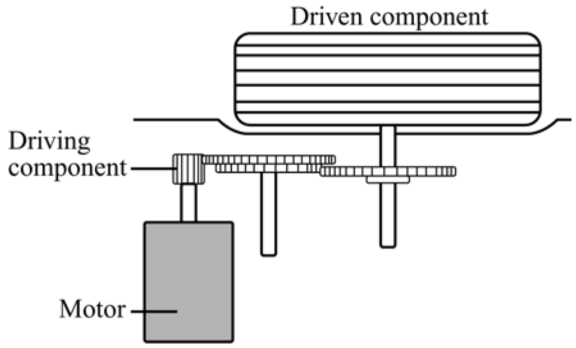
Fig. 24 (a) Rotary motion of linkage system



(b) Crankshaft and linkage mechanism in car Engines

(e) Driving system

In mechanical motion, the specific part of the machine responsible for producing driving force is called the driving component. The part driven by the driving component is called the driven component. The driving system refers to the mechanical parts responsible for transmitting motion. The power source usually comes from human beings, engines and motors. Take a toy car in Fig. 25a as an example. The driving force is produced by the motor. It is the driving component. The rear wheels are driven. They are called the driven component.



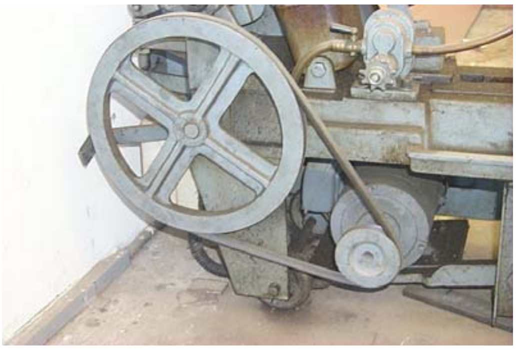
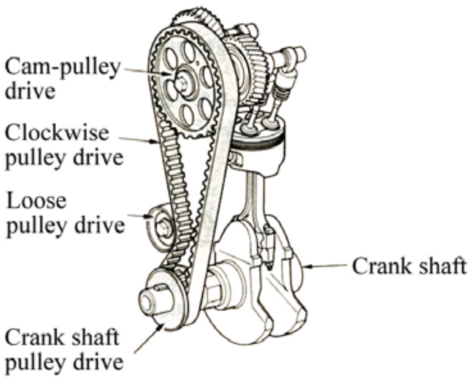


Fig. 25 (a) Driving component and driven component (b) Driving system in machine

Engines and motors can provide momentum for machines for a long time. Their driving forces are produced in the form of rotary motion. Therefore most of the driving systems use rotating shaft with the driving and driven components. As shown in Fig. 25b, when the motor of lathe rotates at a high speed, it will produce a driving force to swirl the rotating shaft. It then use the belt to transmit the motion to the rotating wheel through its rotating shaft, and set the gears in motion.

When designing the driving systems, the rotating shaft should fit with the key groove of the machines components to obtain the best result. Furthermore, in order to suit the needs of design, various transmission mechanisms can be used. For example, levers, linkages, cam, crank, gears, belts, ratchets, chain, etc.

(f) Belt



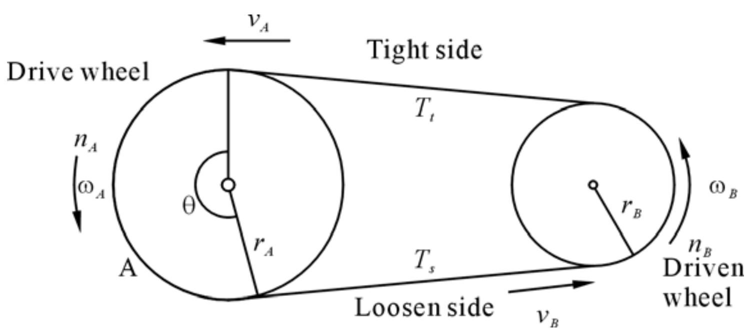


Fig. 26 (a) Belt and pulley of car engine (b) Belt and pulley

Belt and pulley, or simply called the belt, is mainly used to transmit the rotating driving force from the drive wheel to the driven wheel (Fig. 26a). The pulley is often made from materials like iron, steel, nylon etc. Materials like leather, rubber, fibre, etc, are often used in making the belts. Referring to Fig. 26b, the ratio of belt and pulley can be represented by

$$\text{Velocity Ratio} = \frac{\text{Rotational speed } n_A \text{ of the drive wheel A}}{\text{Rotational speed } n_B \text{ of the driven wheel B}} = \frac{\text{Radius } r_B \text{ of the driven wheel B}}{\text{Radius } r_A \text{ of the drive wheel A}}$$

As shown in the equation, rotational speed of the wheel is inversely proportional to its radius. Therefore, driven wheels with smaller diameters can produce a faster output motion (Fig. 27a) but with a smaller driving force. On the other hand, driven wheels with a larger diameters can produce a slower output motion (Fig. 27b) but with a larger driving force.

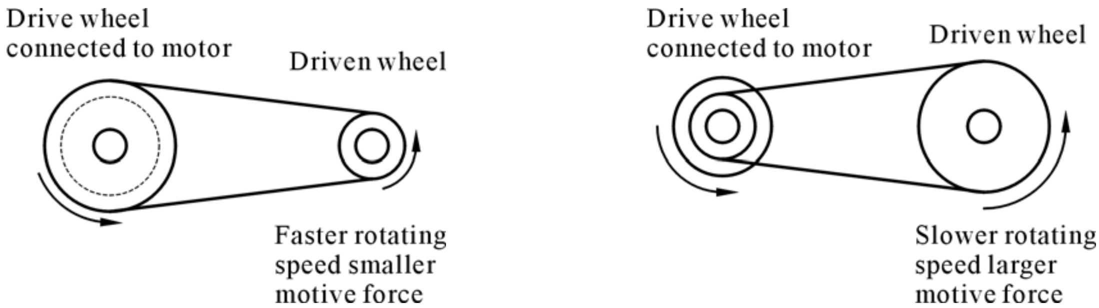


Fig. 27 (a) Driven wheel with smaller diameter (b) Driven wheel with larger diameter

Pulley and belt can be classified into three main types: round-shaped belt, v-shaped belt and flat belt. Table 3 list their main characteristics.

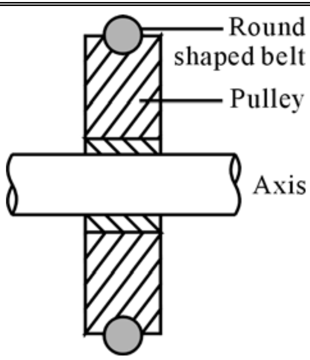
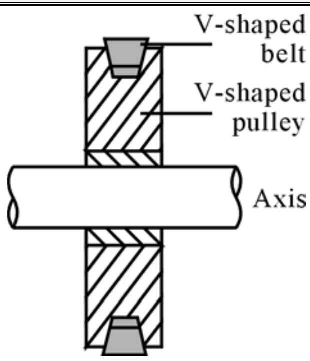
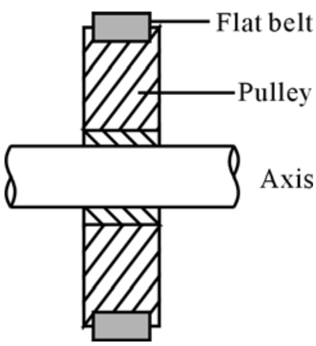
Belt	Round-shaped belt	V-shaped belt	Flat belt
Structure			
Characteristics	Simple structure	Suitable for linkage of two near axles	Does not produce excess torsion
Application of driving machines	Sewing machine, motor and washing machine	Woodwork machine, drilling machine	Grinding machine

Table 3

In general, the rotary directions of both the driven wheel and the drive wheel are the same. However, if the belt is positioned across the driven wheel and drive wheel (Fig. 28), they can move in opposite directions. It should be noted that this method is only applicable to flat belts. To prevent the belt from loosing or falling out of the rail, components are added to increase the tension of the belt.

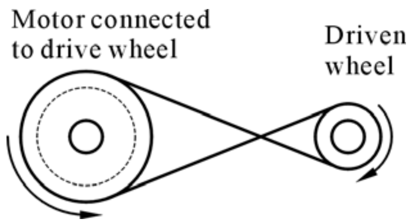


Fig. 28 Wheel system with a crossing belt

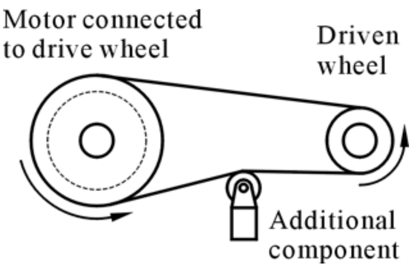


Fig. 29 Additional component to increase tension

In designing and connecting the belts, the two rotating axles of the wheels should be parallel. Otherwise, it will affect the efficiency of the transmitting motion. The belt should be checked regularly. Cracks should be repaired or the belt should be replaced as quickly as possible. Rubber belts should be replaced at regular intervals to prevent the belt from ageing and loosing which can reduce its transmitting efficiency. A protective cover is usually installed on the belt to avoid dragging nearby objects accidentally.

(g) Chain and sprocket

A chain is made of a set of rings linked together. A sprocket is a wheel with saw-teeth shape. To combine, the two sprockets with different sizes are installed in the driving axle and the driven axle respectively, as shown in Fig. 30.

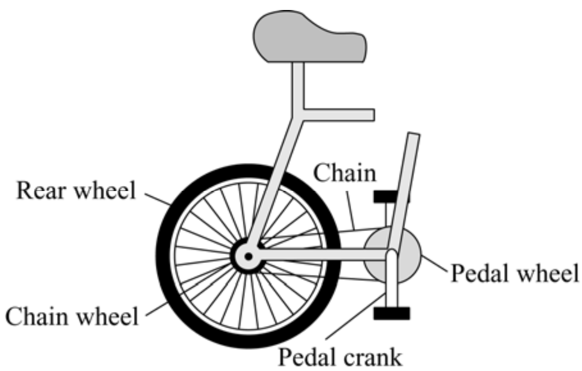


Fig. 30 Chain and sprocket

Chains and sprockets are often used to transmit rotational driving force from the same direction. For instance, most bicycles use chains and sprockets to transmit motion. Using chains and sprockets with different number of teeth can produce various driving forces. In designing the chain and sprocket, note the distribution of the chain hole and the teeth of the sprocket to make sure that they fasten each other precisely.

(h) Bearing

The functions of bearing is to fix, support and guide the rotating axle or sliding component in machines (Fig. 31). For instance, the bearing in the car wheels needs to support the weight of the whole car. There are many types of bearings. They can be roughly categorized into sliding bearing and rolling bearing.

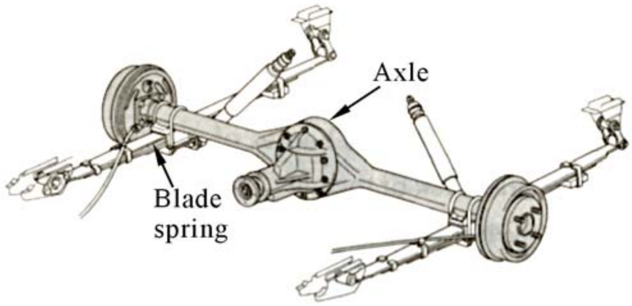
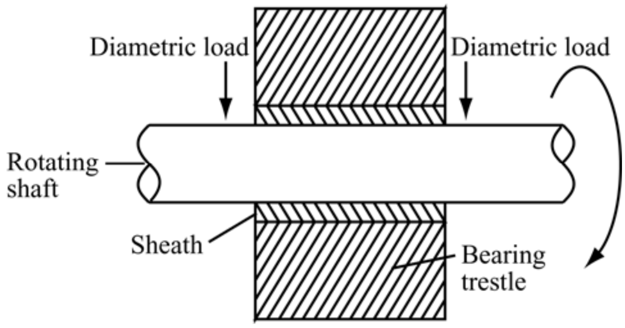


Fig. 31 Car bearing

Sliding bearing includes journal bearing (Fig. 32a) and thrust bearing (Fig. 32b). Journal bearing is used to support the load in the direction of diameter, i.e. the diametric load. Thrust bearing is used to support the axle or which the load lies on, i.e. axial load.



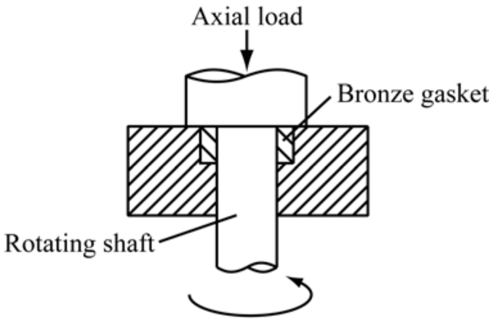
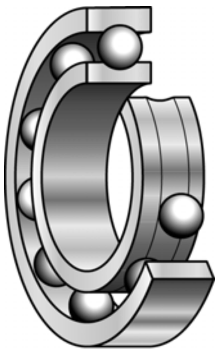


Fig. 32 (a) Journal bearing (b) Thrust bearing

Rolling bearing can reduce the friction produced by the rotating shaft when it rotates. Examples of rolling bearing include ball bearing (Fig. 33a) and roller bearing (Fig. 33b). Ball bearing uses balls as a medium between the fixed components and the rotating components, such as the moving parts at the bottom of a gate. Roller bearing works similarly as ball bearing but it uses cylinders instead of balls.



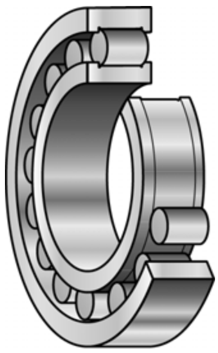
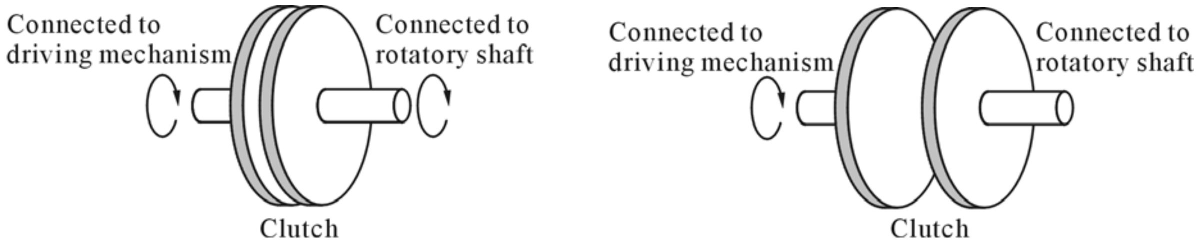


Fig. 33 (a) Cross section of ball bearing (b) Cross section of roller bearing

The distribution of load should be noted when designing the bearing. If the load is too heavy, the bearing would bend and affects its rotation. This will increase friction and may damage the bearing. Bearings at the two sides of the rotating axle should be parallel. To ensure smooth rotation, lubricant should be applied regularly to the bearing to reduce friction.

(i) Clutch

A clutch is used to connect or disconnect the rotating shaft and driving mechanisms. Fig. 34a shows how a clutch works. One side of the clutch is connected to the driving mechanism, and the other side is connected to the rotating shaft. When the clutch is in contact, the rotating shaft will rotate with the driving mechanism. When the clutch is separated, the driving force will not be transmitted to the rotating shaft (Fig. 34b).



(a) Clutch is in contact (b) Clutch separated

Fig. 34 Working of a clutch

There are many different types of clutch. Jaw clutch and friction clutch are commonly used clutches.

(j) Jaw clutch

Fig. 35a shows a jaw clutch. It has a simple structure. When the control arm moves, the two halves of the clutch will be in contact (Fig. 35b). As the two halves collide, they will vibrate violently.

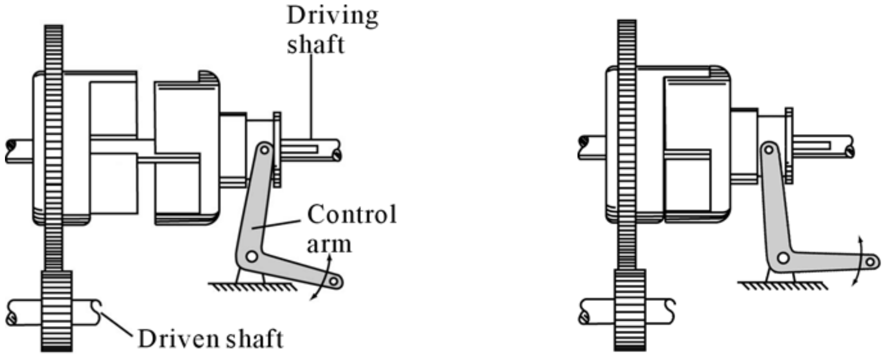
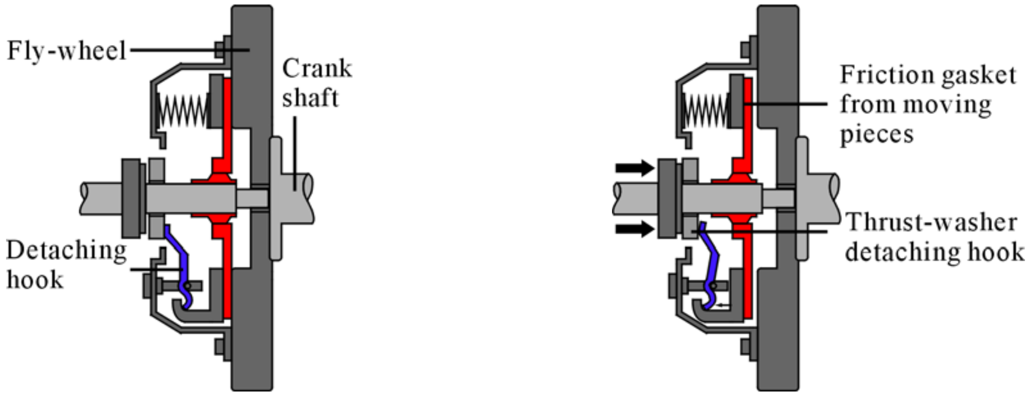


Fig. 35 (a) Clutch separated (b) Clutch in contact

(k) Friction clutch

Cars always use friction clutch to transmit driving force. Fig. 36a shows a helical compression spring friction clutch. Its moving piece is a thin circular disk with friction gaskets on both sides. The spring compresses the moving piece on the flywheel to make the clutch in contact. Friction between the touching interfaces transmits the driving force from the engine to the rotating shaft.

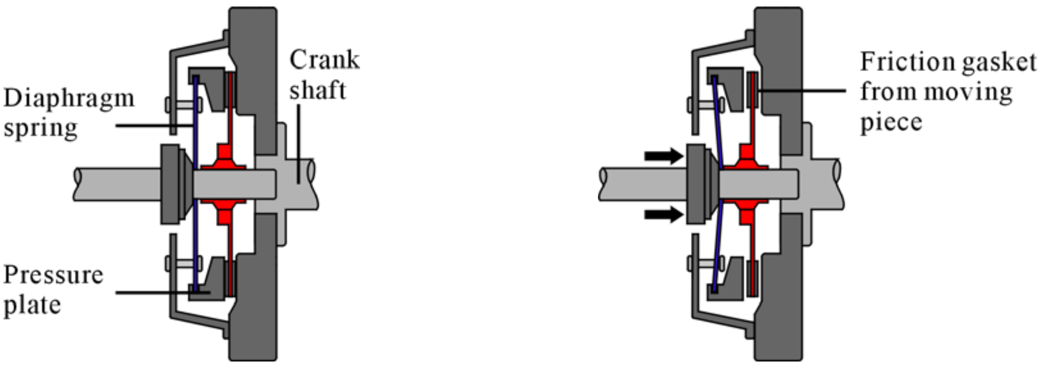
To separate the clutch, we can press on the clutch pedal. As shown in Fig. 36b. The oil compression system will transfer the driving force and pull the pressure plate up. This separates the moving piece and the flywheel.



(a) Clutchin contact (b) Clutch separated

Fig. 36 Working of helical compression friction clutch

Another type of clutch is the diaphragm spring friction clutch (Fig. 37a). It requires less pedaling force. Therefore, it is used in most cars today. The diaphragm spring in the clutch compresses the pressure plate and the moving piece on the flywheel to keep the clutch in contact. To separate the clutch, press the clutch pedal. The oil compression system will transfer the driving force to the clutch and bend the diaphragm spring and the clutch will then be separated.



(a) clutch attached (b) clutch separated

Fig. 37 Working of diaphragm spring friction clutch

The elastic-force produced by the clutch must be great enough to make the moving piece to compress on the flywheel. This will raise the efficiency of transmitting the driving force. Besides, to install the clutch, the flywheel and the centre of rotation in the clutch should lie on a straight line.

(l) Crank and slider mechanism

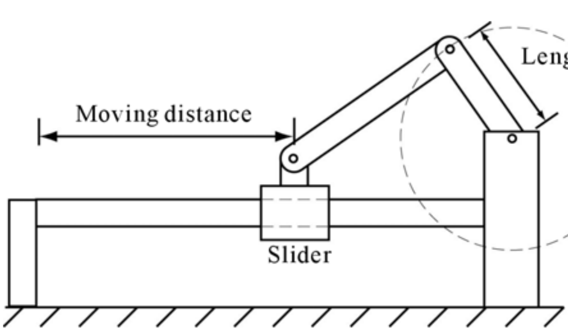


Fig. 38 Relationships between crank and slider

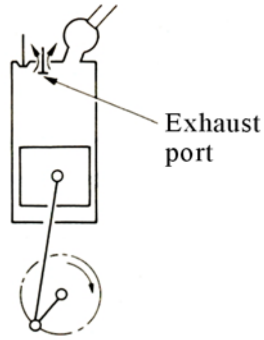


Fig. 39 Piston and crank in car

In crank and slider mechanism, a rotary motion is changed into a reciprocating motion (Fig. 38). Electric jigsaw is an example of crank and slider mechanism. The relationships between the crank and the slider is as follows:

Distance moved by the slider = 2 times the length of the crank

OR

$$d = 2R$$

On the other hand, the slider can be used to rotate the crank. For instance, in the cylinder of a car, the reciprocating motion of the piston will drive the crank to rotate (Fig. 39). The rotating shaft of the crank and the moving direction of the slider is perpendicular to ensure the slider can move smoothly. Lubricant oil should be applied to the crank to reduce friction and increase efficiency. Before a long crank is used, it should be appropriately designed to prevent bending, for example, a U-shaped cross-section is suitable for use.

(m) Cam

A cam is a wheel with a very special shape. Its chief function is to change the rotary motion into reciprocating motion (Fig. 40). A driven component can make use of external force (such as its own weight or the force of a spring) to keep in contact with the cam.

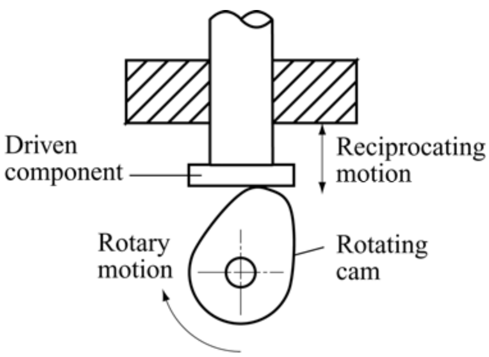


Fig. 40 Cam and a driven component

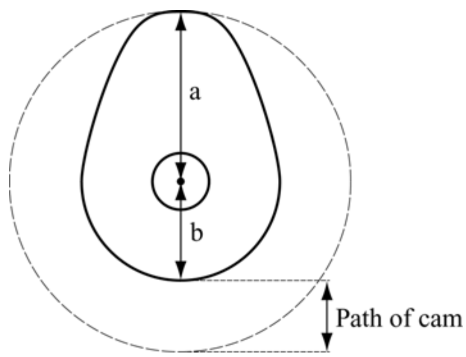


Fig. 41 The relationships between the cam and its path

Referring to Fig. 41, the path of a cam caused by its rotation can be represented as:

Path d = distance a - distance b

The working of a cam is that when the cam is rotating, the driven component will move upwards and downwards. Therefore, it can control the opening and closing of the air valve in the car engine. There are different shapes and functions of cams. Table 4 lists some common examples.

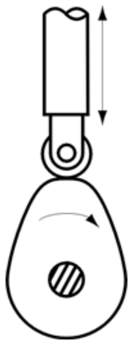
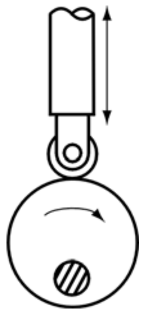
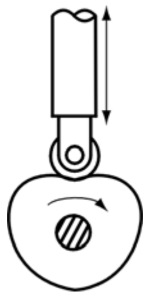
Cam examples	**Pear–shaped cam**	**Eccentric cam**	**Heart-shaped cam**
Structure			
Function	Controls gas valve and piston	Controls steam valve in steam engine	Control the bobbin of sewing machine

Table 4 Common examples of cam

Some cams have their unique shapes. Table 5 shows some examples.

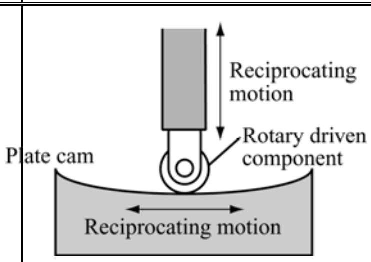
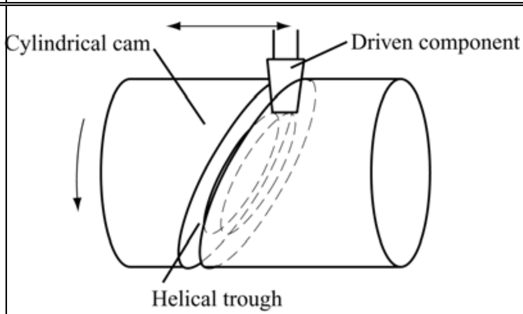
Cam examples	**Linear cam**	**Cylindrical cam**
Structure		
Function	Controls automatic sawing machine	Controls the mechanics in the sewing machine

Table 5 Unique types of cam

Cams need to bear a large load and friction. They should be made with tough materials and appropriate dimensions. However, if the weight of the cam is too heavy, it will affect the rotation. So, tough but light material such as hard aluminium can be used to reduce weight. Besides, suitable bearing and lubricant can be used to reduce friction when it rotates.

(n) Ratchet and Pawl

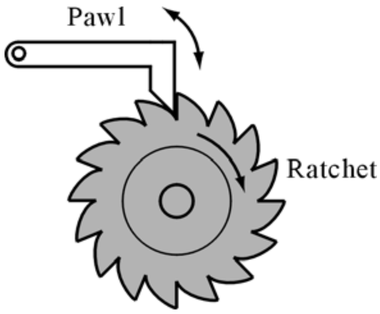


Fig. 42 Ratchet and pawl

Ratchet and pawl can be used to prevent the rotating shaft from moving in the opposite direction. Fig. 42 shows a set of ratchet and pawl. When the ratchet moves in a clockwise direction, the pawl will let every saw-shaped tooth pass. However, if the ratchet moves in an anti-clockwise direction, the pawl will be locked into the base of the ratchet so that the ratchet cannot move. One typical example is the straightening of the volleyball mesh with the use of ratchet mechanism.

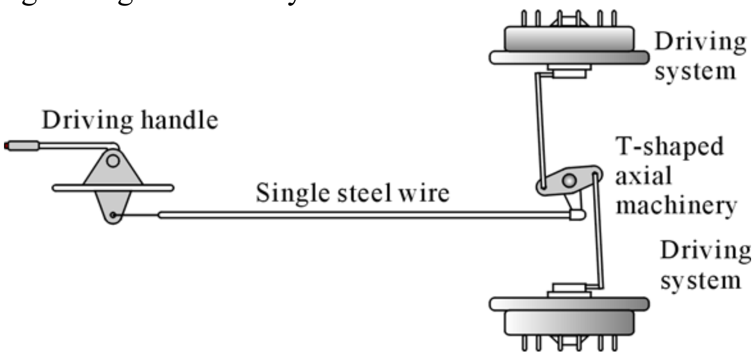
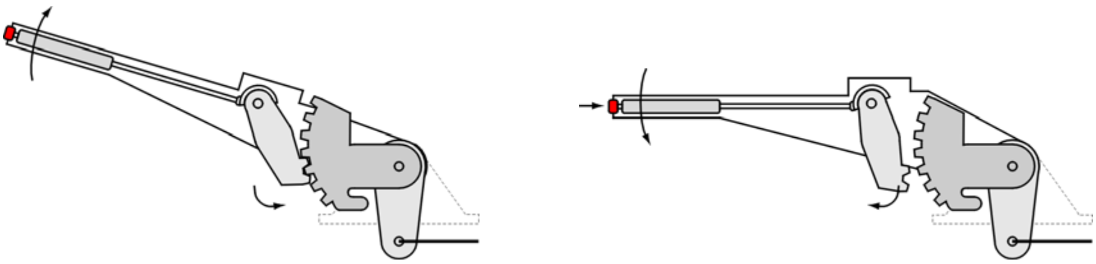


Fig. 43 Manual-brake system

The manual-brake system in car also makes use of ratchet and pawl. It is used to prevent the car from sliding down when it is parked on a slope.

It makes use of the hand-brake to tighten the steel wire and then lock the wheel (Fig. 43). When the hand-brake is being held tight, the pawl blocks the ratchet and locks the hand-brake in a chosen position and the spring presses on the spring hinge (Fig. 44a). When the spring hinge is being pressed, the pawl will separate from the ratchet. The hand-brake can then move freely (Fig. 44b).



(a) Hold the hand-brake (b) Release the hand-brake

Fig. 44 Ratchet system in manual-brake

Another application of ratchet and pawl is to change the swinging action of the pawl into a periodical and uni-directional rotary motion (Fig. 45). This can be applied to the metal sawing machine.

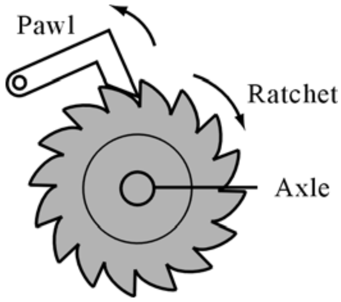


Fig. 45 Pawl driving the ratchet

In designing the ratchet and pawl system, care should be taken to fit them together. Besides, their rotating shafts must be parallel. If they need to withstand a large rotational force, they must be made from a tougher material.

(o) Gear

(i) Simple gear

A gear is a commonly used part in machines. Its chief function is to change velocity, the magnitude of driving force and the direction of motion. The part responsible for input of driving force is called a driving gear, while the one responsible for the output is called a driven gear.

Fig. 46a shows a simple gear combination. When the driving gear of 20 teeth has rotated once, the driven gear has moved twice. From this we know that the smaller the number of teeth in the gear, the faster the rotational speed. Conversely, in Fig. 46b, the driven gear will rotate slower. Therefore, when a gear is connected to other gears, the rotational velocity is inversely proportional to the number of teeth in the gear.

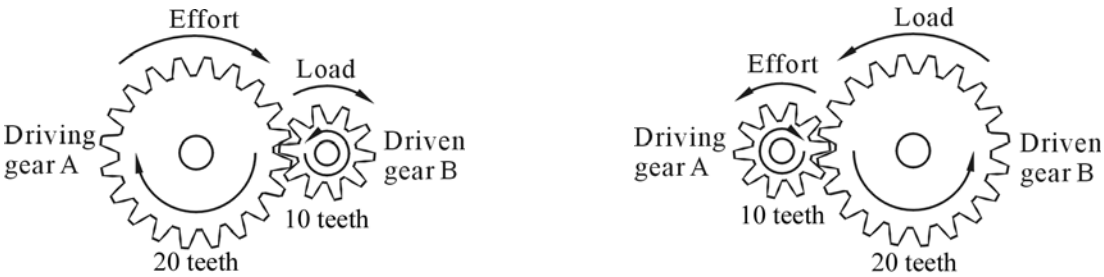


Fig. 46 (a) Produce a higher speed (b) Produce a larger force

Therefore, the velocity ratio of the gear can be represented as:

$$\text{Velocity Ratio (VR)} = \frac{\text{Rotational speed of the driving gear}}{\text{Rotational speed of the driven gear}} = \frac{\text{Number of teeth in the driven gear}}{\text{Number of teeth in the driving gear}}$$

If the rotational speeds of gear A and gear B are n_A and n_B respectively, and their number of teeth are t_A and t_B respectively, then

$$VR = \frac{n_A}{n_B} = \frac{t_B}{t_A}$$

Therefore, in Fig. 46a the velocity ratio of the gear is: VR = 10/20 = 0.5

Conversely, in Fig. 46b, the velocity ratio of the gear is: VR = 20/10 = 2

(ii) Gear mechanism

Gear mechanism is made up of several gears. They can change the direction and the distance of the transmitted motion. Fig. 47a shows some simplified driving gear A and driven gear B. They are rotating in opposite directions. In Fig. 47b, if gear C is added, then the rotating directions of gear A and B are the same. However, gear C will not affect the rotational speed of gear A and gear B, gear C is called an idle gear. In fact, as shown in Fig. 47c, no matter how many gears between gear A and gear B have been added, the rotational speeds of gear A and gear B are the same. Nevertheless, they can change the rotational directions of gear B and the distance between gear A and gear B.

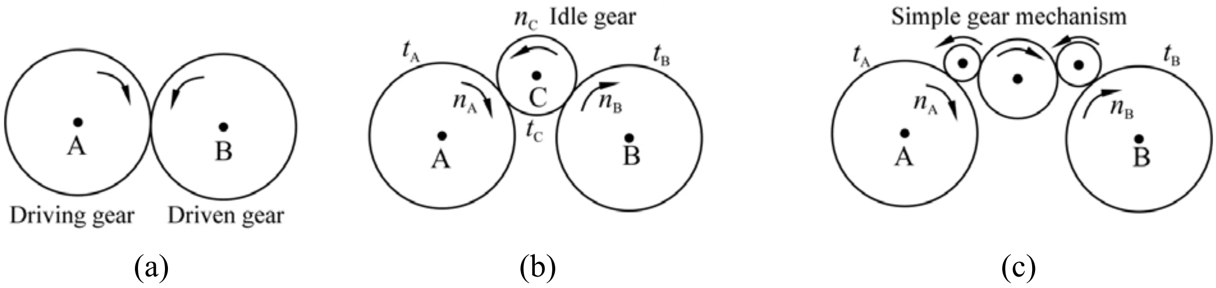


Fig. 47

(iii) Compound gear mechanism

Simple gear mechanism with high speed is very bulky and expensive. Therefore, compound gear mechanism is often used. As shown in Fig. 48a, gear B and gear C are in the same axis with different number of teeth and they are moving with the same rotational speed.

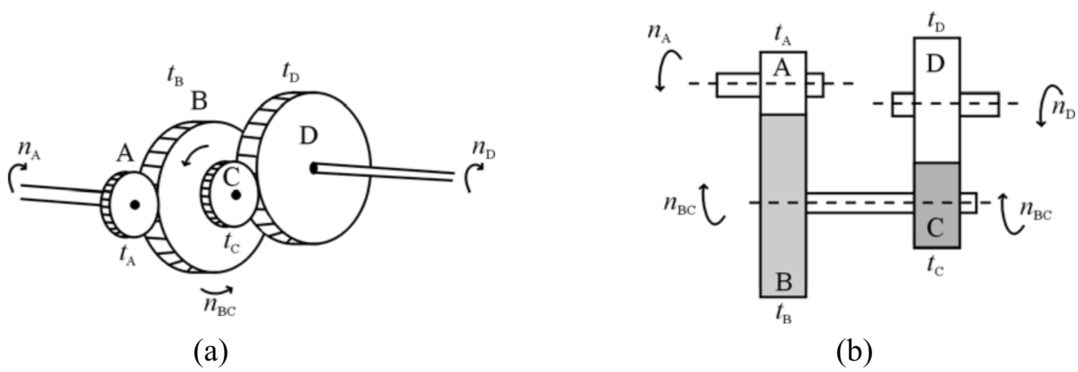


Fig. 48

Cross sections of the compound gear, as shown in Fig. 48b can be used to show its structure. According to the figure,

$$\frac{\text{Rotational speed of A}}{\text{Rotational speeds of B and C}} = \frac{t_B}{t_A} \quad \text{And} \quad \frac{\text{Rotational speeds of B and C}}{\text{Rotational speed of D}} = \frac{t_D}{t_C}$$

$$\frac{\text{Rotational speed of A}}{\text{Rotational speed of D}} = \frac{\text{Rotational speed of A}}{\text{Rotational speeds of B and C}} \times \frac{\text{Rotational speeds of B and C}}{\text{Rotational speed of D}} = \frac{t_B}{t_A} \times \frac{t_D}{t_C}$$

$$\boxed{\frac{\text{Rotational speed of A}}{\text{Rotational speed of D}} = \frac{t_B}{t_A} \times \frac{t_D}{t_C}}$$

Example 7:

Referring to the compound gear mechanism in Fig. 48a,

$t_A = 20$, $t_B = 100$, $t_C = 20$, $t_D = 160$

(a) Find the Velocity Ratio of the gear mechanism.

(b) If the rotational speed of gear A is 200 turns per minute, find the rotational speed of gear D.

Solution:

(a) Velocity Ratio $= \frac{\text{Rotational speed of A}}{\text{Rotational speed of D}} = \frac{t_B}{t_A} \times \frac{t_D}{t_C} = \frac{100}{20} \times \frac{160}{20} = 40$

(b) $\frac{200}{\text{Rotational speed of D}} = 40$

$$\text{Rotational speed of D} = \frac{200}{40} = 5 \text{ turns/ min}$$

(iv) Other types of gear

There are various types of gears and gear mechanism. Common ones are spur gear, bevel gear, helical gear, rack and pinion, worm and worm gear, etc.

Spur gear

Spur gear is used in mechanisms connecting gears with parallel axles. It is the most commonly used gear, for example, in the lathe machine of metalwork (Fig. 49b).

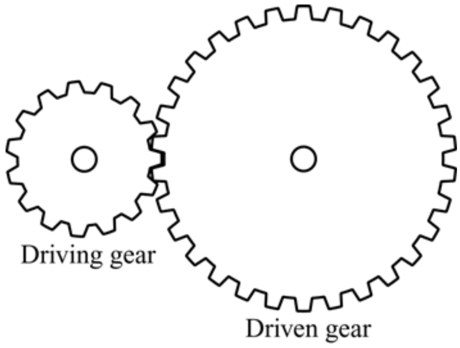
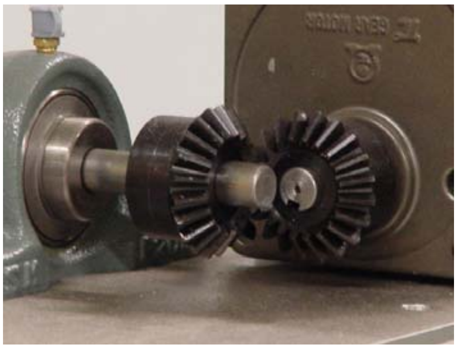


Fig. 49 (a) Spur gear (b) Spur gear in lathe machine

Bevel gear

Bevel gear has teeth like Chrysanthemum (Fig.50a). The gears in the machines are connected with perpendicular axles. It is commonly used in hand-drill (Fig. 50b).



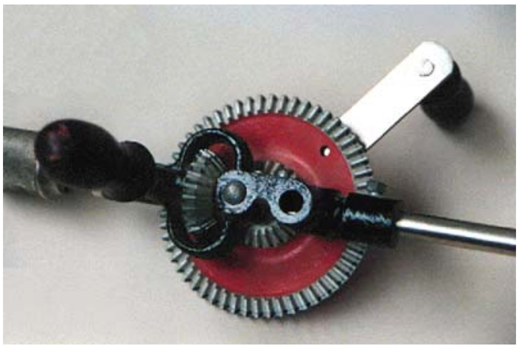


Fig. 50 (a) Bevel gear (b) Bevel gear in hand-drill

Helical gear

Helical gear is a gear mechanism used to connect gears whose axles are neither parallel nor intersecting. This mechanism is mainly used in the mechanical structure where high speed and silence are required.

Fig. 51 Helical gear

Rack and pinion

Rack and pinion is a mechanical device formed by a rod-shaped rack and the gear mechanisms. This combination can be used to convert linear motion to rotary motion and vice versa (Fig. 52a). A typical example is the feeding mechanism of the drilling machine (Fig. 52b).

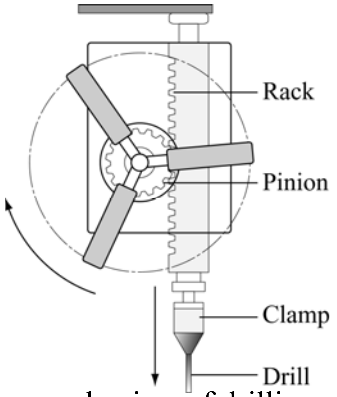


Fig. 52 (a) Rack and pinion (b) Feeding mechanism of drilling machine

Worm and worm gear

Worm lever and worm wheel is also known as ‘Worm tooth’. The worm wheel is a spur gear while the worm is a kind of spiral lever (Fig. 53a). They are used to connect two axles that are neither in parallel nor intersecting. They usually link together perpendicularly (Fig. 53b). The Velocity Ratio of worm lever and worm wheel is very large. Applications of worm lever include the auto feed component the metalwork lathe.

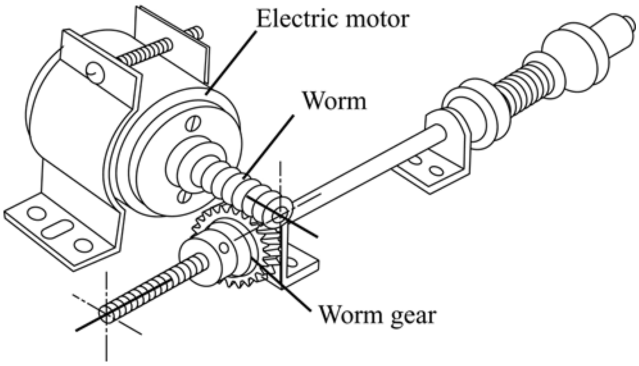


Fig. 53 (a) Worm and worm gear (b) Worm and worm gear linked perpendicularly

To work efficiently, the gear must be linked precisely. The design of the gears should fulfill certain conditions to make sure their number of teeth match each other. Assemble the gears according to the direction of the axle designed. Add lubricant regularly to reduce friction. Protective covers should be installed to prevent the gears from dragging object nearby.

(p) Brake

When machines are working, they possess kinetic energy. If it is necessary to slow down the rotating motion of the machines, a brake is needed to convert the kinetic energy into other forms of energy like heat and sound. Take the car as an example. When the driver presses the brake pedal, the liquid compression system then triggers the brake and creates friction, so that the car will decelerate or stop (Fig. 54). Common types of brakes include drum brakes and disc brakes.

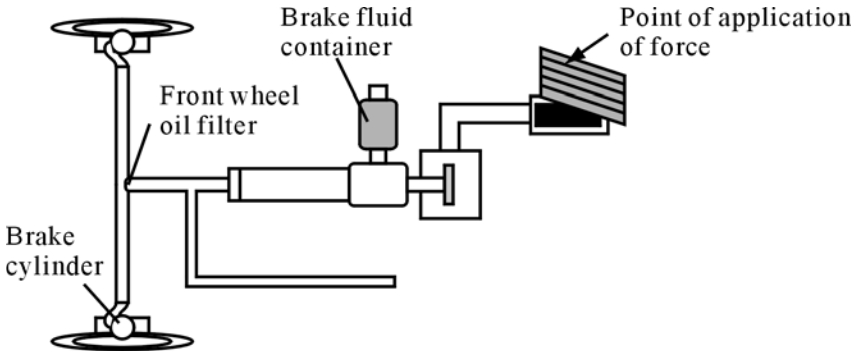


Fig. 54 Braking system of a car

(i) Drum brake

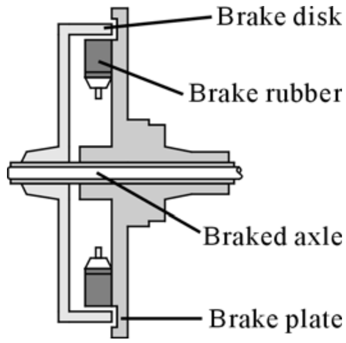


Fig. 55 The structure of drum brake

A drum brake is installed at the wheel and it rotates with the wheel. It has a structure shown in Fig. 55. The brake rubber is installed in a fixed brake plate and does not rotate with the brake drum. The wearproof gasket is then riveted or stuck on the brake rubber. When braking, the liquid compression pump will compress the semi-circle brake rubber and gasket towards the brake drum, producing a friction to slow down the rotation of the wheel.

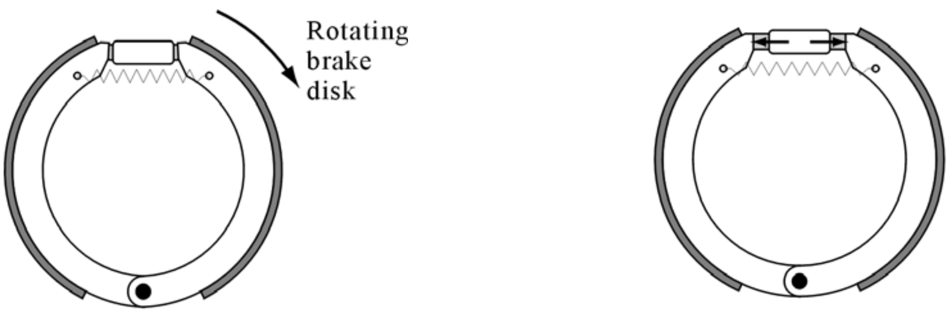


Fig. 56 (a) Release of brake (b) Functioning of brake

When the gasket and the brake drum are in contact to produce friction, heat will be produced and the mechanism will wear out. In a closed braking system, heat dissipation is difficult to occur. Expansion due to heat widens the gap between the brake drum and the gasket. Therefore, the braking effect of drum brake is inferior to that of disc brake. Most cars will install the drum brake in only one set of the wheels (usually at the rear wheel).

(ii) Disc brake

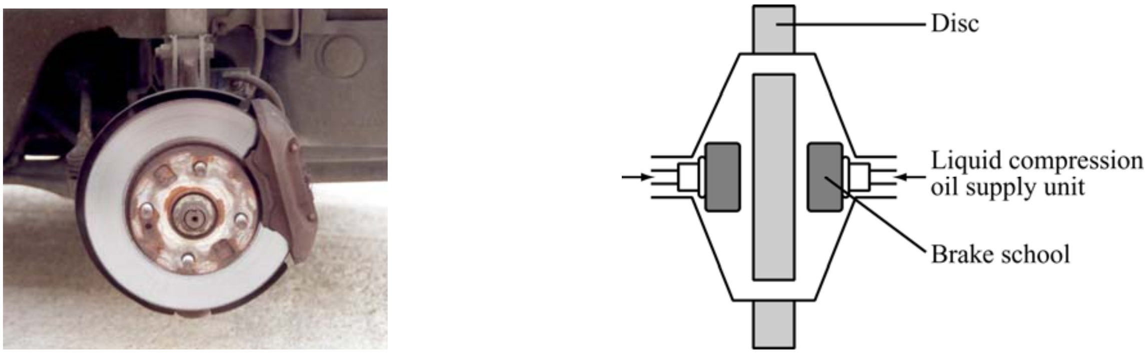


Fig. 57 (a) Disc brake in car (b) The structure of the disc brake

There is a solid iron disc in the disc brake. It is installed at the wheel and it rotates with the wheel. Its structure is shown in Fig. 57. Another disc is partly covered with a caliper and it does not move with the car. There is a liquid pressure piston and a wearproof-braking gasket in the caliper. When braking the car, the liquid brake pump compresses the gasket towards the circular disc. The friction produced slows down the rotational speed of the circular disc and the wheel.

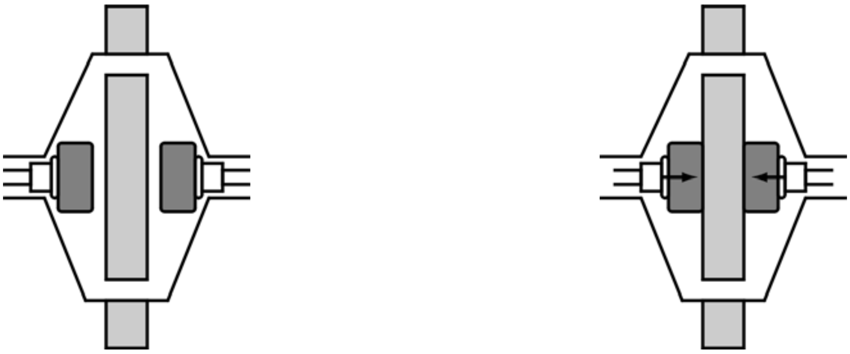


Fig. 58 (a) Brake is released (b) Brake in operation

When the gasket and the brake disc are in contact, heat will be released and the mechanism will wear out. As only part of the circular disc is covered by the caliper, air can effectively cool down the circular disc and the brake gasket. Therefore, its braking effect is better than the drum brake. Disc brake is usually installed in the front wheels of a car. Cars with high performance or racing cars usually install disc brakes at all wheels to give a better braking effect.

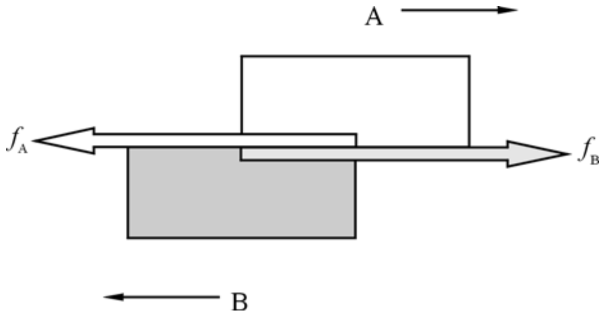
The brake gasket should be checked regularly. If the gasket wears out seriously, it should be replaced as soon as possible. In some cars a sensor will be installed at the gasket to remind the car owner to replace the gasket before it is worn beyond the threshold level.

When the brake is operating, a lot of heat energy is produced. Prolonged use may burn the brake gasket resulting in a brake failure. So, when running down a slope, the brake should not be used for a long period of time. A gear box should be used to adjust the speed of the car instead.

4. Frictions and lubrication

(a) Frictions

When an object is sliding on a surface, friction will hinder the movement of the object. In Fig. 59a, when A and B are sliding against each other, friction will act on the surface of both A and B. A moves to the right while the frictional force f_A acts to the left; B moves to the left while the frictional force f_B acts to the right. Frictional force is produced when both surfaces in contact are not perfectly smooth (Fig. 59b).



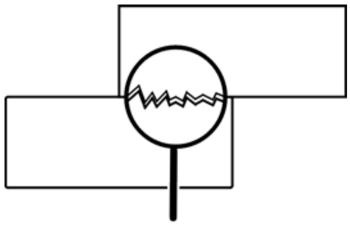
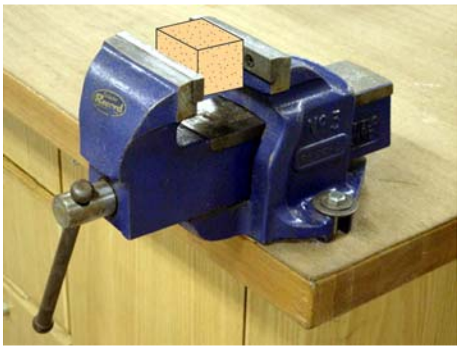


Fig. 59 (a) (b)

There are various applications for friction in machines. For example, the disc brake of a car uses the brake rubber to clamp the metal disc in the car axle. The friction between them can reduce the speed of the car. The vice uses friction to clamp a workpiece (Fig. 60a). Both the pin and screw use friction to fix objects (Fig. 60b).



(a) The vice uses friction to clamp a workpiece tightly

(b) A pin uses friction to fix objects

Fig. 60 Applications of friction

However, friction also causes problems. It will resist the movable parts in a machine to work smoothly, and even it will cause abrasion of these parts. Moreover, it also causes some of the kinetic energy of the machine changing to heat energy resulting in lowering the efficiency. Take a process of cutting a metal workpiece as an example, the heat generated from friction can easily cause damages of the workpiece and the tool. To solve this problem in this case, lubrication oil can be applied to the system, or ball bearing can be installed in the system so as to reduce the friction.

(b) Lubrication

Certain moving parts of the machines cannot operate smoothly or even wear out because of friction. For example, friction can affect the functioning of bearings and gears. The purpose of lubrication is to use lubricants to reduce the friction of the machines. Lubricants can be classified as liquid state (e.g. engine oil) and paste state (e.g. kerosene or grease).

Lubricant with low adhesion ability is applicable to the mechanical components with higher spindle speed or an environment with lower endurance pressure, e.g. typewriter. Lubricant with high adhesive power is applicable to the mechanical components working with higher temperature, such as gear machinery.

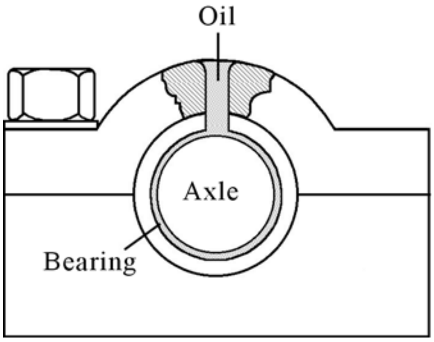


Fig. 61 Example of lubrication: Natural Penetration

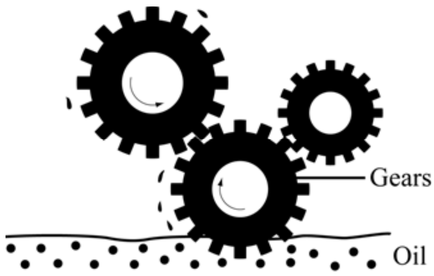


Fig. 62 Example of lubrication: Splashing method

There are three main ways of lubrication. First of all, natural penetration in which the lubricant flows to the axis of rotation by gravitational force or is being leaded to the rotating part by capillary action (Fig. 61). The second method is known as the splashing method. The lubricant is led to the appropriate position when the mechanical components are moving. For example in the lubricating system of the automobile speed control system, the lubricant is transmitted from the lower gear to the upper gears gradually (Fig. 62). The third method is manual pump compression. Oil pump is used to transfer the lubricant to the rotating components in the machines (Fig. 63).

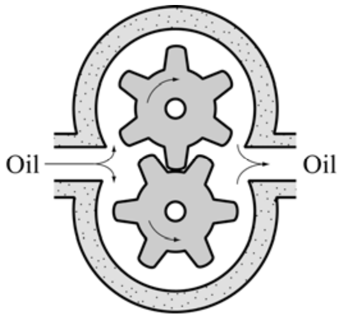


Fig. 63 Example of lubrication: Manual pump compression

5. Safety regulations

The following are some safety regulations in using machines:

(a) Before using the machines, check thoroughly to ensure that it is safe for the user.

(b) Always check the parts to ensure that they are working normally to avoid accidents, for example, to check whether the chain is broken or not.

(c) Change lubricant periodically as the prolonged use of lubricant may affect the operation of the machine.

(d) Heat may be generated during the operation of the machine. Pay attention to the loss of the effectiveness of the lubricant due to over-heating.

(e) Stop the machine and prepare safety measures before starting the maintenance and repair of the machine.

(f) Do not start the operation of any machine without permission, especially the switch or valve with label and lock, to avoid accidents.

(g) Do not remove any protective shield from the machine without permission. If it is necessary to remove the protective shield, install it back immediately after the work.

(h) If there is any abnormal sound, vibration or movement when the machine operates, report to the teacher immediately.

(i) Keep the environment of the machine clean. Place the tools tidily. Clean the grease on the ground. Tidy up the cloth and put it inside the container with a lid after cleaning the machine oil. Place the cleaning oil for the machine in a safe place after use.

(j) Never use gasoline to clean any part of the machine to avoid catching fire.

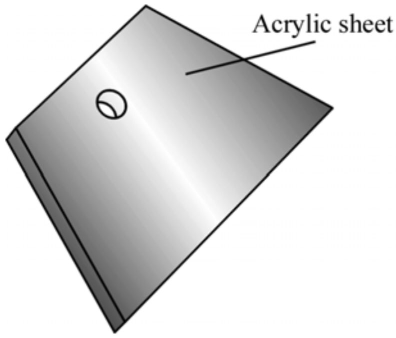
(k) Never use fingers to clean the fragments of metal. Use a brush instead.

(l) Keep the environment clean when installing the bearings. Avoid sweat of the hand making contact with the bearings. Add lubricant immediately right after the installation of the bearings.

Exercise

1. A block and tackle system in a warehouse is used to lift a good of 1000 N for 1 m, the effort required is 400 N downwards 3 m.
   (a) Fine the workdone by the load;
   (b) Find the workdone by the effort.
   (c) What is the efficiency of the block and tackle system? If it is less than 100%, why?

2. The following figure shows a project done by a student using cutter, hand drill and jigsaw. Classify the hand tools according to reciprocating motion, linear motion and rotary motion, and state their features respectively.

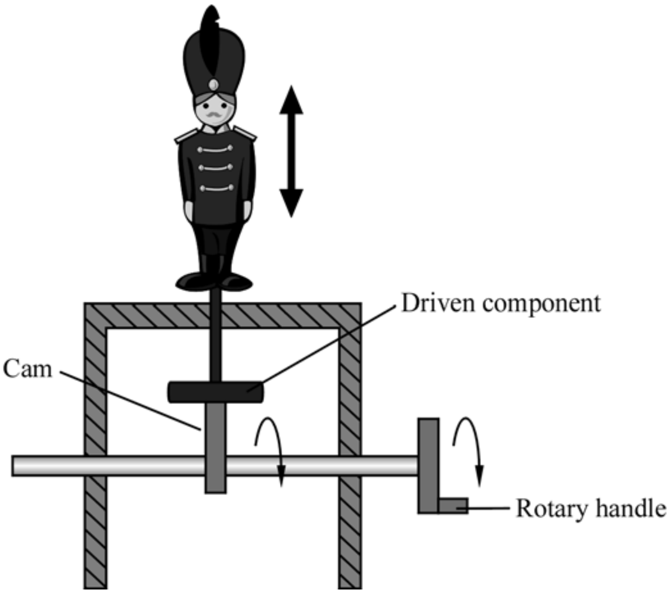


Hand tools	Motion types	Features
Cutter		
Hand drill		
Jigsaw		

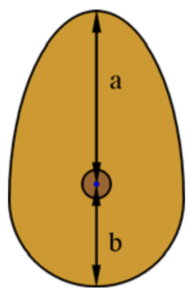
3. Wai Chee is riding a bicycle from his school to the foot of the hill. He will meet Chek Yee to ride togather up to the hill.
   (a) If Wai Chee wants to ride from the school to the foot of the hill with less effort, what is the combination of the chain and sprocket for lesser effort applied. (Note: Assumed the road is flat.)
   (b) What is the combination of the chain and sprocket most suitable for Wai Chee to ride up the hill?
   (c) By what means does the pedal wheel transmit its motion to the rear wheel?

4. The following two hand tools operate based on lever principles, state their features and functions:
   (a) Bottle opener
   (b) A pair of bread tweezers

5. The following figure shows a movable toy. Eelaborate briefly how it works.



6. The following figure shows a pear-shaped cam where the distance of a is 60 mm, while that of b is 30 mm.



(a) Calculate the path of this cam.

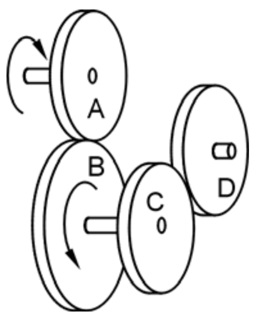
(b) Give an example of the application of this kind of cam.

7. A jigsaw in the workshop is motivated by a motor which drives a 40 mm long crank.

(a) Find the cutting distance of the blade.

(b) By what means can the efficiency of this machine be raised?

8. A compound gear system in a clock is designed as shown below.



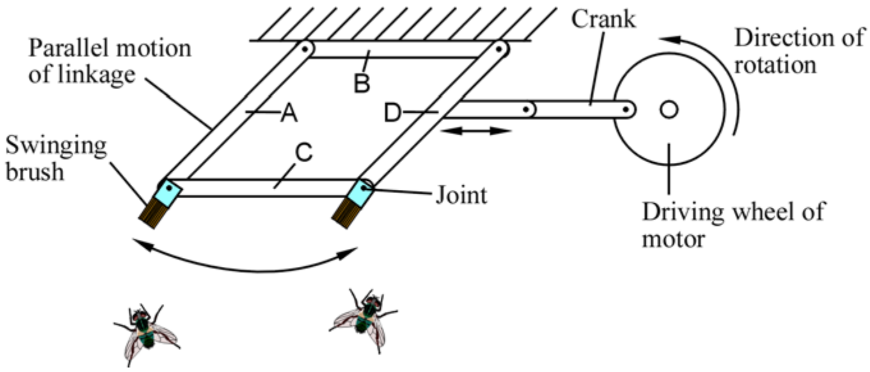
Gear	A	B	C	D
Number of teeth	20	120	40	200

(a) Calculate the Velocity Ratio of this compound gear system.

(b) If the rotational speed of gear A is 400 turns/min, find the rotational speed of gear D.

(c) Use dotted line with arrow head to indicate the direction of rotation of gear D.

9. In a snack shop, the shopkeeper has designed and installed a device to expel the flies from the food in the display window, as shown below.



(a) Briefly describe how the device works.

(b) If the rotational speed of the motor remains steady, how can the rate of swinging of the brush be changed?

(c) Suggest some methods to change the range of swinging of the brush.

10. What is a brake? Why is a drum brake not suitable for installation at the front wheel of the car?