Machines: transmission and transformation of motion

Introduction

A machine is a device that transforms energy into useful work.

From brooms to washing machines, through to vacuum cleaners and bicycles, machines are all defined by three key characteristics: they perform useful work, consume energy, and are formed by a set of mechanisms.

The mechanisms that form machines make it possible for them to perform the functions for which they were designed.

The motion can be linear (in a straight line), circular (rotary) or alternating (back and forth). It is transmitted and transformed from a **conductor** element, which begins it, to a **conducted** element, which receives it. The conductor element is also called **Driver** and the conducted element is also called **Driven**.

Mechanisms for the transmission of motion

Introduction

The main characteristic of motion transmission mechanisms is that the Driver and the Driven have the same type of motion.

Therefore, motion transmission mechanisms can be:

- **Transmission of linear motion**

Both the Driver and the Driven have linear motion. Examples of this type of mechanisms include levers and pulleys.

- **Transmission of circular motion**

Both the Driver and the Driven have circular motion. Examples of this type of mechanisms include friction wheels, gears, belt and pulley systems and cog wheels joined with chains.

Linear motion

Levers

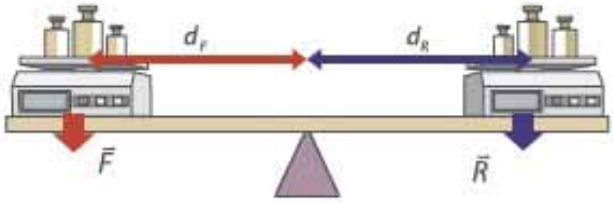
A **lever** is a rigid bar pivoting around an axis point or **fulcrum**.

If used properly, a lever makes it possible to overcome a given resistance force by applying a smaller effort force.

Fundamental law of the lever

The equilibrium of a lever depends on the following magnitudes:

- The applied force.
- The resistance.
- The distance between the point of application of the force and the fulcrum
- The distance between the point of application of the resistance and the fulcrum.



Each of these forces and the associated distance are inversely proportional magnitudes. Besides, the proportionality constant of each of these pairs of magnitudes is the same.

This is the **fundamental law of the lever**, which is mathematically written in this way:

$$\frac{R}{R} = \frac{d_l}{d_e} \Rightarrow F \cdot d_e = R \cdot d_l$$

Types

We can classify levers depending on the position of the fulcrum with regard to the application points of the force and the resistance.

- **First-class levers**

The fulcrum is between the force and the resistance.

- **Second-class levers**

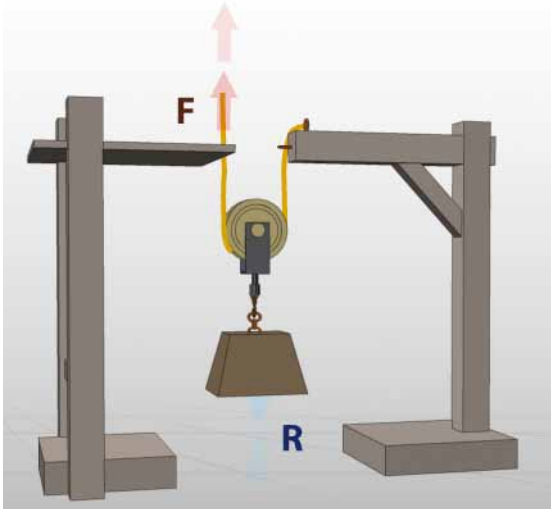
The resistance is between the fulcrum and the force.

- **Third-class levers**

The force is between the fulcrum and the resistance.

Pulleys

A **pulley** is a wheel that rotates around its axis with a groove around its outer circumference. A rope is run through this groove.



Movable pulley

Types

- **Fixed pulley**

Its axis is fixed.

It is in equilibrium when $F = R$.

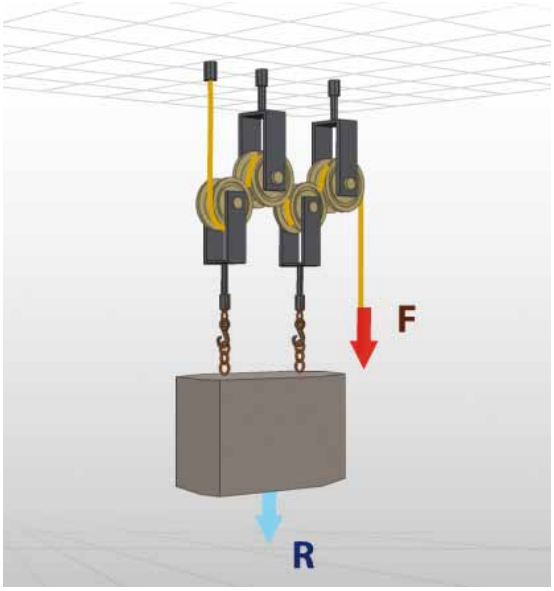
- **Movable pulley**

A pulley with both rotational and translational motion.

It is in equilibrium if $F = R/2$.

- **Block and tackle**

A block and tackle arrangement is a set of fixed and movable pulleys.



Block and tackle

Circular motion

Rotational speed

Rotational speed (n) is the number of turns a wheel makes per time unit.

It is usually measured in min-1 or rpm.

Rotational speed is measured with a tachometer.

Transmission ratio

The **transmission ratio** (*i*) is the quotient between the rotational speed of the conducted wheel and the rotational speed of the conductor wheel.

It is a dimensionless quantity.

If the devices for the transmission of the circular motion operate correctly, the linear speed of the periphery of all rotational elements is the same.

And consequently, the transmission ratio can be written in terms of the geometry of these elements:

$$i = \frac{n_{dn}}{n_{dr}} = \frac{r_{dr}}{r_{dn}} = \frac{D_{dr}}{D_{dn}}$$

Where *r* refers to the radiuses (dr, conductor element; dn, conducted element) and D to the diameters.

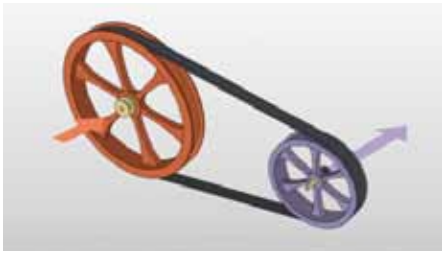
The transmission ratio is a fundamental characteristic of the mechanisms for the transmission of circular motion. In terms of this ratio, we have the following classification:

• **Direct** ($i = 1$)

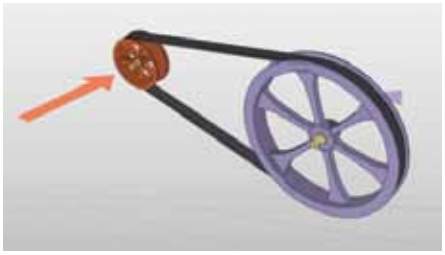
The Driver and the Driven have the same diameter and, therefore, have the same rotational speed.

$$n_{dn} = n_{dr}$$
$$D_{dn} = D_{dr}$$

Direct



Multiplying mechanisms



Multiplying mechanisms

• **Multiplying mechanisms** ($i > 1$)

The diameter of the Driver is bigger than that of the Driven and, therefore, the Driver rotates at a lower speed than the Driven.

$$n_{dn} > n_{dr}$$
$$D_{dr} > D_{dn}$$

• **Reducing mechanisms** ($i < 1$)

The Driver has a smaller diameter than that of the Driven and, therefore, has more rotational speed.

$$n_c < n_m$$
$$D_m < D_c$$

Friction wheels

Friction wheels are cylinders or cone wheels in contact that transmit motion by surface friction.

Types

Friction wheels can be classified according to their friction surface:

- **External friction wheels**

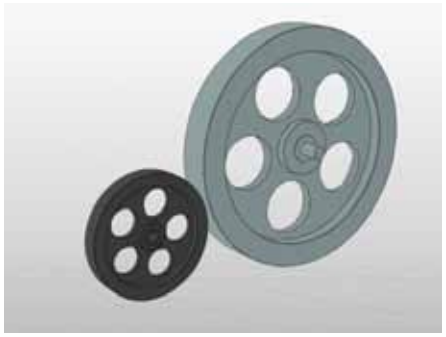
The wheels are cylinders. Their outer edges are in contact and they rotate in opposite directions.

- **Internal friction wheels**

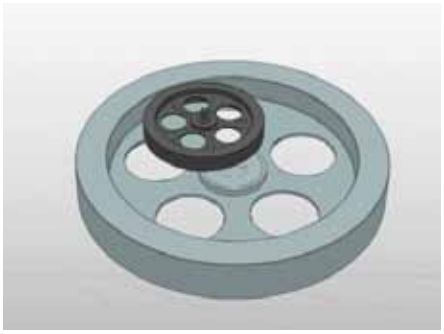
The wheels are cylinders. The inner edge of the bigger wheel is in contact with the outer edge of the smaller wheel. Both wheels rotate in the same direction.

- **Bevel friction wheels**

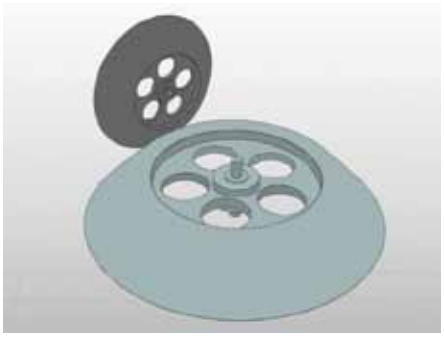
The wheels are cones. The surfaces in contact are the surfaces of the cones. The wheels rotate in opposite directions.



External friction wheels



Internal friction wheels



Bevel friction wheels

Gears

Gears are toothed wheels that mesh together to transmit motion. The motion is transmitted as follows: the teeth of the driving gear push the teeth of the driven gear. An advantage of gears is that, unlike friction wheels, the teeth of a gear prevent slipping. Two meshed gears rotate in opposite directions.

The module (m) of a gear is the quotient between its diameter (D) and the number of teeth (Z). It is usually expressed in millimeters.

$$m = \frac{D}{Z}$$

Two gears mesh together only if they have the same module. This means, transmission ratio for gears can also be expressed as follows:

$$i = \frac{n_{dn}}{n_{dr}} = \frac{D_{dr}}{D_{dn}} = \frac{Z_{dr}}{Z_{dn}}$$

Types

Some of the most common types of gears are the following:

- **Spur gears**

Spur gears or straight-cut gears are the simplest type of gear. They are used to transmit motion between parallel axles.

- **Helical gears**

The teeth of this type of gears are set at an angle, having the shape of a helix. They can transmit motion between both parallel and perpendicular axles.

- **Bevel gears**

Their teeth can be straight or helical. They are used to transmit motion between axles that intersect each other.

- **Worm gears**

This type of gear consists of a toothed wheel that meshes with a screw. They are used to transmit motion between perpendicular axles.

Pulleys and belt

A **belt** and **pulley** system is a system for the transmission of motion made up of grooved wheels located at a certain distance, which are joined by a belt.

The transmission of motion is carried out due to the friction between the pulleys and the belt. The pulleys rotate in the same direction, unless the belt is crossed-over; in that case, they rotate in opposite directions.

Types

We find different types of pulleys and belts.

Of pulleys

- **Pulley**

A pulley is a wheel rotating around its own axis with a groove along its edge for holding a belt or rope.

- **Cone pulley**

A cone pulley is a set of pulleys with different diameters, ordered by sizes and joined forming just one piece.

Of belts

The widest lateral surface is in contact with the pulley.

- **Vee belt**

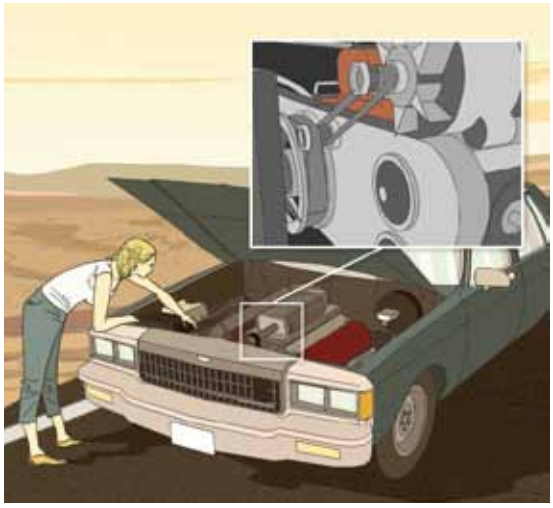
The cross-section is trapezoidal (V-shaped). The internal side is in contact with the pulley.

- **Round belt**

The cross-section is a circle. A part of the surface of the belt is in contact with the pulley.

- **Timing belt**

The toothed side is in contact with the pulley, which must also be toothed.



Toothed wheels and chain

The toothed wheels and chain mechanism is made up of two toothed wheels, the disk and the pinion, which are joined by a chain.

The motion is transmitted by the force of the wheels teeth on the chain and vice versa. The two toothed wheels rotate in the same direction.

Motion transformation mechanisms

Introduction

In a motion transformation mechanism, the Driver and the Driven have different types of motion.

- **Transformation of linear / circular motion**

You can pass from a linear motion in the Driver to a circular motion in the Driven, or vice versa, from a circular motion in Driver to a linear motion in the Driven. Examples include the screw and nut, and the rack and pinion.

- **Transformation of circular / alternating linear motion**

You can pass from a circular motion in the Driver to an alternating linear motion in the Driven, or vice versa from an alternating linear motion in the Driver to a circular motion in the Driven. Examples include connecting rods, eccentrics and cams.

- **Transformation of circular / intermittent circular motion**

The Driver performs a continuous circular motion that is transformed into an intermittent circular motion in the Driven.

Linear motion / circular motion

Screw and nut

The circular motion of one of the elements (screw or nut) is transformed into relative linear motion: from one element with regard to the other. It is used for faucets, vises, monkey wrenches, corkscrews, car jacks, etc.

Parts

- **Screw**

The screw is a cylindrical rod with a head and a thread.

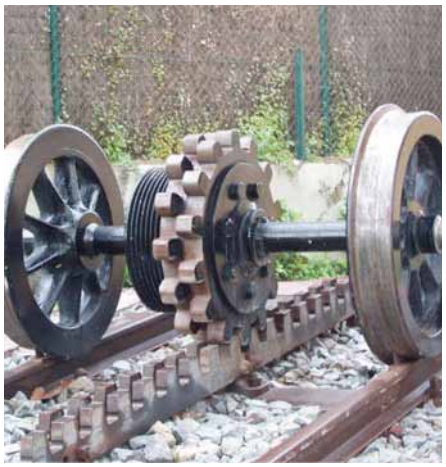
- **Nut**

The nut is a mechanical piece with a threaded hole.

Screws and nuts

Screw

Nut



Pinion and rack

Pinion and rack

A rack and pinion is an arrangement that transforms the circular motion of the pinion into a straight line relative motion. It is a reversible mechanism.

It is used for steering mechanisms of cars, drills, automatic doors, tripods, etc.

Parts

- **Pinion**

A pinion is a toothed wheel.

- **Rack**

A rack is a toothed bar.

Circular motion / alternating linear motion

Connecting rod and crank

Connecting rod and crank

A crank and connecting rod mechanism transforms the circular motion of the crank into the alternating linear motion of a guided system.

It is a reversible mechanism, and it is used for explosion engines, sewing machines, etc.

Parts

- **Crank**
- **Connecting rod**

The connecting rod is a rigid bar that connects the crank to the guided system.

- **Guided system**

Eccentrics

A mechanism with eccentric transforms the circular motion of the eccentric itself into the alternating linear motion of the follower. This mechanism is not reversible.

Parts

- **Eccentric**

The eccentric is a disk or cylinder with the axle displaced from the centre.

- **Follower**

The follower is a rod connected to the eccentric.

Cam

This mechanism transforms the circular motion of the cam into the alternating linear motion of the follower. It is not reversible and it is used in explosion engines among many other mechanisms.

Parts

- **Cam**

The cam is usually a disk, but there are also cylindrical cams.

• **Follower**
The follower is a rod in contact with the cam.
In fact, the eccentric is a specific type of cam.

Eccentric

Circular motion / Intermittent circular motion

Maltese Cross

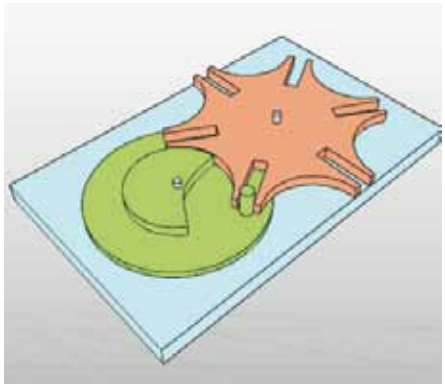
This mechanism transforms the circular motion of the driving wheel into the intermittent circular motion of the conducted wheel.
It is used in mechanical watches, film projectors, canning machines, etc. The Maltese Cross is also known as Geneva drive.

Auxiliary elements

The auxiliary elements also form part of the mechanisms for the transmission and transformation of the motion of machines.

Cam

• **Screws**
They fix the transmission axles to the rotating elements.
• **Fasteners**
They fix the transmission axles to the rotating elements.
• **Cotters**
They block the relative motion between two parties.
• **Couplings**
They connect two shafts together at their ends to transmit rotation movement. There are many types of couplings: flange couplings, disk couplings, elastic joints, splined or sliding axles, or cardan joints.
• **Clutches**
They connect or disconnect the Driver and the Driven. There are different types of clutches: tooth clutch, friction clutch, centrifugal clutch or hydraulic clutch.
• **Brakes**
They reduce rotational speed. Types include band brakes, drum brakes, disc brakes, etc.
• **Ratchets**
They allow rotation in only one direction.
• **Journal bearings**
They support the transmission axles.
• **Bearings**
They allow rotation and prevent sliding.
• **Ball bearings**
They allow rotation and prevent sliding.



Maltese cross