2

Machines: simple machines

Introduction

Machines and tools

Tools are all objects manufactured to perform a determined action, which are used with hands.
A machine is a set of mechanisms with coordinated movements, which can transform energy into useful work.
All machines have three essential features, which differentiate them from all types of tools and other mechanisms:

- They perform useful work.
- They consume energy.
- They consist of a set of mechanisms.

Elements of a machine

In any machine, we can find three essential elements forming it:

- **Structure**

It is formed by supports, press beds, chassis, and all those elements supporting the mechanisms that make the machine operate. The structure must be able to bear the weight of the machine, and to resist all mechanical stresses arising from its operation: vibrations, tensions, etc.

- **Motor**

It is the element which transforms energy into work that we may use by means of the rest of the mechanisms. Depending on the source of energy, we can find human blood powered machines (by direct action of animals or humans), wind powered machines, machines moved by water currents, by steam, by electric currents, etc.

- **Mechanism**

They are the pieces that receive the generated movement and transfer it to other parts of the machine to create useful work.

Scales are first-class levers.

Simple machines

General principle

Simple machines consist of a single mechanism that transforms muscular energy into work.
All these machines work on a principle involving two forces:

- **Driving force**

It is the force exerted on the machine, indicated with an *F*.

- **Resistance force**

It is the force we want to counterbalance, it is represented with an *R*.
Simple machines balance the effects of the driving force (*F*) and the resistance force (*R*).

The mathematical relationship between the two forces *F* and *R* is called the simple machine principle.

Lever

A lever is a rigid bar that pivots around a fixed point called **fulcrum**.

Distance to the fulcrum

The distance between the point of application of the driving force (*F*) and the fulcrum is called the **motor distance** (d_m).

The distance between the point where the resistance force (*R*) is applied and the fulcrum is called the resistance distance (d_r).

The lever principle

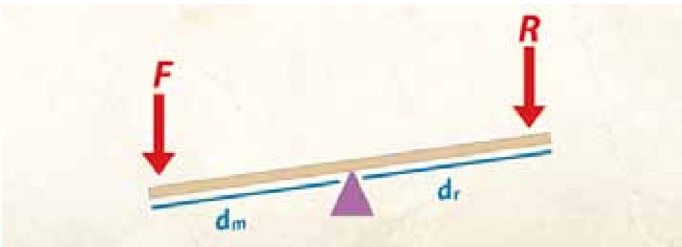
The product of the driving force by the motor distance is called motor work.

The product of the resistance force by the resistance distance is called resistance work.

The lever principle relates these concepts by means of the following equation:

$$F \cdot d_m = R \cdot d_r$$

To sum up, the lever principle states that the **motor work** is equal to the **resistance work**.



Mechanical advantage

When we talk about the relationship between two magnitudes, we refer to the quotient between them: one divided by the other – in this case, *R* divided by *F* (*R*/*F*).

We call this quotient the mechanical advantage (M_A) of the lever, and it tells us the force we have to apply to obtain a resulting force.

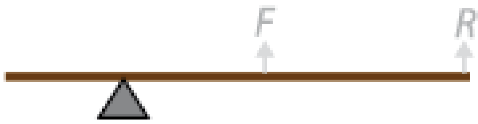
- If we apply force to a lever, and this lever makes a resulting force that is equal to our force ($F = R$), the mechanical advantage of this lever is 1.
- If the force we make is smaller than the resulting force, the relationship *R*/*F* is more than 1 and we are talking about levers with a mechanical advantage (M_A).
- If we have a lever that returns a force (*R*) smaller than the one applied by us (F), the quotient *R*/*F* is less than 1, and we are talking about levers with a mechanical disadvantage.

If we pass *F* to the right and *dr* to the left, we have the following equation:

$$M_A = \frac{d_m}{d_r} = \frac{R}{F}$$

As you can see, the mechanical advantage (MA) directly depends on the distance from each end to the fulcrum, that is, on where the latter is located.

Types of levers

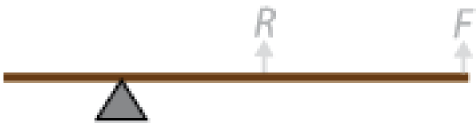


First-class lever

First-class levers

The fulcrum is always in the middle, with the points of application of *F* and *R* at the ends. This type of lever can have mechanical advantages greater than or less than 1, depending on the position of the fulcrum.

Pliers and **scissors** are first-class levers. They have the fulcrum where the two pieces are joined.



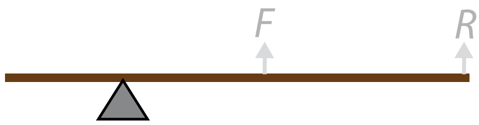
Second-class lever

Second-class levers

The fulcrum is located at one of the ends and the point of application of the resistance force is between the fulcrum and the point of application of the driving force.

This levers always have a mechanical advantage, they always have a quotient $R/F > 1$.

The classical example is the wheelbarrow, in which the wheel acts as the fulcrum.



Third-class lever

Third-class levers

In these types of levers the fulcrum is again at one end, but now the point of application of the force (*F*) is the one which is between the fulcrum and the point of application of the resistance force (*R*).

The mechanical advantage of third-class levers is always less than 1. Third-class levers are used for works which require small forces, but a good precision and control, as in the case of tweezers, or for extending the point of application of a force, as in the case of a broom.

Scissors

Wheelbarrow

Tweezers

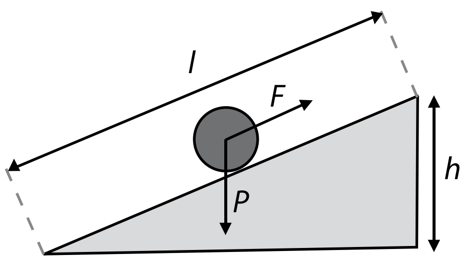
Inclined plane

An inclined plane is simply a flat surface set at an angle against a horizontal surface. It makes it possible to raise an object by applying less force than that which would be needed to lift it vertically.

The force that would have to be overcome to raise a body vertically is equal to its weight (*W*). The necessary force to do so with the help of an inclined plane (*F*) is less.

The expression that relates the weight of the body we want to raise and the force that has to be applied to do so with an inclined plane is called **law of the inclined plane**:

$F \cdot l = W \cdot h$ (*F* = force; *l* = distance traveled; *W* = weight; *h* = height).



It simply says that the longer the inclined plane for a determined height, the less force we will have to make to raise a weight.

The lathe

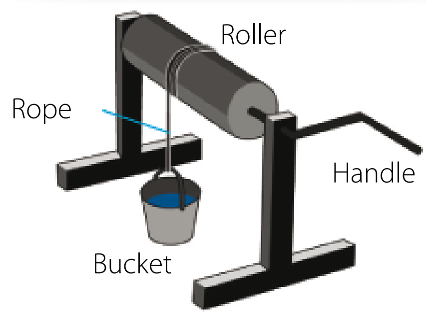
The lathe has a cylinder or roller with a handle that allows it to rotate. The roller collects the rope and lifts the object that we want to raise, in this case, the bucket full of water. The resistance force is the one overcome by the rope to raise the bucket.

Besides, in the lathe we have to take into account the rotation radius of the handle (r_h) and the radius of the lathe cylinder (r_c).

The lathe principle relates forces with these two radiuses: the greater the radius of the handle with regard to the cylinder, the less force you will have to make.

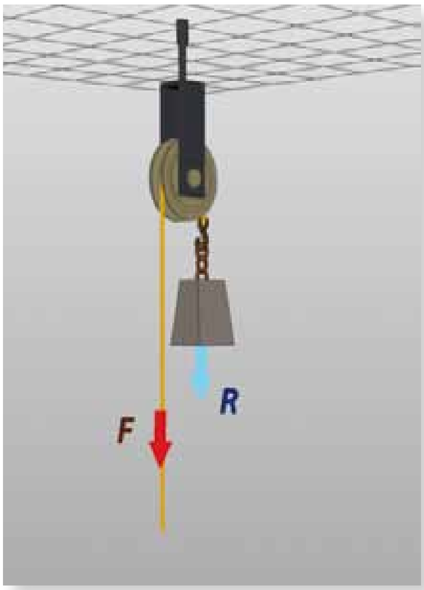
$$F \cdot r_h = R \cdot r_c$$

Lathe

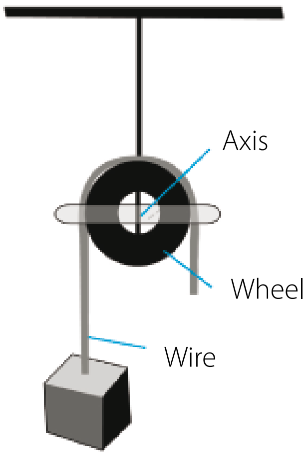


Pulleys

A **pulley** is a wheel or cylindrical structure with a central axis around which it can rotate, and in which a rope or wire is fitted that moves around its outer edge.



Simple pulley



Simple pulley

In a pulley, when we pull the rope, our force is completely transferred through the rope to the object we want to raise.

$$F = R$$

Its mechanical advantage will logically be:

$$V_m = 1$$

Movable pulleys

If we attach a movable pulley to a fixed one, we get a block and tackle. A block and tackle does have a mechanical advantage, because the weight of the object is loaded on the axis of the pulley and not directly to the end of the rope.

The mechanical advantage of a block and tackle depends directly on the number of movable pulleys (*n*).

This is expressed mathematically as follows:

$$M_A = \frac{R}{F} = 2n$$

If we want to halve the input force, we have to use one moveable pulley. If we want to quarter it, we have to use two, etc.

We can work out the block and tackle principle from the equation above:

$$F_m = \frac{R}{2n}$$

Transmission of motion

The part of the machine that already has movement is called **driving part** or **input part** of a transmission system.

The part that receives the movement will be the **driven part** or **output part** of the transmission system.

Period and frequency

When a movement occurs in a cycle that repeats in a given time frame, it is called a periodic motion.

The duration of the cycle is called the **period** (*T*), and its unit of measurement is the **second** (*s*).

Another magnitude which can help us understand these kinds of movement is the **frequency** (*f* or *n*), which is the number of cycles per unit of time. Its unit of measurement is the **hertz** (*Hz*).

The frequency is the reciprocal of the period:

$$f = 1/T \text{ or } n = 1/T$$

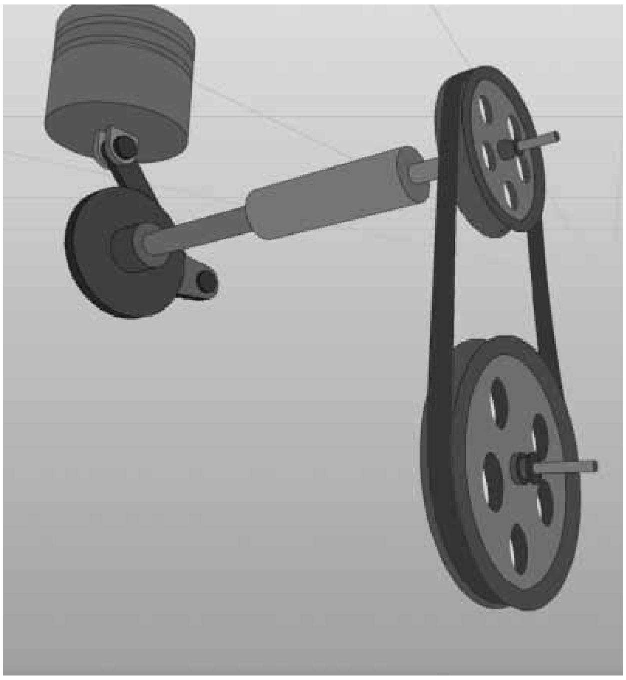
The opposite is also true; the period is the reciprocal of the frequency:

$$T = 1/f \text{ or } T = 1/n$$

Transmission ratio

The transmission ratio (i) is defined as the quotient of the frequencies of the driven part and the driving part:

$$i = \frac{n_c}{n_m}$$



This quantity has no dimension because it is a quotient of two magnitudes of the same units.

To calculate the transmission ratio of a system formed by a lot of elements, you need only divide the frequency of the last one by the frequency of the first one.

Classification

According to the value of the transmission ratio, we can distinguish between reducing, multiplying and direct systems.

- If *i* is equal to 1: the driving and the driven parts have the same frequency. This is direct or natural transmission.
- If *i* is greater than 1: the driven part has a higher frequency than the driving part. This is known as multiplying transmission.
- If *i* is less than 1: the driven part will have a lower frequency than the driving part. This is a reducing transmission.

Transmission systems

Thanks to transmission systems, we can transform movements into movements with different properties.

Pulleys-belt system

It has one belt that joins two pulleys.

- **Transmission principle**

The product of the radius and the frequency refers to both pulleys:

$$r_1 \cdot n_1 = r_2 \cdot n_2$$

Gears

The gear is a system of two cogwheels which fit, in a way that the force and movement are transmitted through the contact area.

The cogwheels cannot slide between themselves, as each cog of a wheel fits in a hole of the other one.

- The gears allow transmission of movement with a high precision and synchronization; that is why we find them in watches in which both hands must move with co-ordination.
- On the other hand, as there is no sliding, forces can be transmitted without many losses, and that is why gears are used in motors and coupling boxes of all types of vehicles.

Not all gears fit. In order for them to fit correctly, the number of cogs they have and the diameter they occupy must be specifically related. In order for gears to fit, they must have the same module.

We define the **module of a gear** as the quotient between the diameter of the wheel (*d*) and the number of cogs (*z*).

$$m = \frac{d}{z}$$

The gear transmission principle is the following:

$$n_1 \cdot z_1 = n_2 \cdot z_2$$