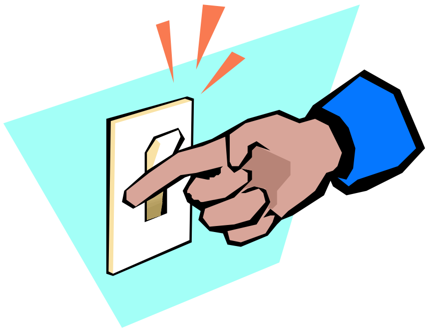
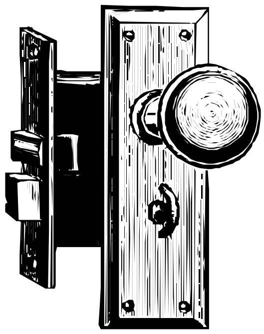
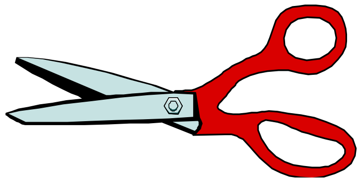
Mechanisms

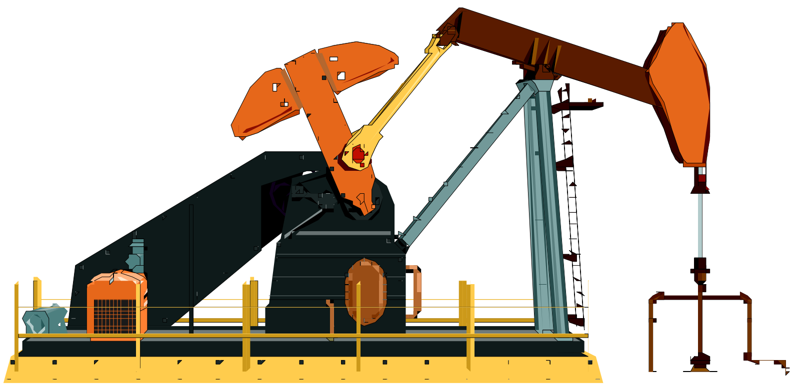
Introduction

Mechanisms are still a large part of modern society. Most of the mechanisms that we use every day are so familiar that we never think twice about them, for example door handles, light switches, scissors, etc.

Mechanisms play a vital role in industry. While many industrial processes now have electronic control systems, it is still mechanisms that provide the muscle to do the work. They provided the forces to press steel sheets into the shape of car body panels, to lift large components from place to place and to force power hacksaws to cut through thick metal bars – the list of jobs is endless. It is only by using mechanisms that industry can make products you use every day.

Some machines are easy to understand, but many are hidden away from sight behind glossy panels and covers. In the past, machines were much easier to see, as with the old steam engine, for example, but as people became more concerned about safety, it was necessary to fit guards over moving parts. Today, guards are often replaced by styled covers that make it much harder to see what is happening, but whether you can see them or not, mechanisms are still playing a vital part in everyday life.



All mechanisms:

- involve some kind of motion
- involve some kind of force
- make a job easier to do
- need some kind of input to make them work
- produce some kind of output.

MOTION

There are four basic kinds of motion.

Rotary

Turning in a circle. This is the most common type of movement, for example wheels, clock hands, compact discs, CD-ROMs.

Linear

Movement in a straight line, for example movement of a paper trimmer cutting a straight edge on paper or a lift moving between floors.

Reciprocating

Backwards and forwards movement in a straight line, for example the needle in a sewing machine or the piston in a car engine.

Oscillating

Swinging backwards and forwards in an arc, for example the pendulum of a clock, a playground swing or a rocking horse.

Motion: task 1

What types of motion do the following sports or leisure activities show when they are being used or carried out?

Activity	Rotary	Linear	Reciprocating	Oscillating
Swing				
100m sprint				
Golfing				
Bungee jump				
See-saw				
Fire button (On game pad)				

Motion: task 2

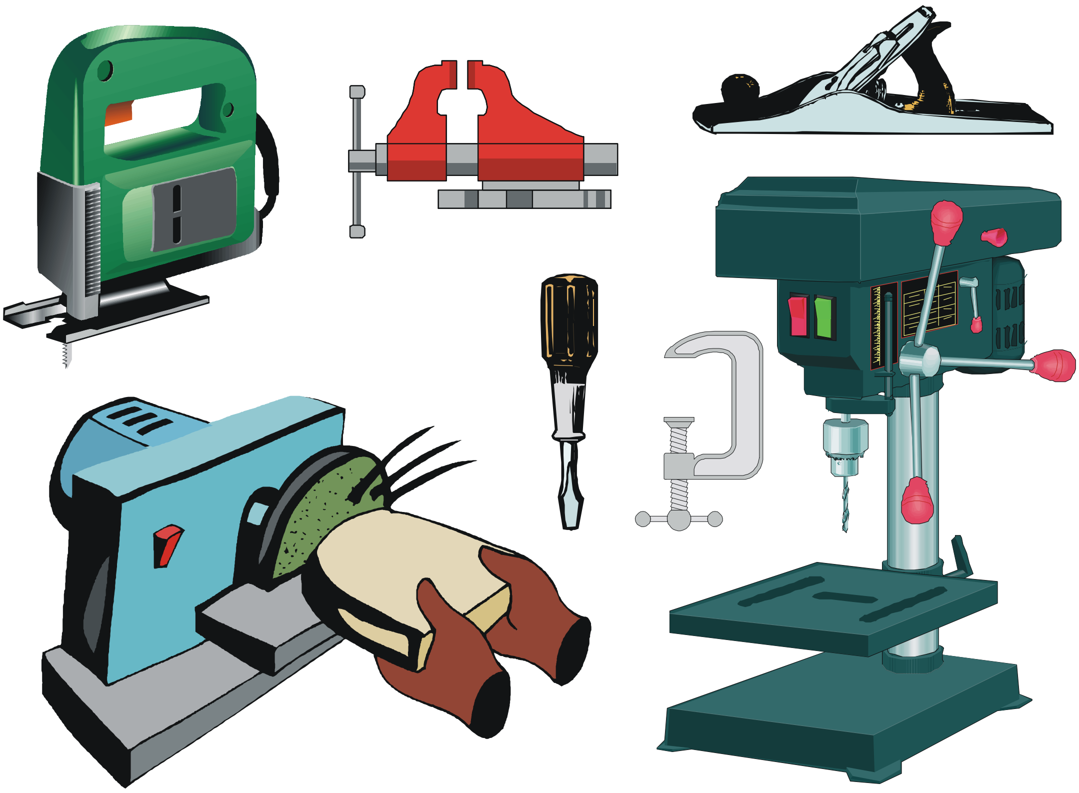
The machines and tools that are used in your practical rooms in school use all types of motion. The four types of motion are listed; now list as many machines/tools as possible for each type of motion.

Rotary

Linear

Reciprocating

Oscillating



FORCES

Forces affect structures in a variety of different ways depending on how they are applied to the structure. Forces can move a structure slightly or cause damage by changing the shape of the structure.

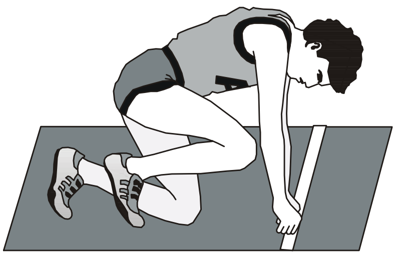
Sometimes when forces are applied to a structure, it may be almost impossible to see changes happening. For example, a bridge will sag slightly when a vehicle drives over it, but this is not visible to the human eye. Nevertheless, the vehicle causes downwards movement of the bridge structure. Loads such as vehicles on a bridge can be deemed examples of forces acting on the bridge. Forces can stop an object from moving or they can make it change direction. When a football is kicked, the forces applied from the player cause the dimensions of the ball to change on impact. It happens so quickly that it is not visible.

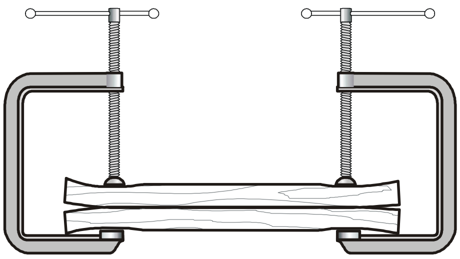
Forces are measured in ***Newtons*** *and the symbol is the letter '****N****'.*

There are a number of different types of forces that can be applied to and which affect bodies and structures.

Static forces

When static loads or forces are applied to structures, the structures do not normally move. Normally the total downwards force comprises the weight of the structure plus the load it is carrying. The runner below is in his starting position; his weight is a static or stationary downwards force.





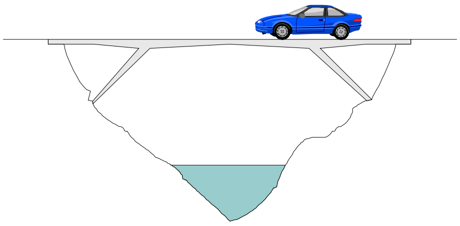
Dynamic forces

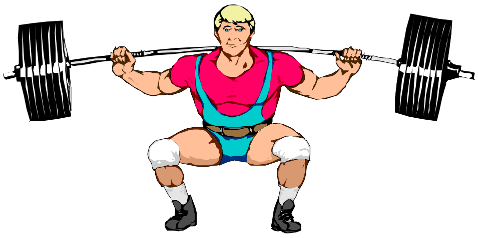
When dynamic loads or forces are applied to a structure, the structure does move and the forces applied can be varied. Dynamic forces are visually more noticeable and are produced by a variety of means and effects: machines, wind directions, people, etc. The picture below shows the sprinter after the starting gun has been fired; he is creating a dynamic impact to gain momentum.

Bending forces

Structures that carry loads across their length are subject to bending forces. The weightlifter lifting a weighted bar feels the effect of the downward forces of the weights and these cause the bar to bend.

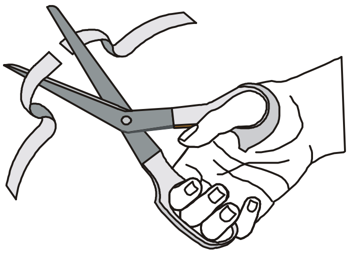
A car driving across a bridge will cause bending forces on the structure but often they are not visible.

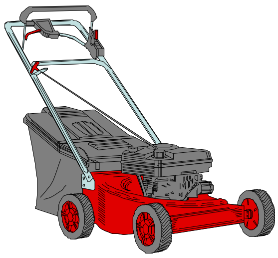




Shear forces

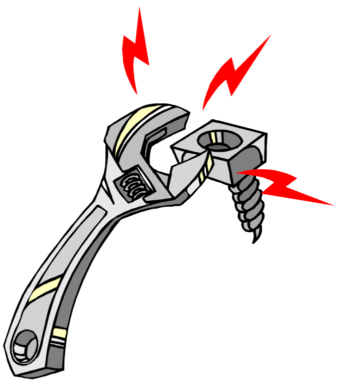
Shear forces can be described as tearing or cutting forces affecting structures. Simple examples are a pair of scissors used to cut a ribbon at an opening ceremony and a mower cutting the grass.





Torsion forces

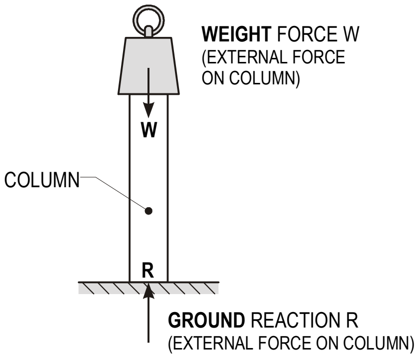
Torsion or torque forces have the effect of trying to turn or twist a structure or a piece of material. A screwdriver being twisted to apply a force to a screw and a spanner turning a bolt to lock it into place are examples of torque being applied.

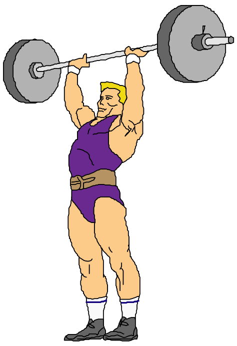


Compression forces

The figure below shows a column with a weight pressing down on it, but the column does not disappear into the ground because the ground exerts an upwards reaction force on the column's base. The downward pressure of the weight and the upward reaction are external forces trying to squash or shorten the column. Forces that act like this are called compressive forces and the column is said to be in compression.

For example, when you sit on a stool in the classroom, your weight acts as a downward force on the chair. However, there must be an upward force on the legs of the chair; therefore the legs are said to be in compression.

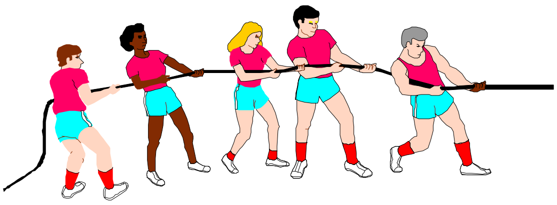


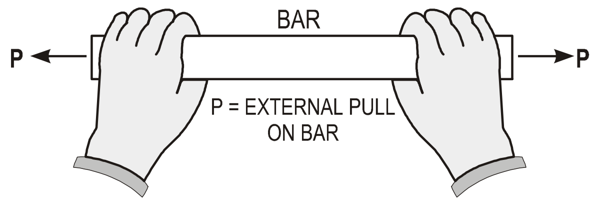


The same can be said about the weightlifter's arms and legs.

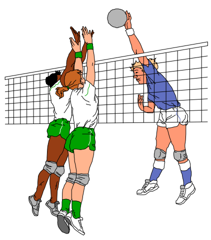
Tension force

We have noted that compression occurs when things are being pushed together. The opposite of compression is 'tension' – when a structure is being pulled apart. In a tug of war, the two sides are pulling the rope in opposite directions. The forces applied by the teams are called tensile forces and cause the rope to be in tension. It could also be said that the arms of team members are in tension.





The wire rope holding the net in volleyball is also in tension.



FORCE: TASK 1

AGAINST EACH OF THE SIX FORCES MENTIONED MAKE A LIST OF 'REAL LIFE' SITUATIONS WHERE THESE TYPES OF FORCES MAY BE FOUND. ASK THE TEACHER IF YOU ARE UNSURE WHICH CATEGORY THE SITUATIONS FIT INTO.

Static

Dynamic

Bending

Shear

Torsion

Compression

Tension

Levers

Figure 1(a) shows an early lever. The large boulder is too heavy to move by pushing it. By using a small boulder as a pivot point and a branch as a lever, it is possible to amplify the force applied to the large rock. The further from the pivot the effort is applied, the easier it is to move the large rock or load.

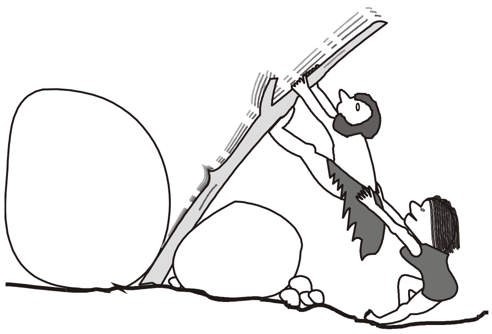


Figure 1(a)

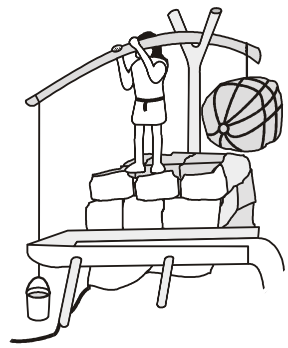


Figure 1(b)

When a weight is attached to one side of a lever to assist the user, it is known as a counterbalance.

A universal systems diagram of a lever is shown in figure 2. A lever system changes an input force and an input motion into an output force and an output motion.

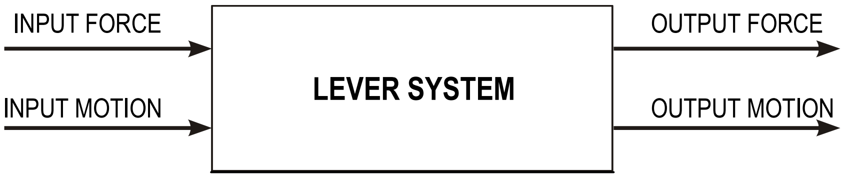


Figure 2

The point that a lever pivots about is called a fulcrum. A line diagram of a lever is shown in figure 3. The input force is called the effort and the input motion is the distance moved by the effort force. The output force is called the load and the output motion is the distance moved by the load.

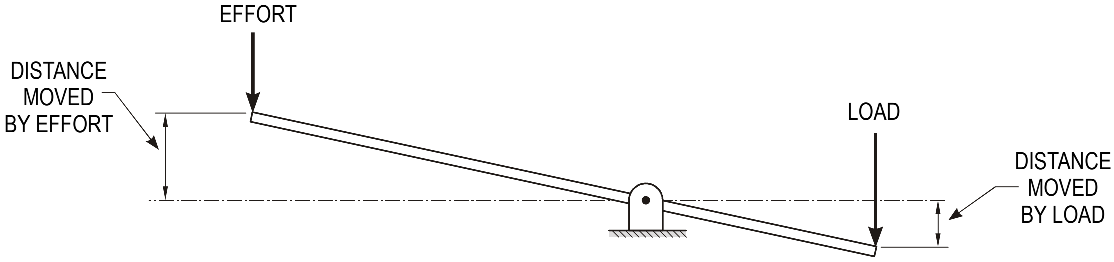


Figure 3

Classes of levers

Levers can be divided into three distinct types (classes) determined by the position of the load, effort and fulcrum. Applications of their use are found almost everywhere, from the home or school to equipment on the space shuttle. The classes of levers are as follows.

Class 1

In class 1 levers the effort is on one side of the fulcrum and the load is on the opposite side (figure 5). Class 1 levers are the simplest to understand: the longer the crowbar the easier it is to prise open the lid.

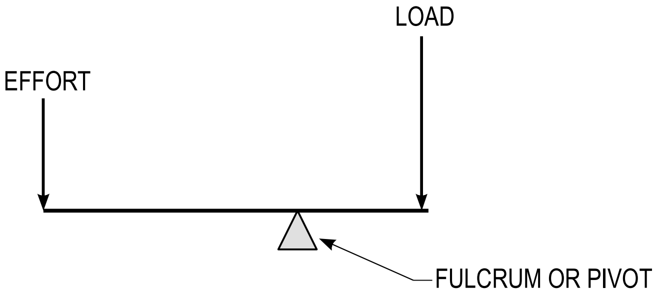


Figure 5

Class 2

In class 2 levers the fulcrum is at one end of the lever and the load and the effort are spaced out on the other end of the bar. The load must be closer to the fulcrum than the effort (figure 6). A wheelbarrow is a good example of a class 2 lever. The wheel is the fulcrum, the load is in the container area and the effort is applied to the handles. Similarly, a door has a hinge (fulcrum), the load can be considered as acting in the door's centre of gravity and the effort is applied as far from the hinge as possible.

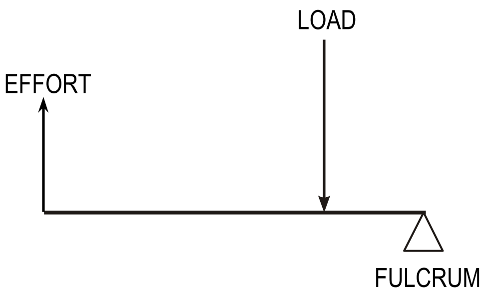


Figure 6

Class 3

Class 3 levers are similar to class 2 levers except that now the effort is closer to the fulcrum than the load (figure 7). This means that more effort has to be applied to move the load. This type of lever is used when mechanisms require a large output movement for a small input movement.

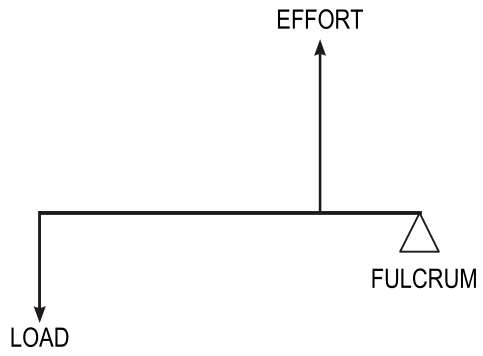
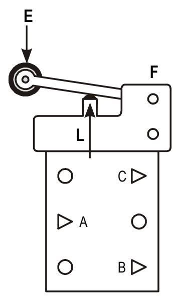
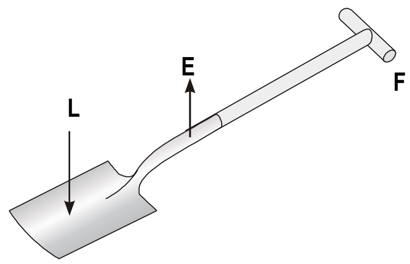
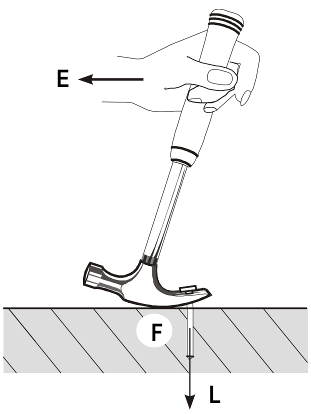


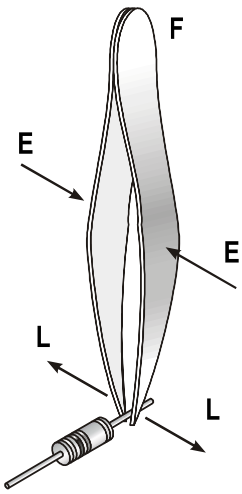
Figure 7

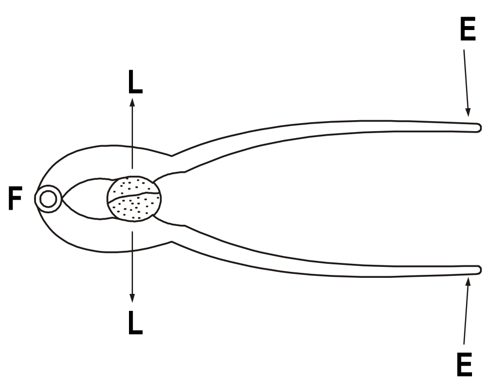
Examples of various types of lever are shown below; in some cases it is difficult to tell exactly into which class they fit.











Levers: task 4

Complete the following table by listing as many examples of the different classes of levers as you can.

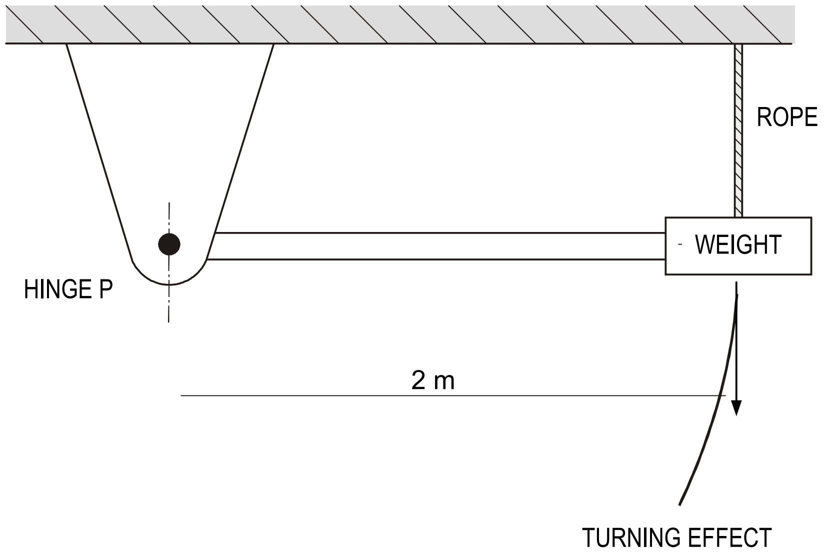
Class 1	Class 2	Class 3

Moments

The sketch in figure 8 shows a weight attached to a metal rod, and the rod is free to rotate around a hinge (pivot) P. If the rope holding the weight stationary is cut, what happens to the rod? If the rope is cut, the force on the weight causes the rod to swing or turn around the pivot. This 'turning effect' is called a *moment.*

The weight in figure 8 shows a moment of 20 Nm (10 N x 2 m). A moment is measured in newton-metres.

As long as the rope is not cut, the weight and rod are held in balance by the force in the tie rope.



When any system is in a steady state it is said to be in *equilibrium.*

Figure 8

The lever system in figure 9 shows a lever that is in a state of equilibrium (balance). The input force is tending to turn the lever anticlockwise; the load is tending to turn the lever clockwise. The forces on each end of the lever are exerting a moment: one clockwise, the other anticlockwise. If the beam (lever) is in equilibrium, both of these moments must be equal.

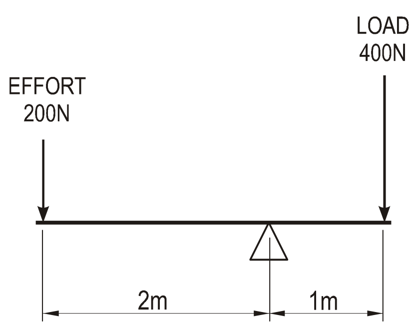


FIGURE 9

The *principle of moments* states that the sum of the moments must equal zero or the sum of the clockwise moments must equal the sum of the anticlockwise moments. The Greek letter ∑ stands for 'the sum of' and can be used as a shorthand way of writing the principle of moments:

$$\sum CWM = \sum ACWM$$
$$F_1 \times d_1 = F_2 \times d_2$$

The force times the distance turning the lever clockwise is equal to the force times the distance turning the lever anticlockwise. As stated, moments are measured in newton-metres. It can be seen that the moment on one side of the lever is equal to the moment on the other side. (Work done = force x distance in the direction of motion.)

Example 4

Using the lever system in figure 10, use the principle of moments to show that the lever is in equilibrium.

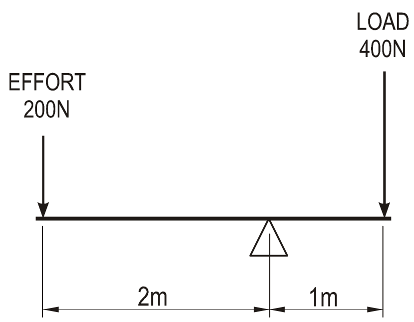


Figure 10

Answer

For equilibrium, the ∑CWM = ∑ACWM. A moment is a force multiplied by a distance

$$\mathbf{\sum CWM = \sum ACWM}$$
$$\mathbf{F_1 \times d_1 = F_2 \times d_2}$$

The load is exerting a clockwise moment; that is, it is tending to make the lever turn clockwise.

Clockwise moment = 200 N x 2 m = 400 Nm

The effort is exerting an anticlockwise moment.

Anticlockwise moment = 400 N x 1 m = 400 Nm

Therefore, ∑CWM = ∑ACWM

Therefore the lever is in a state of equilibrium.

Example 5

A car footbrake uses a lever action to amplify the force transmitted by the driver to the braking system when the driver's foot presses the foot-pedal. If the driver's foot can exert a force of 5000 N, what force will be transmitted to the braking system?

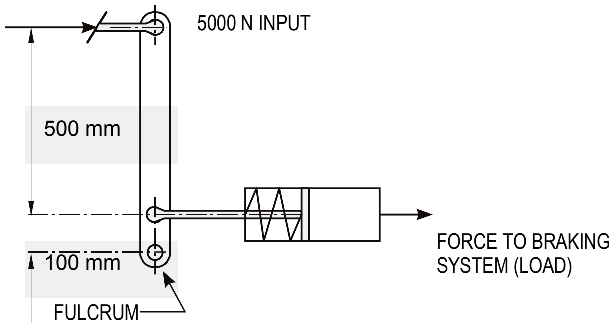


Figure 11

This is a class 2 lever. Take moments about the fulcrum to find the force on the braking system. Notice the distance from the fulcrum to the input is 600 mm.

The input tends to make the lever turn clockwise; the braking system is opposing the input and so acts to turn the lever anticlockwise.

The principle of moments states that

$$\sum CWM = \sum ACWM$$
$$F_1 \times d_1 = F_2 \times d_2$$

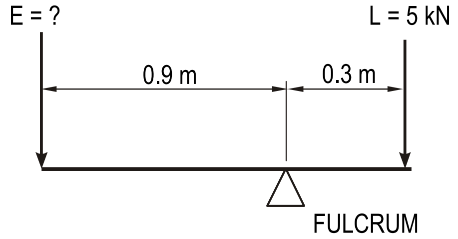
5000 N x 0.6 m = braking force x 0.1 m

$$\text{braking force} = \frac{5000\text{ N} \times 0.6\text{ m}}{0.1\text{ m}}$$

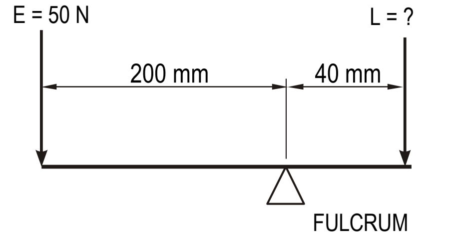
braking force = 30,000 N or 30 kN

Moments: task 1

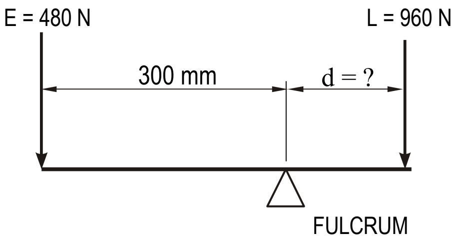
Use the principle of moments to find the missing force or distance in the following problems. Show all working.



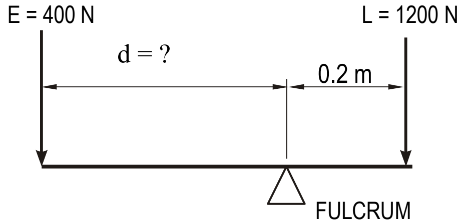
$\sum CWM = \sum ACWM$



$\sum CWM = \sum ACWM$



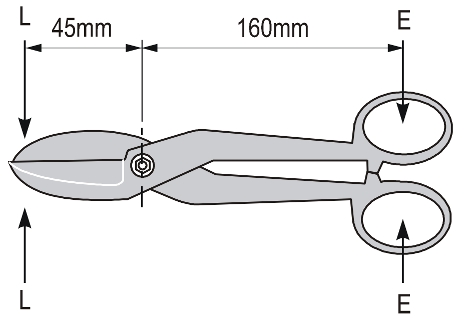
$\sum CWM = \sum ACWM$



$\sum CWM = \sum ACWM$

Moments: task 2

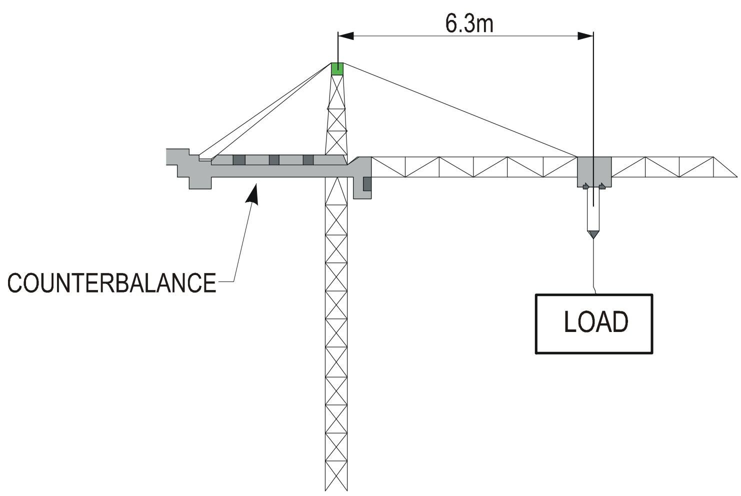
The hand-cutters shown are used to cut thin metal with the effort and load shown.



What effort will have to be applied if the force required in the hand-cutters to shear metal is 1.5 kN?

Moments: task 3

The diagram below shows a tower crane carrying a load of 90,000 N. At the other end a counterbalance load is applied.



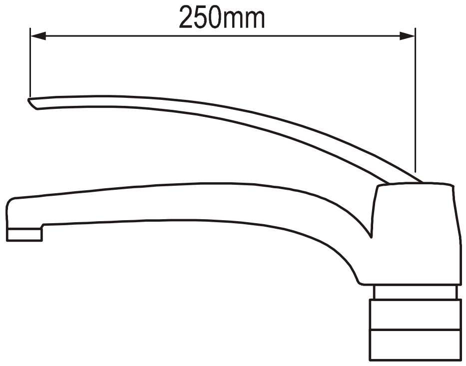
a) Explain why the crane would be unstable without the counterbalance.

b) Is it an advantage for the counterbalance to be able to move, either towards the centre of the crane or away from its centre?

c) The crane in the diagram is lifting a load of 90,000 N, which is 6.3 m away from the tower. How far from the tower should a 100,000 N counterbalance be placed so that the crane remains stable?

Moments: task 4

A single-lever monobloc tap is shown below.



a) If the length of the handle is 250 mm and the effort to turn it is 15 N, what moment would close the tap valve?

b) What is the benefit of this type of tap?

c) Where would this type of tap be very useful?

Moments: task 5

When a fish has been hooked, the pull from the fish is 22 Newtons at right angles to the fishing rod. The pivot is at the end of the rod, which is 2.4 metres long. The angler applies an effort at 0.4 metres from the end of the rod.

a) Draw a line diagram with dimensions, loads, pivots, etc.

b) Calculate the anticlockwise turning moment applied by the fish.

c) Calculate the effort the angler must apply to stop the rod from turning anticlockwise.

The angler has to exert a greater effort than the load applied by the fish to maintain equilibrium. Is this an advantage or disadvantage to the angler?

The bell-crank lever

The bell-crank lever shown in figure 12 is used to transmit the input force and motion through a right angle. It gets its name from part of the bell mechanism used to summon servants in Victorian houses. By varying the lengths of the two arms of the bell crank, it is possible to use it either to magnify an input force or to magnify an input motion.

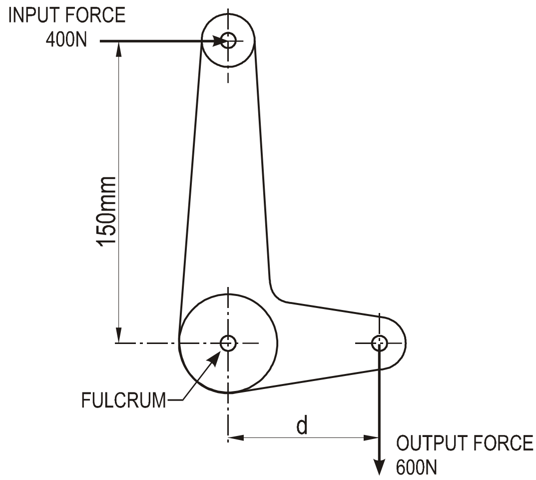


Figure 12

Example 6

Use the principle of moments to determine the length of the output side of the bell-crank lever in figure 12.

Calculate the force-multiplier ratio of the lever.

Answer

This is a class 1 lever with a right-angled bend. To find the distance 'd', take moments about the fulcrum. Assume the lever is in equilibrium so that the output force opposes the input force.

$$\Sigma CWM = \Sigma ACWM$$
$$F_1 \times d_1 = F_2 \times d_2$$

$$600\ N \times d = 400\ N \times 0.15\ m$$

$$d = \frac{400\ N \times 0.15\ m}{600\ N}$$

$$d = 0.1\ m$$

$$\textit{The force-multiplier ratio} = \frac{\textit{load}}{\textit{Effort}}$$

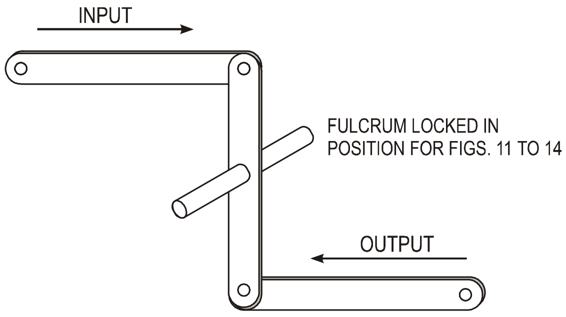
$$= \frac{600\ N}{400\ N}$$

$$= 1.5$$

Linkages

Levers are often linked together to transmit force or motion. A linkage consists of two or more levers connected together. Linkages are useful for changing the direction of an input or for giving greater force or distance amplifications.

Five common linkages found in many machines are shown below.



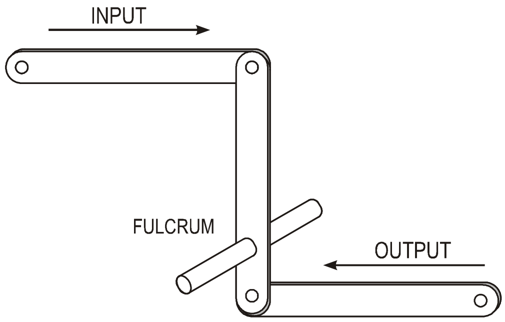


Figure 1
Reverse motion output; distance from fulcrum is the same, therefore, same force.

Figure 2
Reverse motion output, but fulcrum is nearer the output so the force is amplified.

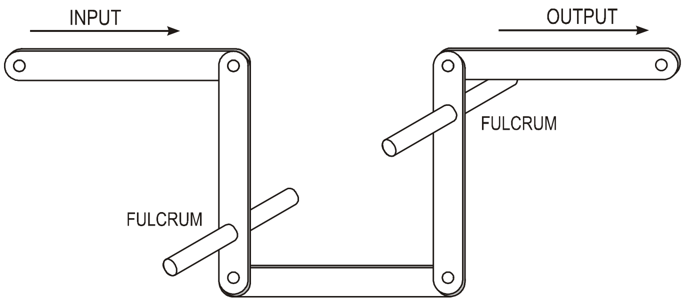
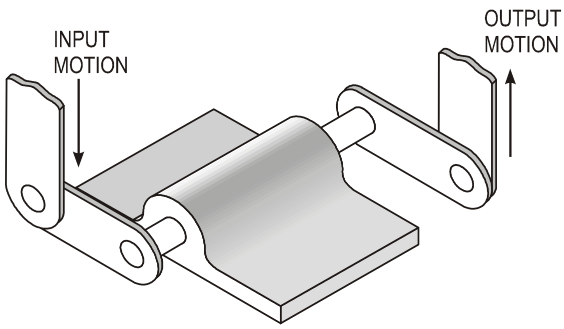


Figure 3

Input and output motion are the same, but there is a large amplification of force.



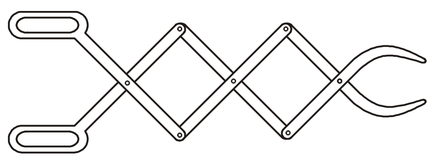


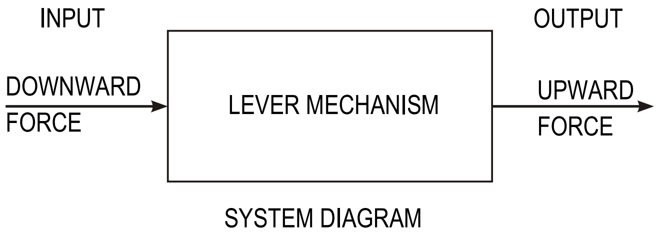
Figure 4
Reciprocating motion transformed to rotary motion.

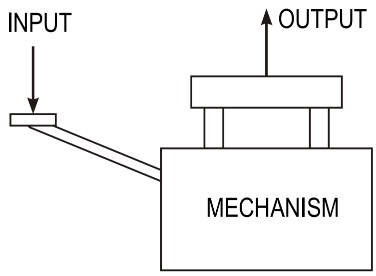
Figure 5
Lazy tongs linkage for extra reach.

Linkages: task 1

A system diagram of a lever mechanism is shown below. The requirements state that when the lever is pushed down, the output should rise.

The force-multiplier ratio should be 2:1.





Design a suitable linked lever system that will achieve the desired output.

A sketched diagram should show:

- a line diagram
- the load, effort and fulcrum
- your notional load and effort indicated in Newtons
- your calculation showing the force ratio.

Free-body diagrams

It is important to isolate different parts of a structure or body from its adjacent surroundings. In a line diagram this can be done by drawing a free-body diagram, which is a diagrammatic representation of all or part of the structure showing the forces affecting it.

Example

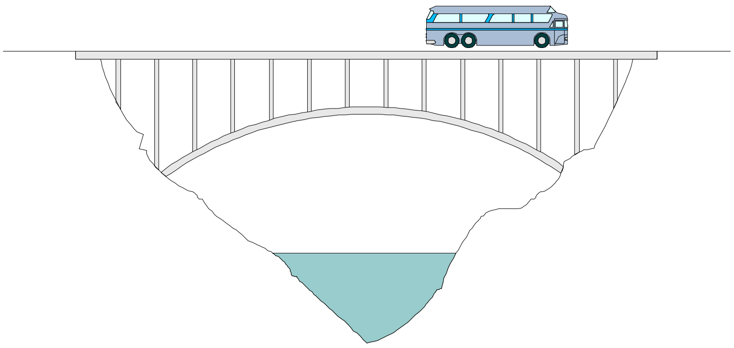


Figure 1

If all the visual components acting on the structure or body were removed and replaced with their force value, a simplified diagram would allow a better understanding of how the forces are affecting the structure.

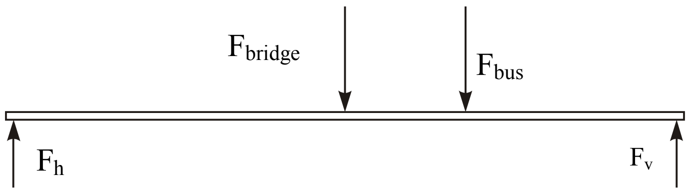


Figure 2: free-body diagram

Figure 2 is a simplified free-body diagram of figure 1. The forces representing the bus and the weight of the bridge act downwards and are taken through the centre of the bus and the middle of the bridge. Because of the point of contact of the bus, the arrow is drawn through its centre. The forces F_h and F_v represent the forces that the supports have on the structure, therefore they also have to be shown. We could be more detailed and draw the angled support for the bridge in the rock face.

FREE-BODY DIAGRAMS: TASK 1

Draw a free-body diagram of the car indicating the downward force and reactions with arrows. Use suitable lettering.

Beams

Apart from levers, structural beams and beam-related objects are also affected by forces and turning moments. For a horizontal structure to be stable (in equilibrium) when being affected by forces in a vertical plane, the following conditions must be satisfied.

> *The sum of the forces acting upwards must equal the sum of the forces acting downwards.*
>
> ***Σ upwards forces = Σ downwards forces***
>
> *The sum of the clockwise moments about any point must equal the sum of the anticlockwise moments about the same point. That is*
>
> ***Σ clockwise moments = Σ anticlockwise moments***
>
> (principle of moments)

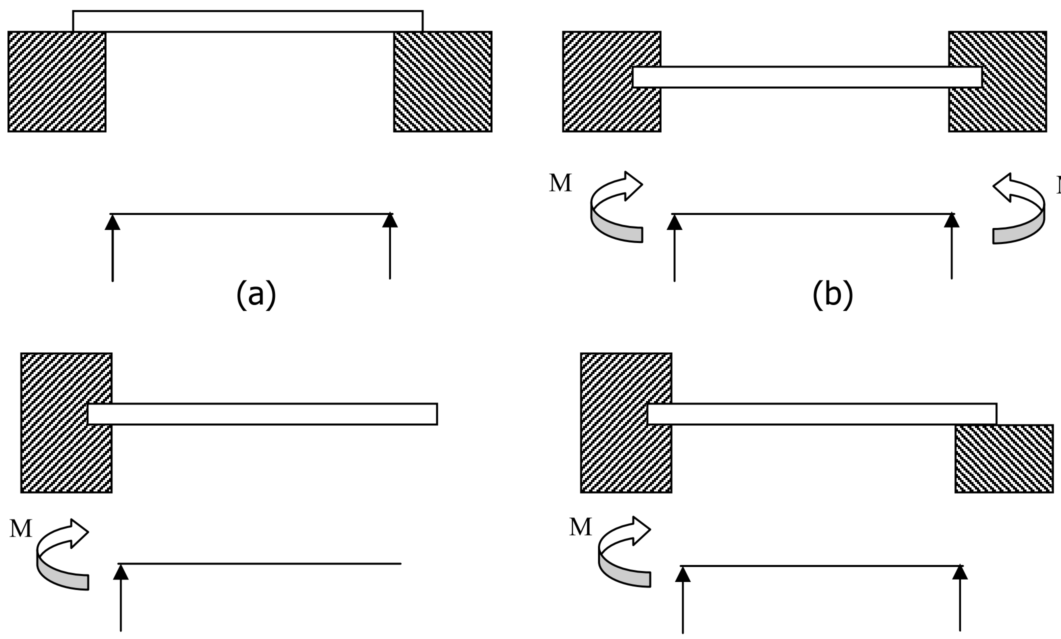
Beam reactions

Beams, however, have to be supported differently from lever applications and this determines beam-support reactions. Beams, therefore, are supported in a number of ways, such as:

1. simply supported at both ends
2. built in at both ends (this type of end-fixed beam is called an encastre)
3. built in at one end only (this type of beam is called a cantilever)
4. built in at one end only and simply supported at the other.

Examples of these methods are shown below.

Types of beam support



At the points of support, the downwards forces acting on the beam are resisted by the forces acting upwards. These upward forces are known as beam reactions, or simply the reactions.

Example 1

Determine the reactions R_1 and R_2 for the simply supported beam (beam weights will be ignored in this case).

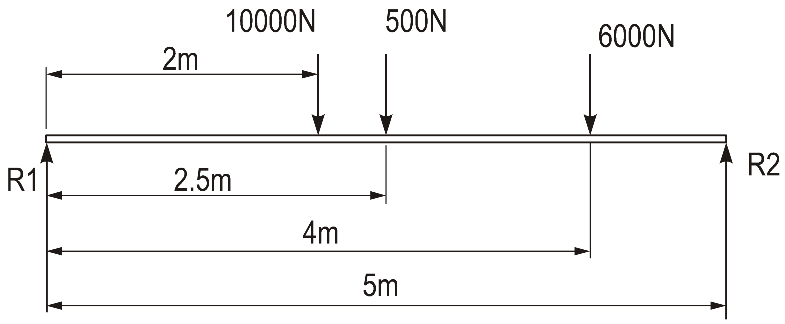


Figure 1: free-body diagram

TAKE MOMENTS ABOUT R_1

$$\Sigma \text{ clockwise moments} = \Sigma \text{ anticlockwise moments}$$

$$(10{,}000\ N \times 2\ m) + (500\ N \times 2.5\ m) + (6000\ N \times 4\ m) = R_2 \times 5\ m$$

$$R_2 = \frac{20{,}000\ Nm + 1250\ Nm + 24{,}000\ Nm}{5\ m}$$

$$= 9050\ N$$

$$\text{Also} \quad \Sigma \text{ upwards forces} = \Sigma \text{ downwards forces}$$

$$R_1 + 9050\ N = 10{,}000\ N + 500\ N + 6000\ N$$

$$R_1 = 16{,}500\ N - 9050\ N$$

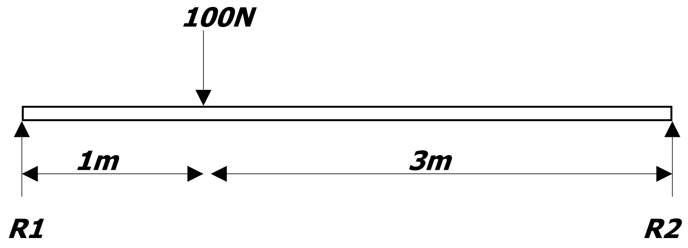
$$= 7450\ N$$

Therefore the reactions for the beam supports are R_1 = 7450 N and R_2 = 9050 N

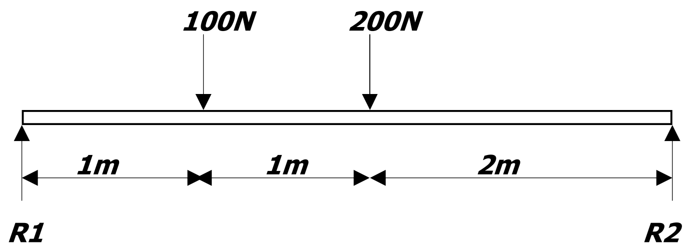
BEAMS: TASK 1

Determine the reactions R_1 and R_2 for the simply supported beams in the following examples (beam weights will be ignored in this case).

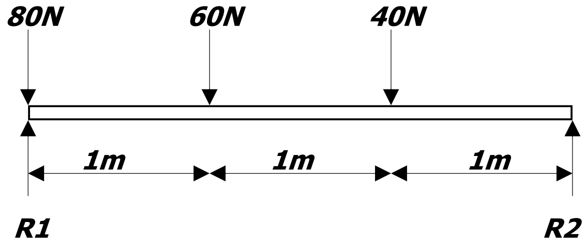
a)



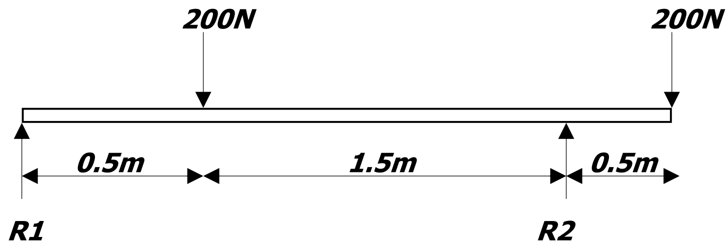
b)



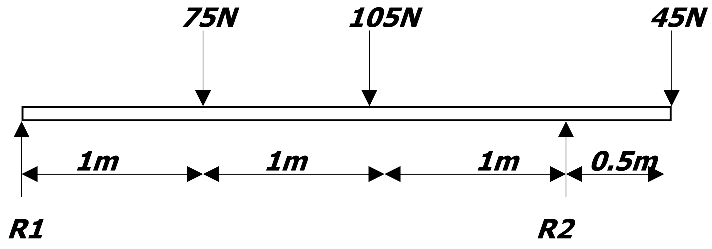
c)



d)

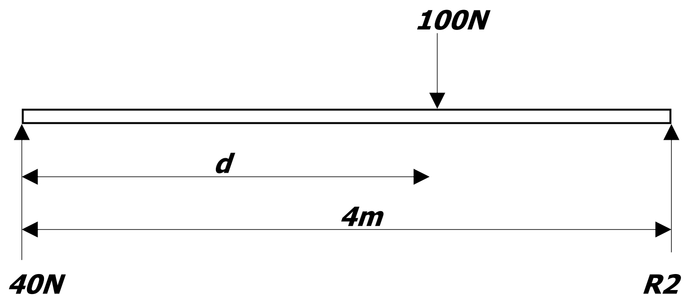


e)

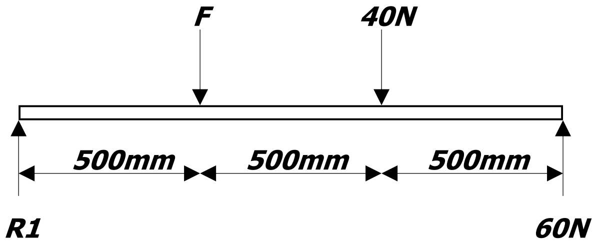


2 : Find the missing quantity in the following beams. Use the principle of moments and assume that each beam is in a state of equilibrium.

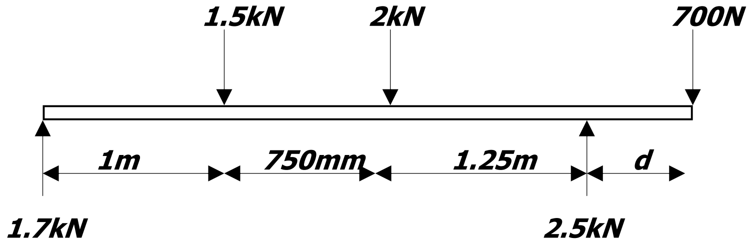
a)



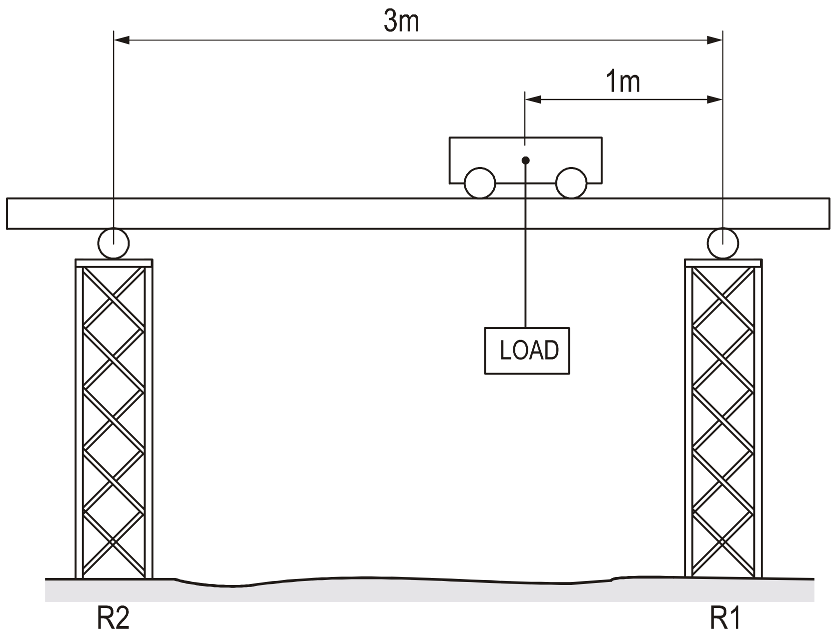
b)



c)

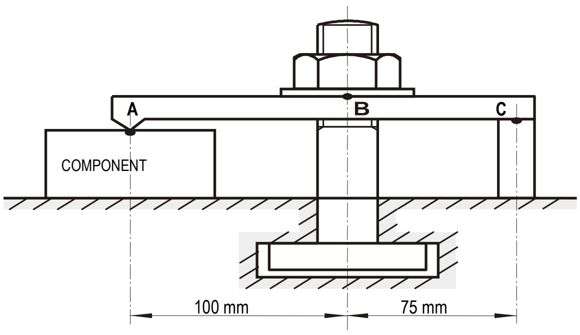


3 : A beam is simply supported at each end with a span of three metres. The beam carries a small lifting device having a weight of 1 kN.



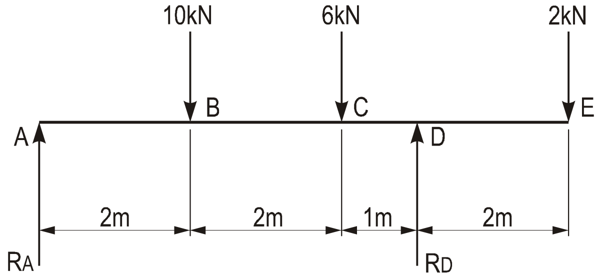
- Complete a suitable free-body diagram.
- When the lifting device is positioned at the ***mid-point*** of the beam and carries a casting weighing 2.5 kN, what are the reactions at R_1 and R_2?
- When the lifting device is positioned one metre from one end and carries a machine component weighing 6 kN, what are the reactions at R_1 and R_2?

4 : The figure below shows a clamp on a milling machine table for fixing a component for machining. A clamping force of 1200 N is applied by the bolt to the component and rear-distance piece when the nut is fully tightened.



- Draw a free-body diagram to show the arrangement of the forces.
- Calculate the clamping forces on the component (RA) and the distance piece (RC).
- How could the arrangement be altered to give a bigger clamping force on the component?

5 : The diagram below shows a free-body diagram of a horizontal beam, seven metres long, which is part of a bridge structure. The beam is simply supported at A and D. Determine the reaction forces at A and D.



6 : The supermarket trolley shown is a form of cantilever.

- Sketch the free-body diagram to indicate the major forces.
- If the groceries are spread throughout the trolley, can it tip over? If not, why?
- What happens if someone leans on the back of the trolley?
- What happens if someone applies weight to the front of the trolley?

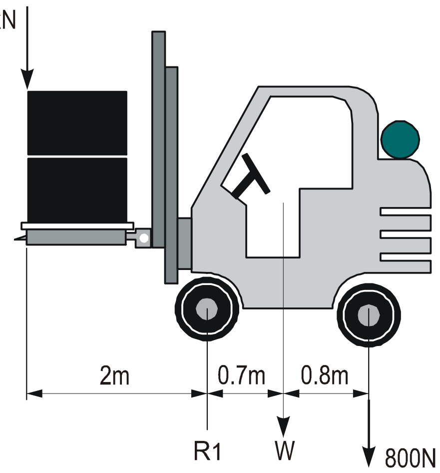
Refer to your free-body diagram in your answers.

7 : The forklift truck must have a minimum downward force of 800 N acting through the rear wheels. ie R2 will be 800N.

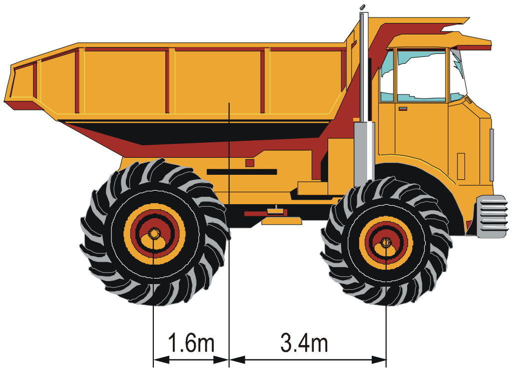
- Draw an appropriate free-body diagram.

- Calculate the weight required to balance the load on the lift with R_2 = 0 N.

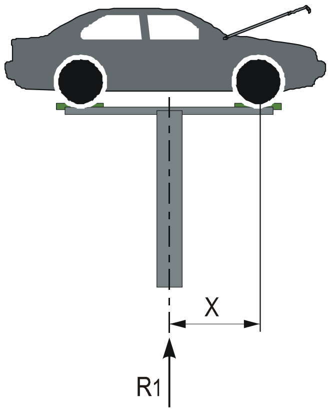
- Find the additional weight acting through the centre of gravity of the truck to produce 800 N at the rear wheels.



6 : The total downward load when the truck shown below is empty is 30 kN and when fully loaded 55 kN. Draw a suitable free-body diagram. Find the reaction in each of the axles when the truck is empty and when fully loaded.

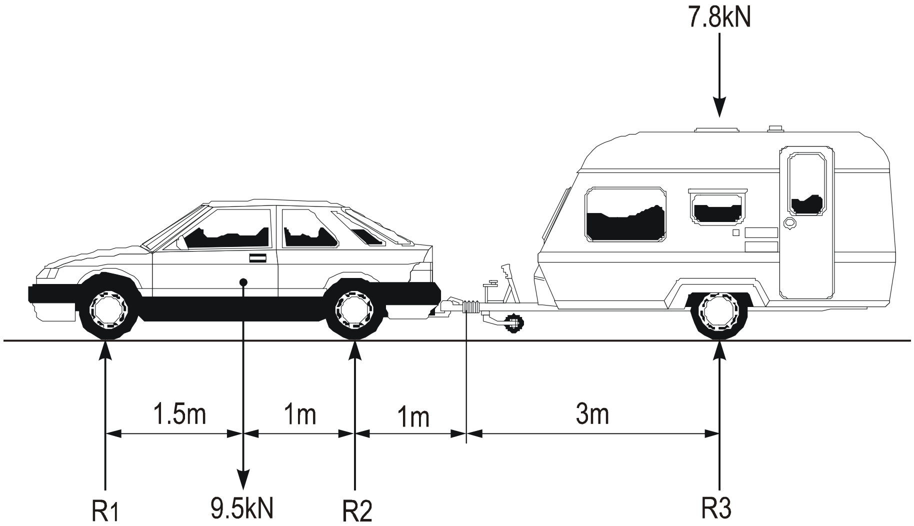


7 : A car has been raised on a ramp to look at the drive shaft. The downward load on the car’s rear and front axles are 5970 N and 3980 N, respectively. The wheel-base of the car measures 2.5 m.



- Draw a free-body diagram.
- What is the reaction at R1?
- What distance (x) will R1 have to be from the front axle to maintain equilibrium?

8 : The car and caravan shown below have a ball-jointed tow-bar that connects the car and its caravan. The weights of each are shown, together with the reaction forces in the centre of all three wheels.



- Draw a free-body diagram for the car and caravan.
- Looking at the caravan, calculate the force acting at the tow-ball.
- Calculate the reaction forces R_1 and R_2.

Gears

Gears are toothed wheels designed to transmit rotary motion and power from one part of a mechanism to another. They are fitted to shafts with special devices called keys (or splines, etc.) that ensure that the gear and the shaft rotate together. Gears are used to increase or decrease the output speed of a mechanism and can also be used to change the direction of motion of the output.

The type of gear wheel most commonly used is the spur gear.

Simple gear train

Gears work by interlocking or 'meshing' the teeth of the gears together as shown in figure 1.

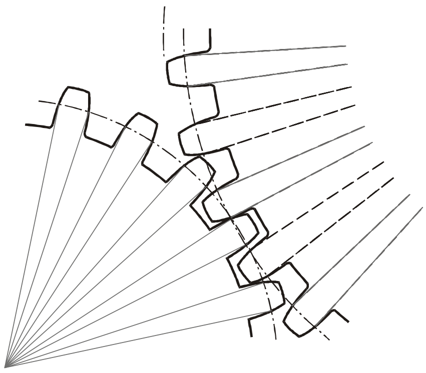


Figure 1

When two or more gears are meshed they form a 'gear train'. The input gear, which causes the system to move, is called the 'driver'; the output gear is called the 'driven'. Both gears are mounted and supported on separate shafts.

Example

Figure 2 below shows a method of increasing the output speed of a mechanism.

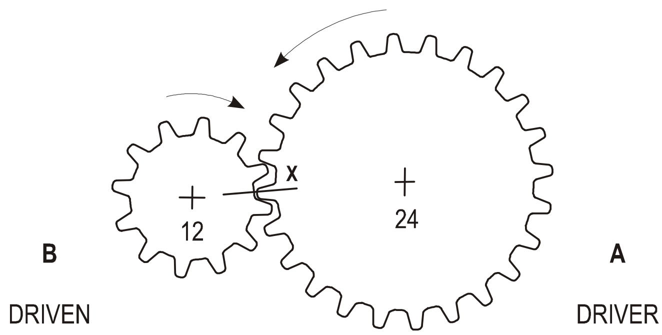


Figure 2

If driver gear A has 24 teeth and it makes one complete turn, then 24 teeth will have passed point X on the diagram. If driven gear B is meshed with driver gear A, then for every tooth of gear A to pass point X, one tooth of gear B must pass this point.

If 24 teeth of gear A pass point X, then 24 teeth of gear B must pass point X. To be able to do this, gear B must make two complete revolutions but in the opposite direction.

Velocity ratio in gears

The ratio of change in speed between the gears is called the velocity ratio.

The ratio of a gear system is found by dividing the number of teeth on the driven gear by the number of teeth on the driver gear. This can be used to calculate the output speed of a gear system.

$$\text{Velocity ratio} = \frac{\text{number of teeth on driven gear}}{\text{number of teeth on driver gear}}$$

Example
For the gear system shown in figure 2 the gear multiplier ratio is

$$Gear\ Ratio = \frac{12}{24}$$
$$= \frac{1}{2}\ or\ 2:1$$

This means that if gear A was rotating at 100 rpm (revolutions per minute) clockwise then gear B would rotate at 200 rpm anticlockwise.

Gears can also be used to decrease the speed of a mechanism, as shown in figure 3.

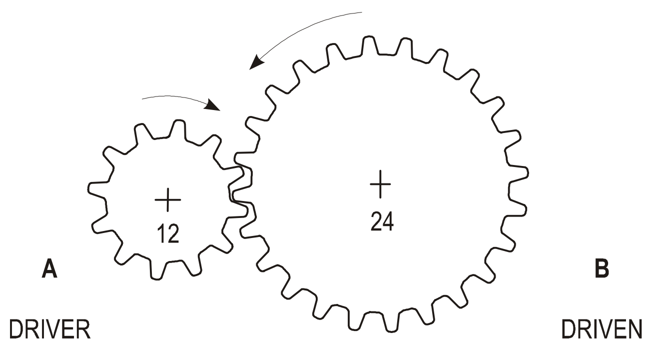


Figure 3

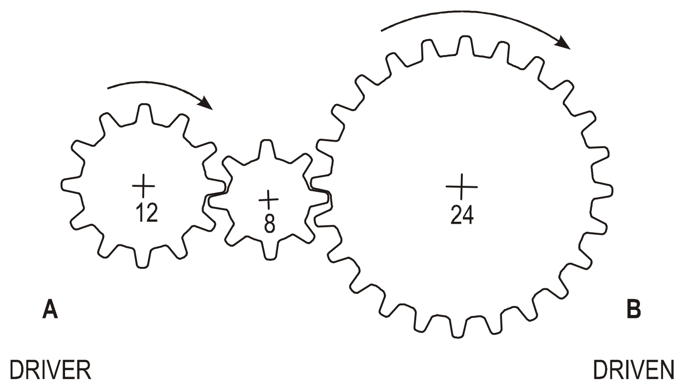
$$Gear\ Ratio = \frac{24}{12}$$
$$= \frac{2}{1}\ or\ 1:2$$

If gear A is still rotating at 100 rpm in a clockwise direction then gear B will now rotate at 50 rpm in an anticlockwise direction. It is sometimes necessary to obtain a change in speed without changing the direction of the driven gear. How can this be done?

Idler gears

To get the driven gear to rotate in the same direction as the driver, a third gear is inserted in the system. This idler gear has no effect on the multiplier ratio of the system. The size of the idler is not important and is normally a small gear, as in figure 4.

Figure 4



The velocity ratio for the simple gear train in figure 4 is still 2:1. If gear A still rotates at 100 rpm clockwise then the output of gear B will rotate at 50 rpm clockwise.

Ratchet and pawl

A wheel with saw-shaped teeth round its rim is called a ratchet. The ratchet wheel usually engages with a tooth-shaped lever called a pawl. The purpose of the pawl is to allow rotation in one direction only and prevent rotation in the opposite direction. A ratchet and pawl mechanism is shown in figure 5.

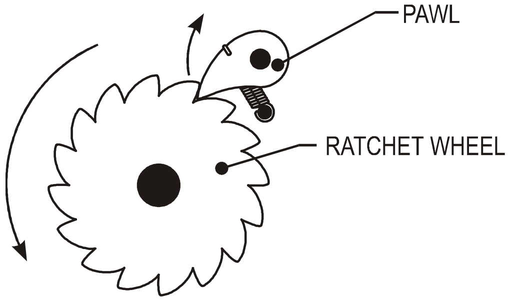


Figure 5

A crane-winding mechanism shown in figure 6 makes use of a ratchet and pawl to allow rotary motion in one direction only. The crane can be wound up, but the tension force in the cable cannot unwind the winch because of the ratchet mechanism.

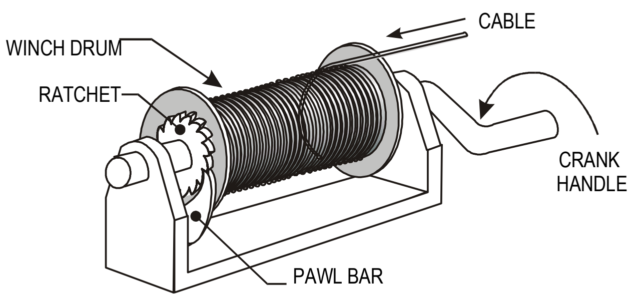


Figure 6

Task 1: simple gear train

Using the mechanical components within *Crocodile Technology* build a simple gear train, similar to the ones in figure 7, where the driven gear will rotate at twice the speed of the driver gear. (Use the constant speed motor.)

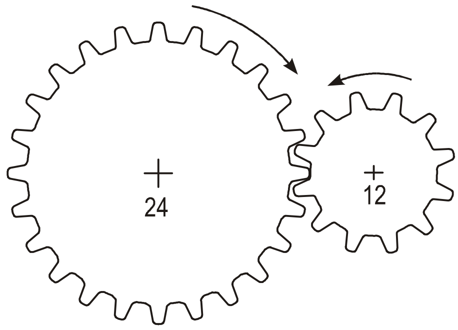


Figure 7

Gears: task 2

You know how to build a simple gear train that will increase the speed of rotation of the driven gear compared to the driver gear.

From a selection of four gear wheels – 8 t, 16 t, 24 t and 40 t – design and build a simple gear train that will provide the biggest increase in speed between the driver and driven gears.

Sketch your results and calculate the multiplier ratio of your system.
(A circle can represent a gear wheel.)

Gears: task 3
Modify your simple gear train so that it will give you the biggest decrease in speed between the driver and driven gears, but this time with both the input and output gear rotating in the same direction.

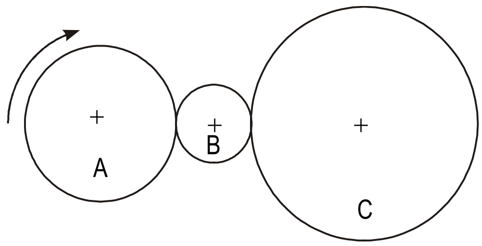
Sketch your results and calculate the velocity ratio of your system.

Gears: task 4
Using ***Focus On Mechanisms*** investigate some of the different situations where gearing systems are in operation.

Gears: task 5

Calculate the velocity ratio for the simple gear train below and then find the output speed and direction if gear A rotates at 250 rpm in a clockwise direction. Show all your working.

A = 20 teeth
B = 5 teeth
C = 30 teeth



Answer
Output speed

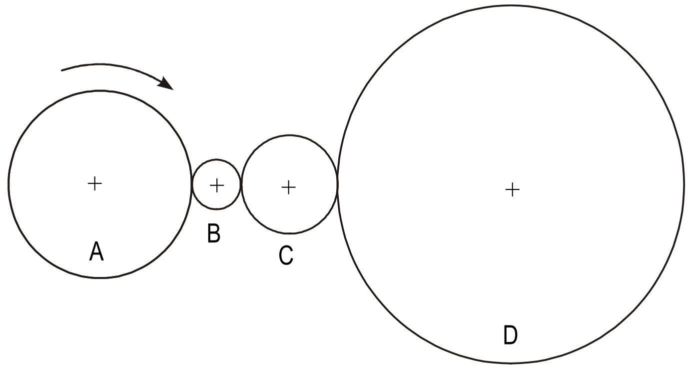
Velocity ratio

Gears: task 6

For the simple gear train shown below, find the following.

a) The gear that rotates in the same direction as A.
b) The speed of B, C and D if A rotates at 500 rpm.
c) The velocity ratios of A to B, A to C and A to D.

A = 50 teeth
B = 10 teeth
C = 25 teeth
D = 100 teeth



ANSWERS

(a)

(b) B = C = D =

(c) A to B A to C A to D

Compound gears

If gears are required to produce a very large change in speed, for example if the multiplier ratio is 100:1, then problems can arise with the size of gear wheels if a simple gear train is used. This problem can be overcome by mounting pairs of gears on the same shaft, as shown in figure 7.

This arrangement is described as a compound gear train. This type of gear train can also be used to provide different outputs moving at different speeds and in different directions.

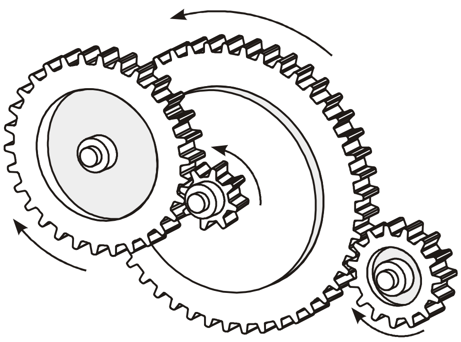


Figure 7

The compound gear system in figure 8 shows how the shafts are connected between the 'pairs' of gears. Gears B and C are connected and rotate at the same speed. To calculate the velocity ratio for the gear train it is necessary to calculate the ratio for each pair of meshing gears.

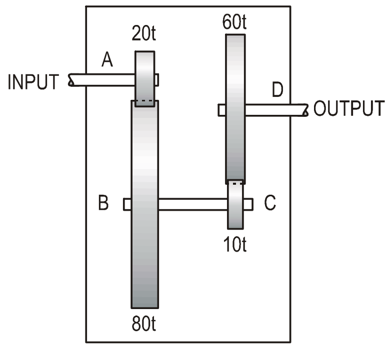


Figure 8

Example

The velocity ratio for the system shown in figure 7 is as follows.

The velocity ratio for the first pair of meshing teeth is

$$\text{Ratio of AB} = \frac{driven}{driver} = \frac{80}{20} = 4:1$$

The velocity ratio for the second pair of meshing teeth is

$$\text{Ratio of CD} = \frac{driven}{driver} = \frac{60}{10} = 6:1$$

The total velocity ratio is calculated by multiplying both ratios:

$$\text{Total ratio} = \frac{4}{1} \times \frac{6}{1} = 24:1$$

For an input speed of 100 rpm, the output speed would be less than 5 rpm, that is, 4.17 rpm.

Worm and wheel

Another way of making large speed reductions is to use a worm gear and worm-wheel, as shown in figure 9. The worm, which looks rather like a screw thread, is fixed to the driver shaft. It meshes with a wormwheel, which is fixed to the driven shaft. The driven shaft runs at 90 degrees to the driver shaft. When considering the speed changes in most worm gear systems, you can think of the worm as if it were a spur gear with one tooth. It is a single tooth wrapped around a cylinder.

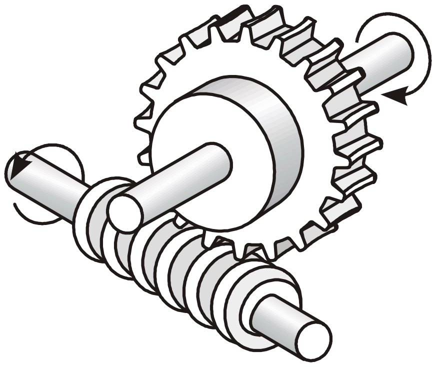


Figure 9

Example

The multiplier ratio between the gears in figure 9 is

$$\text{velocity} = \frac{driven}{driver} = \frac{30}{1} = 30{:}1$$

This would mean that for a motor rotating at 100 rpm, the output driven gear would rotate at only 3.33 rpm.

Bevel gears

Bevel gears, like worm gears, use shafts at 90 degrees to each other, as shown in figure 10.

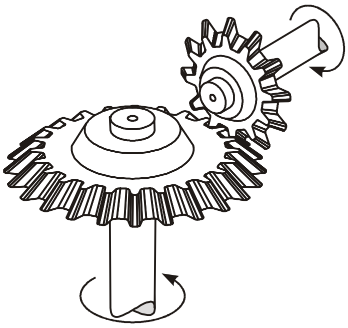


Figure 10

The food whisk shown in figure 11 uses bevel gears not only to change rotary motion through 90 degrees, but also, by using different sized gears, to increase the speed of rotation.
The one shown gives a speed increase of 1:5.

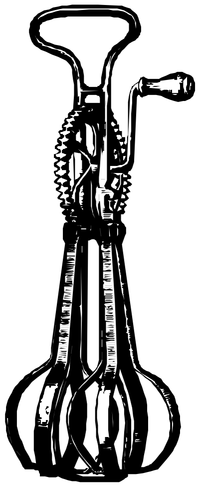


Figure 11

Gears: task 7

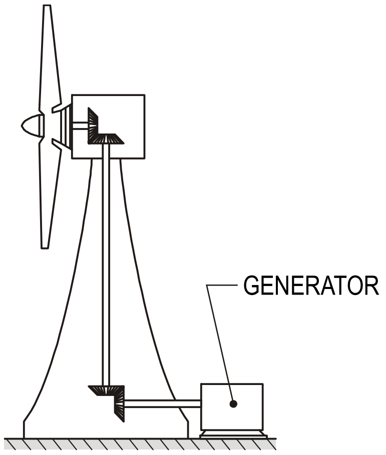
Produce the greatest possible speed within a compound gear train using spur gears with 8 t, 16 t, 24 t and 40 t. This can be done using computer simulation if available with the 1 rev motor constant speed motor as a power source.

Complete the following.

- Sketch or print out your results.
- Sketch your gear train graphically (as in figure 8).
- Calculate the velocity ratio for your system.

Gears: task 8

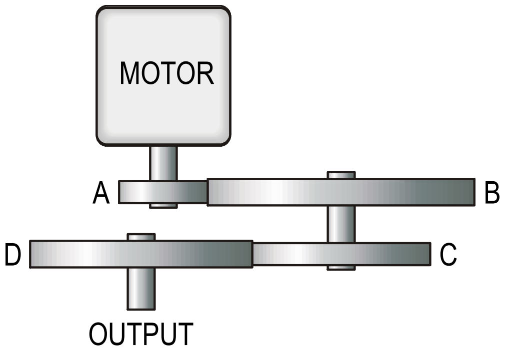
Two pairs of bevel gears, all of equal size, are used to model the wind generating system shown below. The output from these bevel gears can be connected to the compound gear system of the previous assignment. Calculate the output speed if the vanes of the windmill are rotating at 10 rpm.



Gears: task 9

The compound gear train shown below is driven by a motor that runs at 1000 rpm. Calculate the velocity ratio of the motor to the output shaft and then the output speed. Show all your working.

A = 20 teeth
B = 60 teeth
C = 40 teeth
D = 50 teeth



Answer

velocity ratio =

Output speed =

Gears: task 10

A motor with a single worm wheel output rotates at 500 rpm. You are given the following sizes of worm gears from which to select.

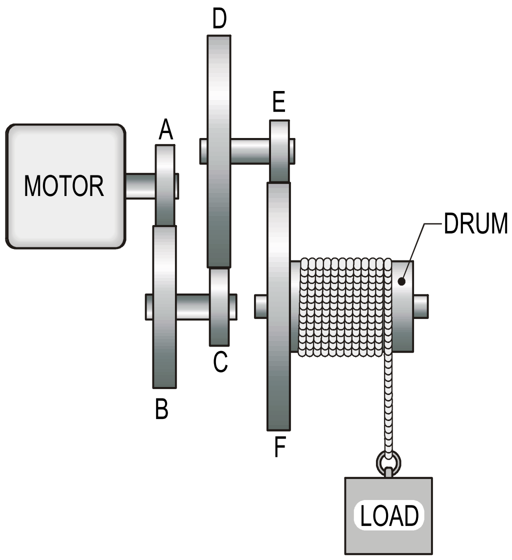
= 10 teeth
= 25 teeth
= 50 teeth

Explain which gear should be connected to the motor to give the slowest output speed and why. What is the output speed?

Gears: task 11

The motorised winch shown below runs at a speed of 1200 rpm. The drum is to rotate at 25 rpm. Calculate:
the velocity ratio required to produce the speed reduction
the number of teeth gear A must have to meet this requirement.

A = ?
B = 32 teeth
C = 15 teeth
D = 45 teeth
E = 12 teeth
F = 48 teeth



Answer

velocity ratio =

Number of teeth in A =

Also calculate for the above system the following.

If the radius of the drum is 50 mm, what is the speed of the load being raised? (Answer in m/s)

Answer

Torque and Drive Systems

Torque is the amount of turning produced by a force. The turning or twisting action exerted by a force or number of forces will cause or tend to cause rotary motion. Drive shafts in cars, tools turning, belt-and-pulley systems, etc. are all affected by torque.

A simple example of this is when the propeller of a model builder's toy boat connected to a rubber band is twisted by torsion forces. When the propeller is released, the rubber band, having been under the twisting effect, releases energy to drive the boat through the water.

Example 1
How much torque is required to tighten the nut if the force required is 45 N and the radius of the tool is 200 mm.

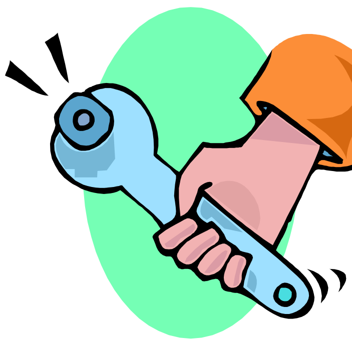
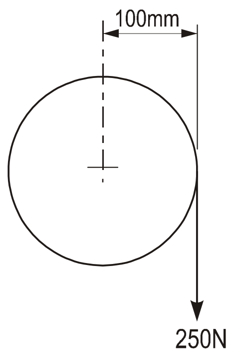


Figure 1

Torque = force x radius
= 45 N x 0.2 m
= ***9 Nm***

Example 2
A belt drives a pulley with a diameter of 200 mm. If the effective belt tension tending to turn the pulley is 250 N, find the work done per revolution.

When a force of *F* newtons acts at the rim of a pulley of *r* metres radius, then the work done per revolution is $F \times 2\pi r$; that is, *F* newtons x circumference (2p*r*).



Therefore, the work done per revolution
= torque (*Fr*) x 2p

$$= 2 \times 3.14 \times (250N \times 0.1m)$$

$$= 157\,J$$

Power transmitted by a belt drive

Example 3
The effective pull on a belt drive is 420 N when driving a 500 mm diameter pulley. The speed of rotation is 220 revolutions per minute. Find the power.

When a force, F newtons, acts at the rim of a pulley, of r metres radius, revolving at n revolutions per second, the power or work done per second is given by

$$F \times 2\pi r n.$$

Power =force (F newtons) x circumference ($2\pi r$) x revolutions/s (n)

Thus power, or work done/s = torque (Fr) x angle rotated through/s ($2\pi n$)
$= 2\pi nT$

The effective driving torque = force x radius

$$= (F_1 - F_2)\frac{\text{diameter } (d)}{2}$$

F_1 is the tension on the tight side.
F_2 is the tension on the slack side.

Therefore power transmitted = $\pi dn(F_1 - F_2)$

Power = $\pi dn(F_1 - F_2)$

$$= \frac{3.14 \times 0.5 \times 220 \times 420}{60}$$

= 2140W or 2.42kW

Torque: task 1

a) A shaft transmits 18 kW when rotating at 200 rpm. What is the torque in the shaft?

b) A railway traction motor develops 150 kW when the train moves along the track. The rail wheel rotates at 1500 rpm. Find the torque in the driving axle.

c) An electric motor exerts a torque of 23 Nm and rotates at 2800 rpm. Find the power of the motor.

d) The effective pull on a belt is 360 N when driving a 400 mm diameter pulley. The speed of rotation is 250 rpm. Calculate:

- the power without slip
- the power with three per cent slip.

e) During a machining test on a lathe, the tangential force on the cutting tool was found to be 220 N. If the work-piece diameter was 120 mm, what was the torque on the lathe spindle?

f) Calculate the power transferred if a 230 mm diameter pulley wheel revolves at 25 revolutions per second. The pulley has one belt and the tension in the tight side of the belt is 436 N, while in the slack side it is 186 N.

Belt-and-chain drives

Many mechanisms make use of rotary motion, often provided by someone turning a handle or by an electric motor. But to be useful, this rotary motion has to be frequently transmitted from one part of a mechanism to another, often with a change of speed. While gears can be connected together in a simple gear train, if too many gears are used there can be large efficiency losses due to friction.

There are two simple means of transmitting rotary motion over relatively large distances. One is to use a belt wrapped around two or more pulleys as shown in figure 1. The belt is tightened or tensioned by pulling one of the pulleys out and locking it in place. Pulleys are thin metal discs with a groove cut into the circumference of the disc.

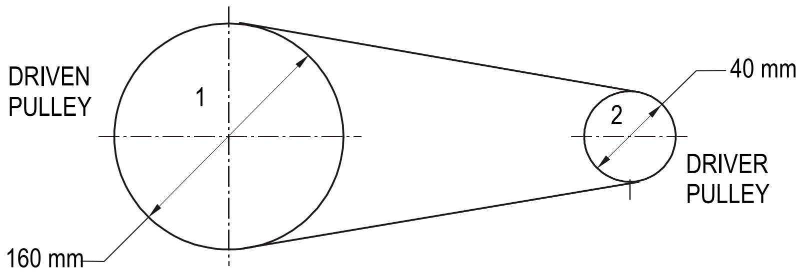


Figure 1: belt-and-pulley symbol

The tensioned belt transmits the rotary motion from pulley 2 to pulley 1. The belt is angled as shown in figure 2 to give better grip to prevent the belt from slipping. A change in speed can be accomplished by varying the diameter of the driver pulley and driven pulley.

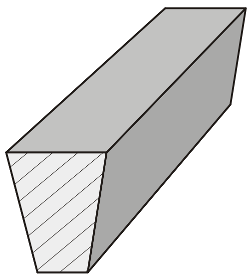


Figure 2: vee belt for extra grip

Changes in direction can be achieved by crossing the belt as shown in figure 3.
In belt-drive systems, the belt must be crossed between the two pulleys if the direction of the output shaft is to be opposite to that of the input shaft.

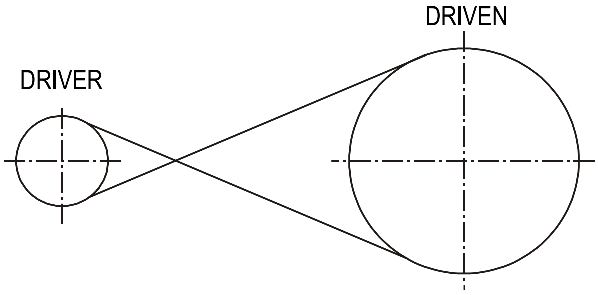


Figure 3

Belt drives are used in a wide variety of situations. They are made from a composite of two materials, rubber and string. The string helps to prevent the rubber from stretching too much. Drive belts are inexpensive to produce. They are easy to replace and need little maintenance, as they do not require lubrication. They also absorb shock loads. For instance, if a belt drive is used to transmit the power from a motorcycle engine to the rear wheel and the biker tries to 'wheelie', the belt tends to slip, preventing damage to the engine. Belt drives are found in many household machines such as washing machines, vacuum cleaners (figure 4), tumble dryers and so on.

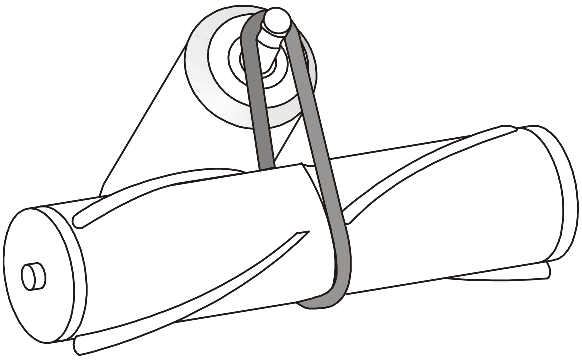


Figure 4: vacuum cleaner drive belt

Drive systems: task 1

Many machines and mechanisms use belts and pulleys to transmit rotary motion. Write down any machines or mechanisms that you know of which use belts and pulleys.

Drive systems: task 2

Draw a systems diagram for one of your above answers.

Drive systems: task 3

Draw a symbol for two pulleys that produce a decrease in speed and with a change in direction for the driven pulley.

Multiplier ratio for belt drives

Pulley systems can be used to transmit rotary motion over a large distance. The input rotary motion is often from a fixed-speed and fixed-torque electric motor. Torque is a turning force produced by mechanisms and is measured in newton-metres (Nm). Changing the ratio of the diameters of the pulleys can vary both the speed of the output and the torque at the output.

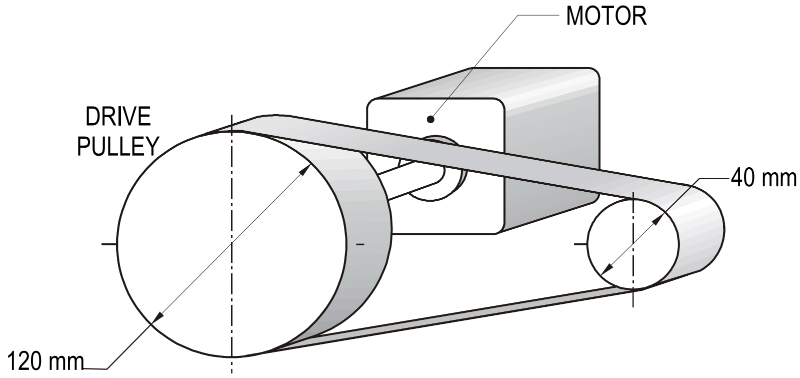


Figure 4: belt-and-pulley system

Example

The motor in figure 4 is connected to a pulley of diameter 120 mm. This is the driver pulley. The driven pulley has a diameter of 40 mm. The multiplier ratio of the pulley system is the diameter of the driven pulley divided by the diameter of the driver pulley.

$$\text{Velocity ratio} = \frac{\text{diameter of driven pulley}}{\text{diameter of driver pulley}}$$

For the system in figure 4 the multiplier ratio is $\frac{40}{120} = \frac{1}{3}$ or 1:3

Example

Motor speeds

If the motor speed is 1200 rpm, the output can be found by dividing the input speed by the velocity ratio.

The output speed can also be found from the velocity ratio: $\frac{\text{input speed}}{\text{output speed}}$

$$\text{Output speed} = \frac{\text{input speed}}{\text{velocity ratio}}$$

$$\text{Output speed} = \frac{1200 \text{ rpm}}{1/3}$$

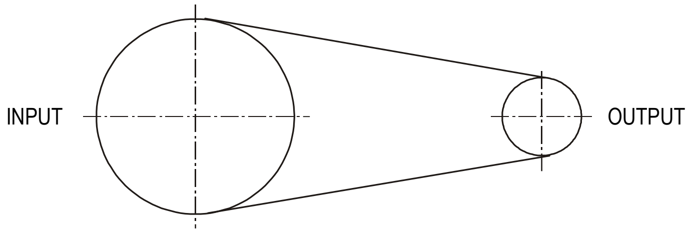
Output speed = ***3600 rpm***

In figure 4 the speed of the motor is increasing; there must be some loss to compensate for this gain. The loss is in output torque. In general, as the output speed increases, the torque decreases. As the speed decreases, the torque increases and this affects the turning force. Electric motors are rated at certain torques for specific voltage supplies.

Drive systems: task 4

Label the line diagram of the belt-drive system shown below using the following terms.

- driver pulley
- driven pulley
- belt



Drive systems: task 5

(a) In the above system, when the driver is turned, does the driven pulley turn faster or slower?

Answer

(b) If the diameter of the driver pulley is 40 mm and the diameter of the driven pulley is 10 mm, what is the multiplier ratio?

Answer

(c) If you placed a chalk or tape marker at the top - dead centre - of each of the two pulleys and turned the driver pulley once, how many revolutions would the smaller driven pulley make?

Answer

Example

Figure 5 shows a belt-drive system for transmitting rotary motion from an electric motor to a spin-dryer system in a washing-machine drum. The motor has an input torque of 800 Nm at 1000 rpm.

Calculate the velocity ratio of the system, the speed of the drum and the output torque produced by the drum.

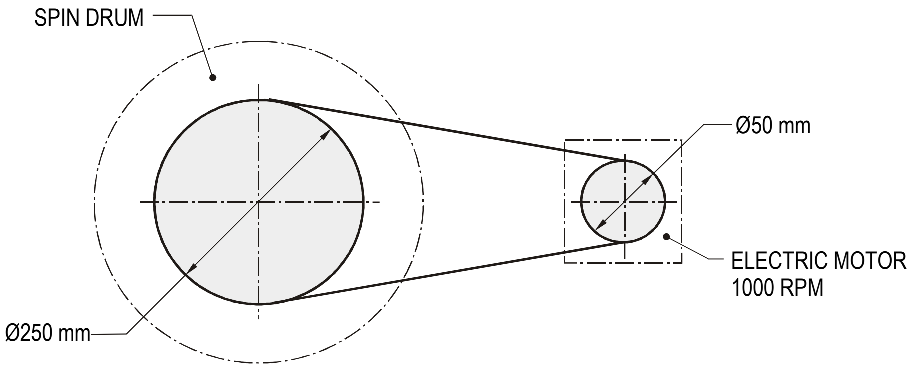


Figure 5: washing-machine spin dryer

Answer

$$\text{velocity ratio} = \frac{\text{diameter of driven pulley}}{\text{diameter of driver pulley}}$$

$$= \frac{250}{50}$$

$$= 5:1$$

$$\text{The output speed of the drum} = \frac{\text{input speed}}{\text{velocity ratio}}$$

$$= \frac{1000\,rpm}{5}$$

$$= 200\,rpm$$

$$\text{Output torque} = \text{input torque} \times \text{velocity ratio}$$

$$= 800\,Nm \times 5$$

$$= 4000\,Nm$$

A variety of output speeds and output torques can be achieved by using stepped-cone pulleys, as shown in figure 6. The drive motor is attached to one set of pulleys and the drive belt can be moved between the various pairs of pulleys to give a selection of speeds.

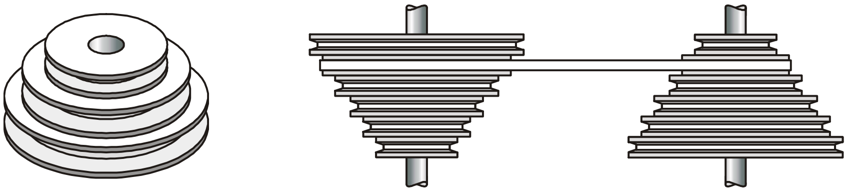


Figure 6: stepped-cone pulley system

One of the advantages of belt drives is that they will absorb shock loads by slipping. However, excessive slipping will create inefficiency in the system. At the same time, if the belt is too tight the pulley bearings could be damaged. One method of keeping the belt correctly tensioned is to use a spring-loaded jockey pulley, as shown in figure 7.

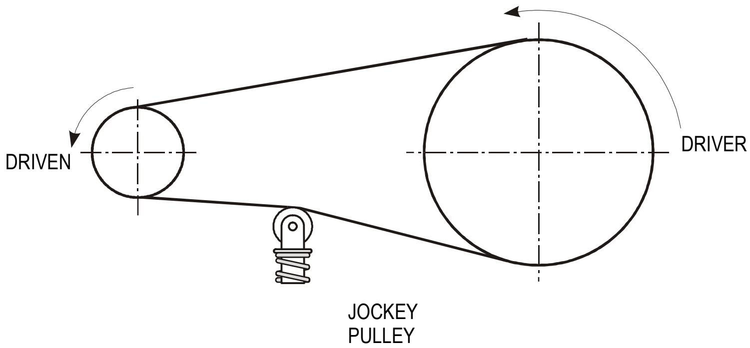


Figure 7: a jockey pulley for tensioning

Toothed belts

Belt drives tend to use their ability to slip to their advantage. However, where slippage would damage a mechanism, toothed belts have been developed that retain the advantages of normal belts but do not slip.

Many cars have toothed belts (for example timing belts) to control the opening and closing of the inlet and outlet valves in the car engine. If the belt slipped, the pistons would collide with the valves, damaging the engine. These belt drives are quiet, require little maintenance and are easily changed if required (figure 8).

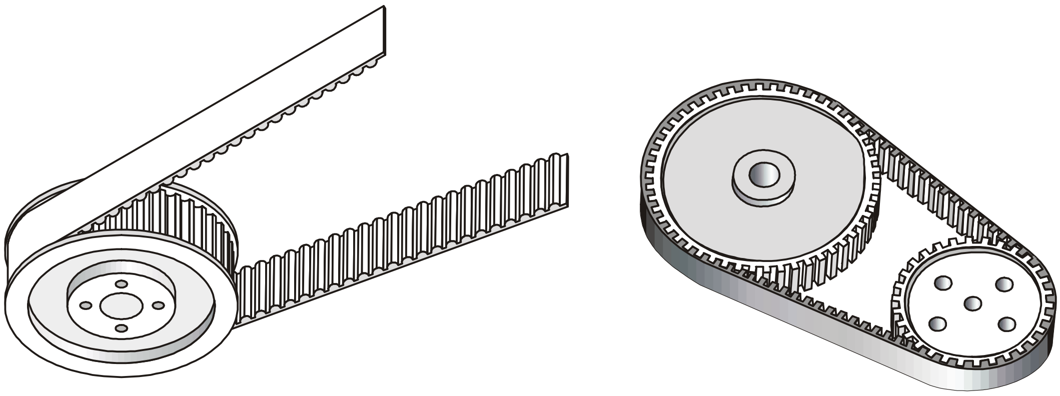


Figure 8: toothed belts

Chain drives

Where large forces have to be transmitted, and there can be no slippage allowed, chain drives are used. Instead of a pulley, a toothed wheel known as a sprocket is used to drive a chain. The chain in turn drives another toothed wheel. Once again, the speed can be varied by making the sprockets different sizes.

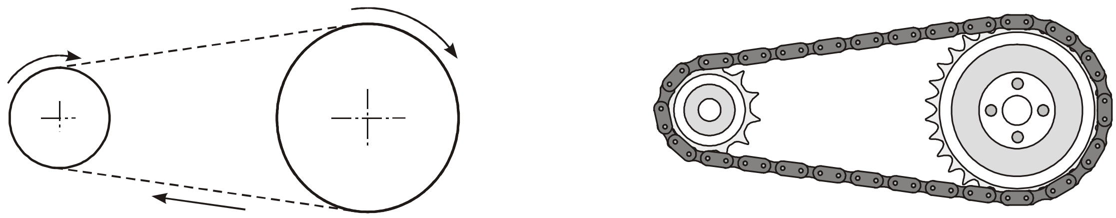


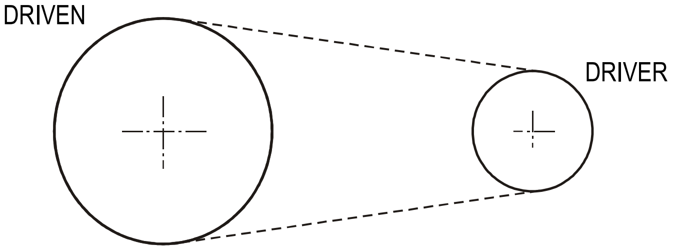
Figure 9: Bicycle-chain drive

Figure 9 shows an application of a chain drive that is familiar to everyone. This can help to illustrate the advantages and disadvantages of chain drives. When cycling, if you want to go faster suddenly, you stand up and put extra weight (force) into the pedals. This force is transmitted to the back wheel by means of the chain. If the chain were to slip, what would happen? Unless the chain and sprockets are worn, the chain will not slip and the extra force will carry out its task in allowing you to go faster.

Chains are very strong, and unless badly worn, they will not slip. However, they have to be oiled regularly, and both the chain and sprockets are prone to wear. They are also more expensive to make and buy than belt drives. Chain drives are also much noisier that belt drives.

Drive systems: task 6

Look at the chain drive shown below.



(a) When the driver is turned, does the driven gear turn faster or slower than the driven sprocket?

(b) If a mark was placed at the top of the large and small sprockets and the driver sprocket rotated, how many times would the driven sprocket rotate? (driver 30 teeth, driven 60teeth)

(c) Explain in technological language how the chain could be kept at the correct tension.

(d) What is lubrication and why is it important to keep the chain well lubricated?

(e) Draw a system diagram for a tensioned chain drive.

(f) Is the above system an open or closed looped system?

Velocity ratio for chain drives

Calculating the multiplier ratio, output speed and torque of a chain drive system is very similar to calculating them in belt-drive systems.

Example

A pedal cycle has 60 teeth on the driver sprocket and 10 teeth on the driven sprocket. What is the multiplier ratio of the chain-drive system?

$$\text{velocity}\,ratio = \frac{number\,of\,teeth\,on\,driven\,sprocket}{number\,of\,teeth\,on\,driver\,sprocket}$$

$$= \frac{10}{60}$$

$$= 1:6$$

CHAIN TENSION

Chain-drive systems must also have a means to tension the chain. If the chain is over-tensioned there will be excessive wear on the chain, sprockets and bearings in the system. In some bicycles and even motorcycles, the chain is tensioned by gently pulling the wheel back until the chain is tight and then tightening the locking wheel nuts. However, to give better control, a spring-loaded jockey wheel such as that used in Derailleur gears on racing bikes and mountain bikes is used, as shown in figure 10.

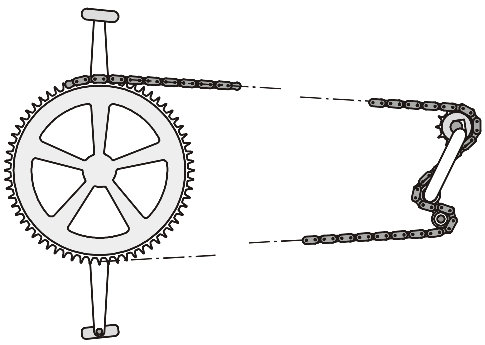


Figure 10: Derailleur gears

Example

The bicycle shown in figure 11 has two rear sprockets, one with 50 teeth and the other with 80 teeth. The driver sprocket has 200 teeth. Calculate the output torque for the two rear sprockets if the input torque is 20 Nm.

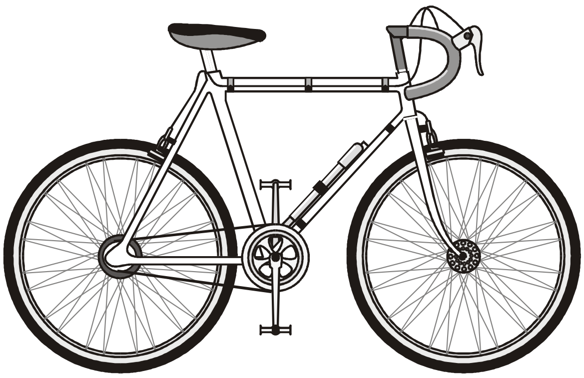


Figure 11: a two-gear bicycle

ANSWER

First find the multiplier ratio for the two driven sprockets.

$$\text{velocity } ratio\ of\ small\ sprocket = \frac{number\ of\ teeth\ on\ driven\ sprocket}{number\ of\ teeth\ on\ driver\ sprocket}$$

$$= \frac{50}{200}$$

$$= 1:4$$

$$\text{velocity } ratio\ of\ large\ sprocket = \frac{number\ of\ teeth\ on\ driven\ sprocket}{number\ of\ teeth\ on\ driver\ sprocket}$$

$$= \frac{80}{200}$$

$$= 1:2{\cdot}5$$

The output torque for each size of sprocket can now be found.

$$\text{Torque}(\text{small sprocket}) = \text{input torque} \times \text{velocity ratio}$$

$$= 20\,\text{Nm} \times 1:4$$

$$Output\ torque(small) = 5\,\text{Nm}$$

$$\begin{aligned}
\text{Torque(large sprocket)} &= \text{input torque} \times \text{velocity ratio} \\
&= 20\,\text{Nm} \times 1 : 2 \cdot 5 \\
\textit{Output torque}(large) &= 8\,\text{Nm}
\end{aligned}$$

Example

A motorcycle uses a belt drive to transmit power from the engine to the rear wheel as shown in figure 12. If the engine rotates at 3000 rpm, what will be the rotary speed of the rear wheel?

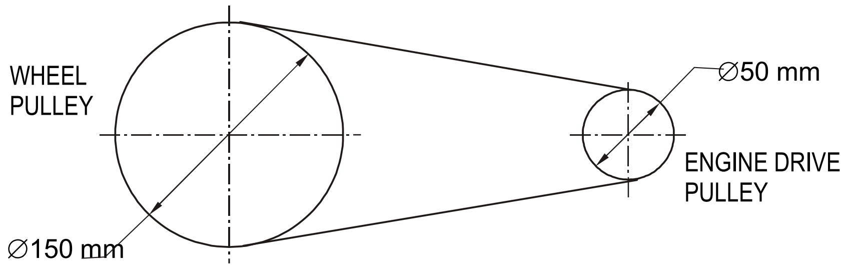


Figure 12: motorcycle belt drive

ANSWER

The rotary speed of the driver pulley multiplied by the diameter of the driver pulley is equal to the rotary speed of the driven pulley multiplied by the diameter of the driven pulley.

Rotary speed of driver pulley x diameter of driver pulley
=Rotary speed of driven pulley x diameter of driven pulley

$$\text{Rotary speed of driven pulley} = \frac{\text{rotary speed of driver pulley} \times \text{dia of driver pulley}}{\text{diameter of driven pulley}}$$

$$= \frac{3000 \times 50}{150}$$

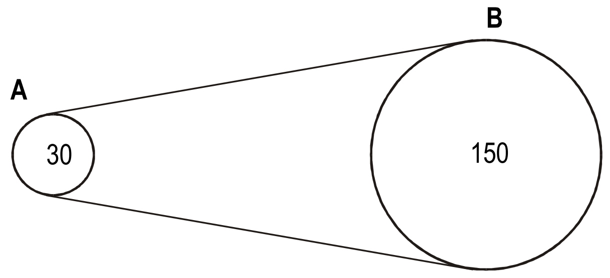
$$= 1000 \text{ rpm}$$

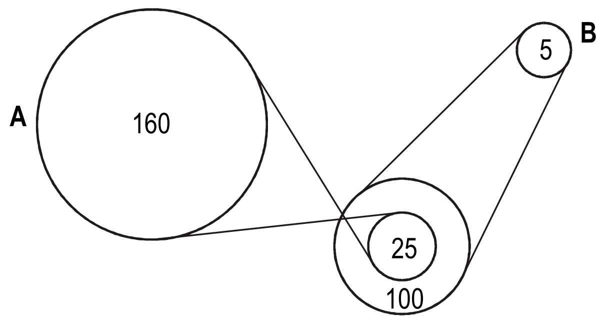
The rotary speed of the rear wheel is 1000 rpm.

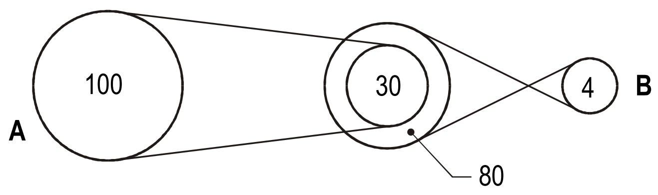
Drive systems: task 7

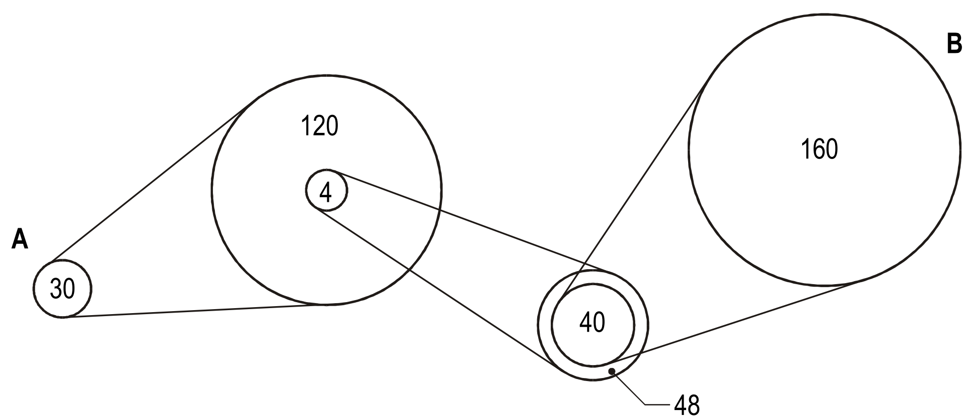
Calculate the velocity ratios for the following belt-drive systems.

They are driven from A to B. Also indicate with an arrow the direction of rotation of B assuming A is clockwise.









Converting motion

We know that there are four kinds of motion. These comprise:

- rotary
- linear
- reciprocating
- oscillating.

Many mechanisms involve changing one type of motion into another. For example, the rotary motion of a pillar-drill handle is changed to the linear motion of the chuck and drill bit moving towards the material being drilled.

Cams

A cam is a specially shaped piece of metal or plastic which can be used to change an input rotary motion to an output motion that is oscillating or reciprocating.

The cam operates by guiding the motion of a follower held against the cam, either by its own weight or by a spring. As the cam rotates, the follower moves. The way that it moves and the distance it moves depend on the cam's shape and dimensions.

The two main types of cam and follower are shown below.

1. The circular or eccentric cam (figure 1)
2. The pear-shaped cam (figure 2)

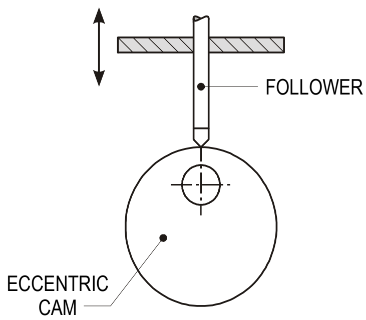


Figure 1

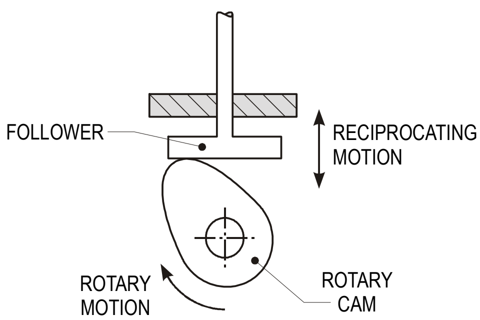


Figure 2

Other, more complex, shapes can also be used.

Cam motion

Pear-shaped cams are often used for controlling valves. For example they are often used on motor-car camshafts to operate the engine valves. A follower controlled by a pear-shaped cam remains motionless for about half a revolution. During the time that the follower is stationary, the cam is in a dwell period. During the other half-revolution of the cam, the follower rises and then falls. As the pear-shaped cam is symmetrical, the rising motion is the same as the falling motion.

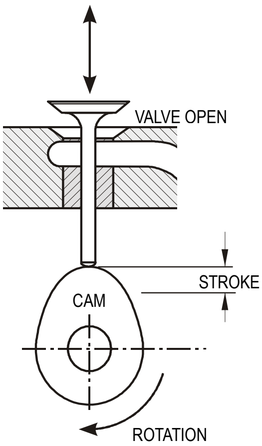


Figure 3

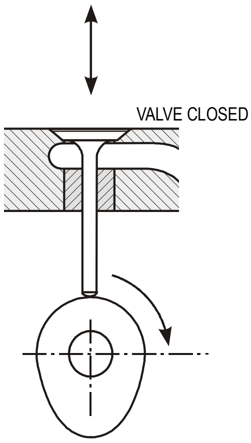


Figure 4

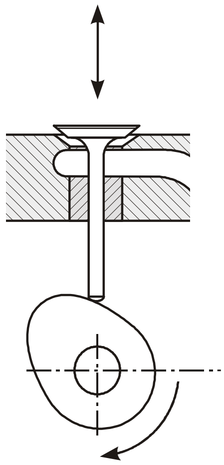


Figure 5

Figure 3 shows the valve fully opened as the follower is in contact with the highest point of the cam, its crown.

Figure 4 shows the valve closed as the follower is in contact with the lowest point of the cam, its heel.

Figure 5 shows the valve about to open at the end of its dwell period.

When not on the 'dwell' part of the cam cycle, the follower rises and falls and the valve opens and closes. The distance between the highest and lowest points on the cam profile is called the stroke of the cam. The distance the valve opens is the same as the stroke of the cam.

In a car engine, cams are fixed on a camshaft. As each cylinder has two valves, an inlet and an exhaust valve, there are two cams on a camshaft for each cylinder, as shown in figure 6.

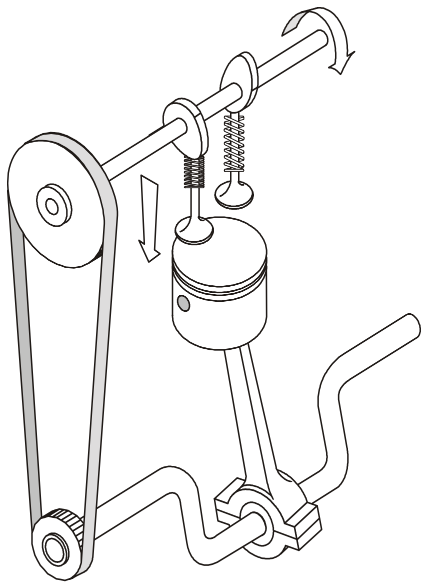


FIGURE 6

Crank slider

Crank slider mechanisms involve changes between rotary and reciprocating motion, as shown in figure 7. The crank rotates while the slide reciprocates. The longer the crank the further the slider will move. The two main ways that crank-slider mechanisms are used are described below.

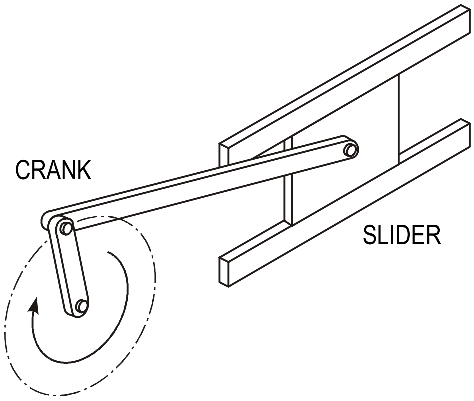


Figure 7

1. **Reciprocating motion to rotary motion**
   Car engines use reciprocating pistons, which are connected to a crankshaft by connecting rods, as shown in figure 8. As the pistons move up and down the connecting rods push the crankshaft round. Each piston moves down in turn, so keeping the crankshaft turning.

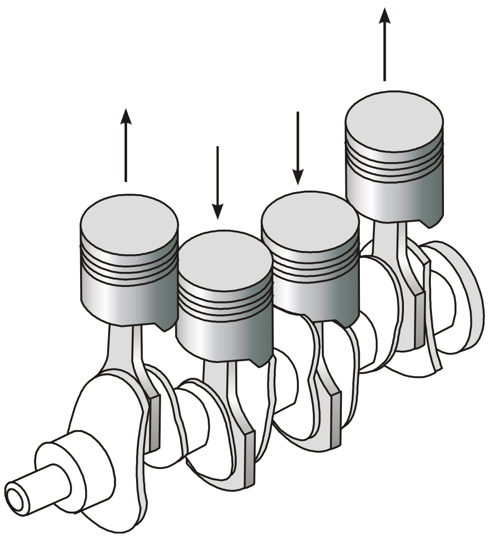


Figure 8

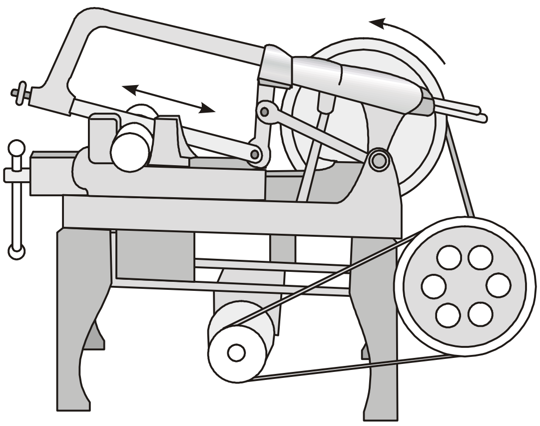
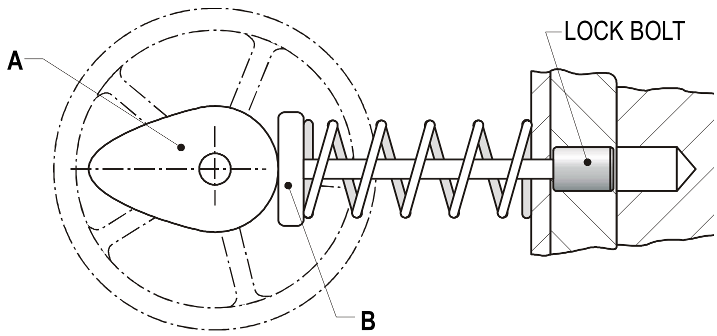


Figure 9

2. **Rotary motion to reciprocating motion**
   A power hacksaw, shown with guards removed in figure 9, uses an electric motor to power a crank, which is connected to a saw frame. The saw frame is free to slide on the 'arm'. As the crank rotates it causes the frame to slide backwards and forwards on the arm. The longer the crank the further the saw frame will move.

Converting motion: task 1

The pear-shaped cam and follower shown represent a simple locking mechanism.



1. Name parts A and B

A ____________________

B ____________________

2. How much of a turn does the wheel have to make to push the lock-bolt closed?

Tick the correct answer.

☐	☐	☐	☐
¼ turn	½ turn	1 turn	2 turns

Complete the system diagram for the movement of the lock.

Input → LOCK → Output

__________ Motion __________ Motion

What does the spring do?

____

____

Converting motion: Task 2

The cam-and-valve mechanism is part of a car engine and is shown in figure 2. Complete the systems diagram to show the input and output motion of the mechanism.

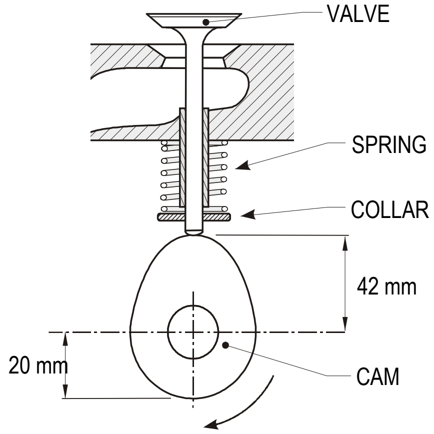


Figure 10

________________motion ________________motion

If the cam on the valve mechanism turns half a revolution from the position shown on the diagram, what distance does the valve move?

____________________mm

Converting motion: task 3

A crank-and-slider mechanism is used in a fabric-testing machine, as shown in figure 11.

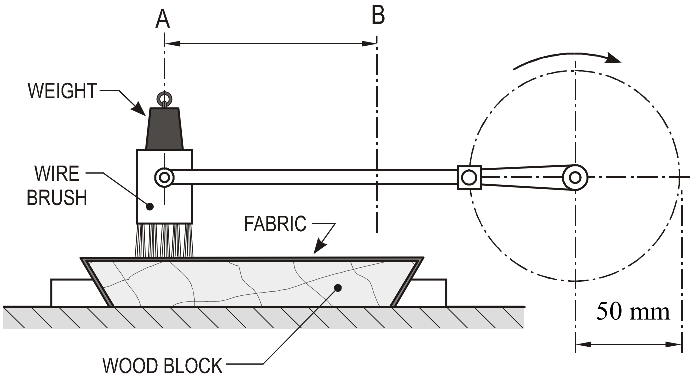
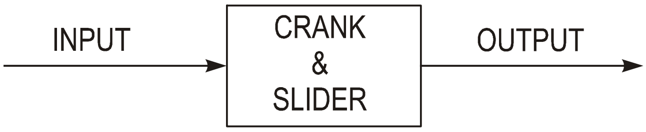


Figure 11



________________motion ________________motion

(a) What is the distance from A to B?

(b) What effect does the wire brush have on the fabric?

Rack and pinion

A rack-and-pinion mechanism is used to transform rotary motion into linear motion, or linear into rotary motion. A round spur gear, the pinion, meshes with a 'rack' that can be thought of as a spur gear with teeth set in a straight line (figure 1).

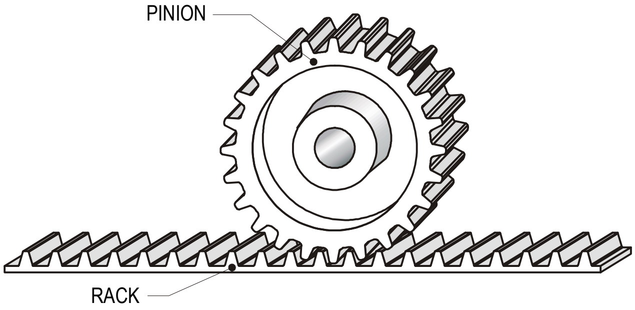
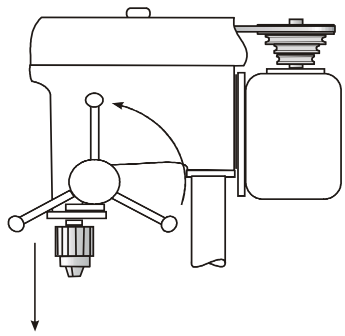


Figure 1

Gear wheels are normally made from metal or plastic. Plastic gears have the advantage that they are much quieter running and need less lubrication.

The rack and pinion can transform rotary motion into linear motion and linear motion into rotary motion in three ways.



1. Movement of the rack in a straight line causes the pinion to rotate about a fixed centre (figure 1 above).
2. Rotation of the pinion about a fixed centre causes the rack to move in a straight line as used in a pillar drill (figure 2).

Figure 2

3. If the rack is fixed and the pinion rotates, then the pinion's centre moves in a straight line, taking the pinion with it like the movement of the carriage along the bed of a centre lathe (figure 3).

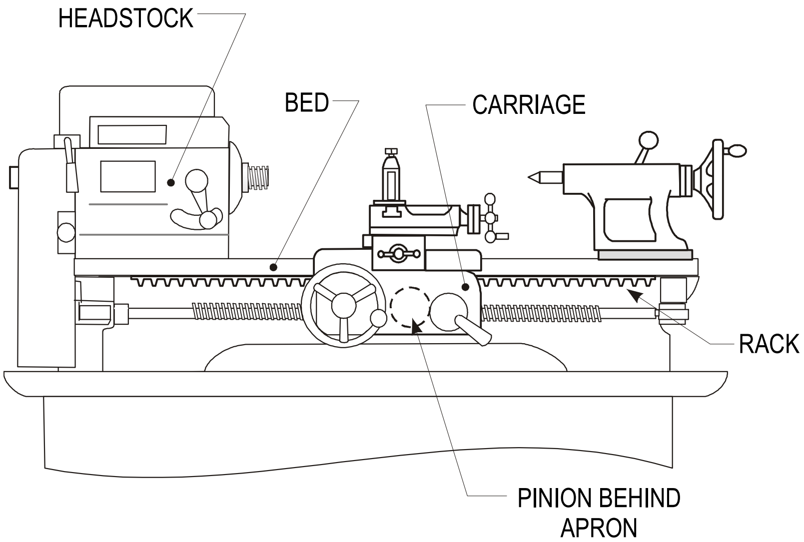


Figure 3

Rack and pinion: task 1

A rack with 100 teeth per metre is meshed with a pinion that has 10 teeth.

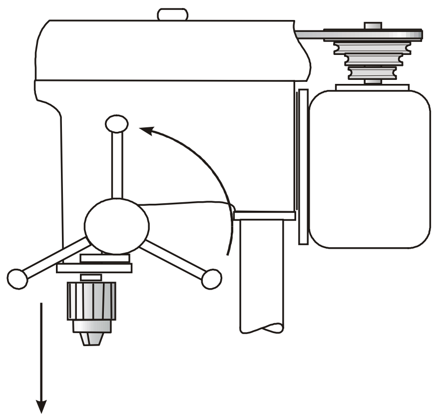


Figure 4

(a) If the pinion rotates one revolution, how far does the rack move?

(b) How many revolutions does it take to move the rack from one end to the other?

Rack and pinion: task 2

A rack with 100 teeth per metre is meshed with a pinion that has 15 teeth.

1. If the pinion rotates one revolution, how far does the rack move?
2. How many revolutions does it take to move the rack from one end to the other?
3. Figure 2 below shows a rack and pinion mechanism being controlled by a stepper motor. If the movement of the motor is 7.5 degrees per pulse, what is the number of pulses required to move the rack 50 mm?

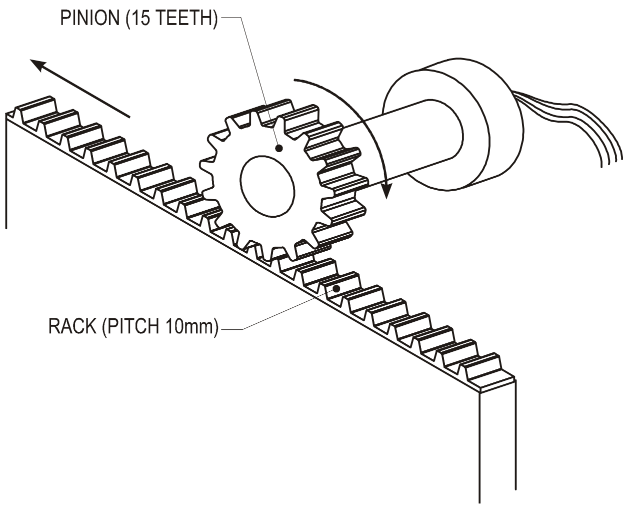


FIGURE 2

Couplings

Rotary machines employ a variety of methods of transmitting motion from one part of a machine to another. The motion is often transmitted through shafts, which are round metal rods. Often these shafts must be connected together to transmit the motion.

Shafts are joined using a device called a coupling. In small models, such as those used in schools, simple sleeves or tubes of plastic use friction to drive two shafts, which are pressed into the sleeve. Stronger couplings are required for industrial-sized

Aligned shafts

Where shafts are in line with each other they are joined either with a flanged coupling or a muff coupling. All couplings must be 'keyed' to the shafts they are joining to give a positive drive. Figure 1 shows a flange coupling and a muff coupling.

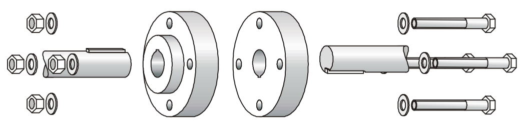


Figure 1(a): flange coupling

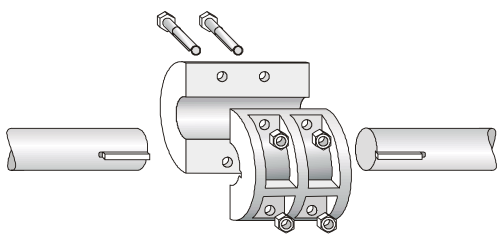


Figure 1(b): muff coupling

Non-aligned shafts

Where shafts meet at a slight angle, some method of compensating for misalignment must be used. Where the misalignment is small, a flexible coupling (flexi-coupling), using either rubber or a mixture of rubber and steel, is used. The rubber is flexible enough to compensate for small changes in angle (figure 2).

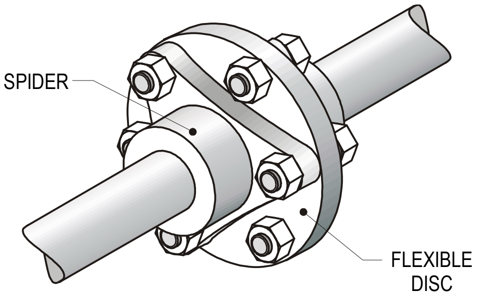


Figure 2: flexi-coupling

When the alignment is more than a few degrees out, a universal joint is used. A universal joint can transmit motion through an angle of 20 degrees. Figure 3 shows Hooke's universal joint. The two yokes are free to pivot on the central 'spider'. Modern universal joints use needle roller-bearings between the spider and the yokes.

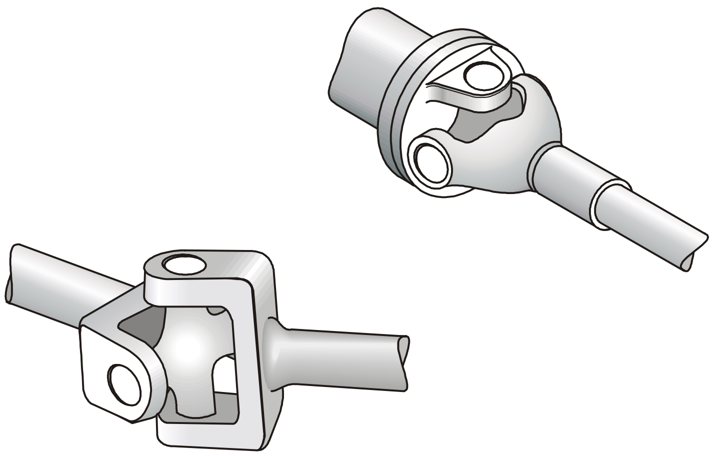


Figure 3: universal joints

Bearings

Parts of mechanisms that slide over each other use flat bearings. Flat bearings tend to be made from cast iron, brass or bronze. Brass and bronze bearings, which are softer than the materials sliding through or over them, will wear. They are sometimes called wear strips. When badly worn they are replaced. Cast iron is a self-lubricating material and is very strong when compressed.

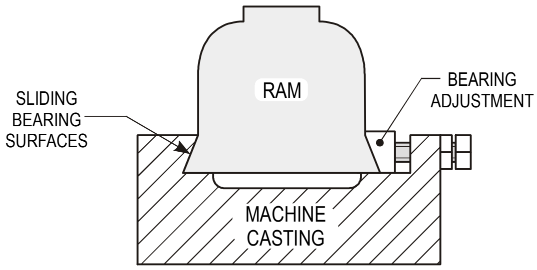


Figure 1: a flat bearing and wear strip

When a shaft is turned, it must be supported in some way. Friction opposes motion, and when a shaft is turning there is likely to be heat and wear at the supports. The amount of heat and wear due to friction will vary with the materials used, the forces involved and the speeds involved. Various types of bearing and bearing materials have been developed to reduce friction in mechanisms.

Bearings that support a round shaft are called journal bearings. When a journal bearing has to take some axial load, it must have a shoulder to take this load. When a shaft has a large axial load, it must have a thrust bearing. Figure 2 shows a combined thrust and journal bearing.

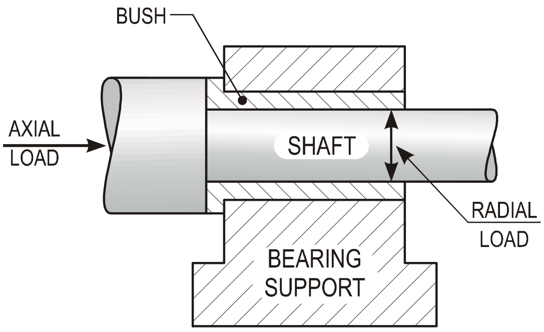


Figure 2: combined thrust and journal bearing

Journal bearings are made from a variety of materials: the most common are bronze and white metal. Bronze is used where slow, heavy loads are carried. White metal, an alloy of tin, copper and antimony, which is soft and melts when overheated, is used in systems with light loads. Plastic and nylon bearings are also very common.

Split bearings

As bearings are designed to wear, it stands to reason that they must be able to be removed and replaced. When the bearing support is at the start or end of a shaft, it is simple to remove and replace it. However, when a shaft is very long, it may be supported at several points along its length. To make it easy to remove and replace bearings, split bearings are used (figure 3).

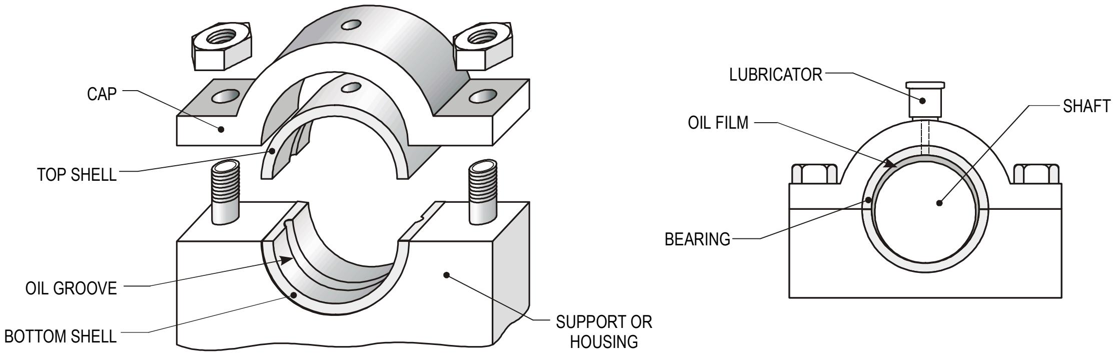
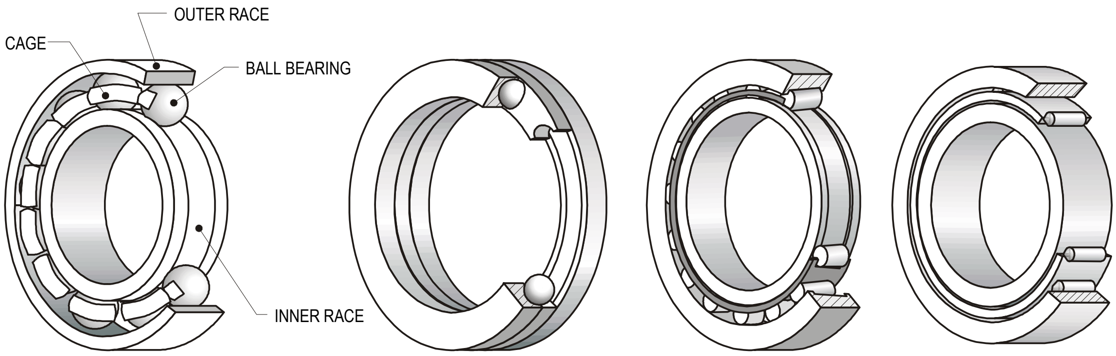


Figure 3: a split bearing

When the bearing wears, the bearing housing can be separated by removing the two nuts. The bearing shells can then be removed and replaced. Notice that the inside of the shells has a groove. This groove is normally fed by a reservoir of oil, which helps to lubricate the shaft and bearing, thus reducing friction. A car big end is a common example.

Ball-and-roller bearings

Ball and roller bearings change the action of rubbing to that of rolling. Ball and roller bearings use hardened steel balls or rollers, which rotate inside an inner and outer case. The outer case or 'race' presses into a housing; the inner race is a press fit on the shaft. These bearings are used in high-speed, high-force applications.



Ball Thrust ball Roller Needle roller

Figure 4: ball and roller bearings

Clutches

We want to reduce friction in moving parts. To achieve this bearings are used, surface contact area is minimised and lubricants are used. However, without friction between the tyres and road, cars would not be able to stay on the roads or even start to move.

Clutches are devices that allow two rotating shafts to be connected and disconnected. There are two types of clutch, the positive clutch and the friction clutch. A dog clutch is a positive clutch. This has four interlocking blocks (dogs) on one shaft that can be interlocked with four dogs on the other shaft.

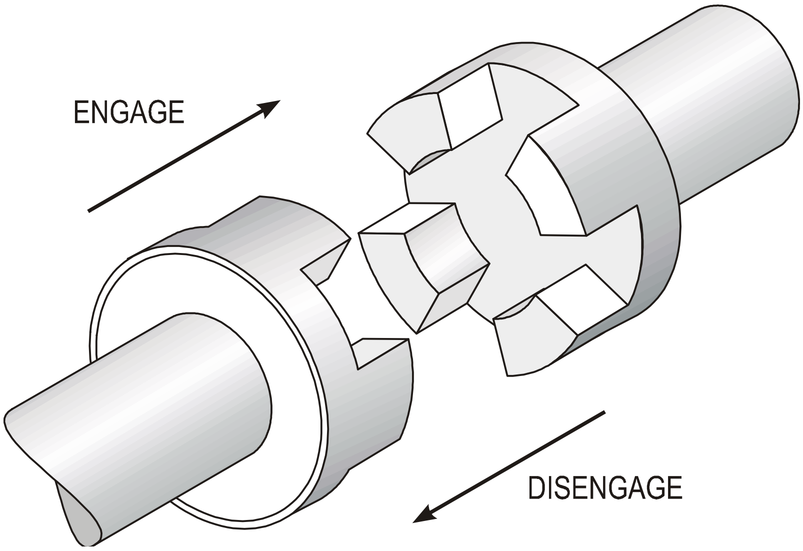


Figure 1: a dog clutch

When the clutch is engaged, the two dogs are interlocked and the drive shaft rotates the driven shaft. When the clutch is disengaged, the two shafts are separated. In clutch systems, the two shafts must be carefully aligned.

Positive-drive clutches require the drive shaft to be stationary when the two clutch plates are brought together. Friction clutches can be engaged and disengaged while both shafts are still turning. Friction clutches rely on the friction between the plates to transmit the power from one shaft to another. Figure 2 shows a simple example of a friction clutch.

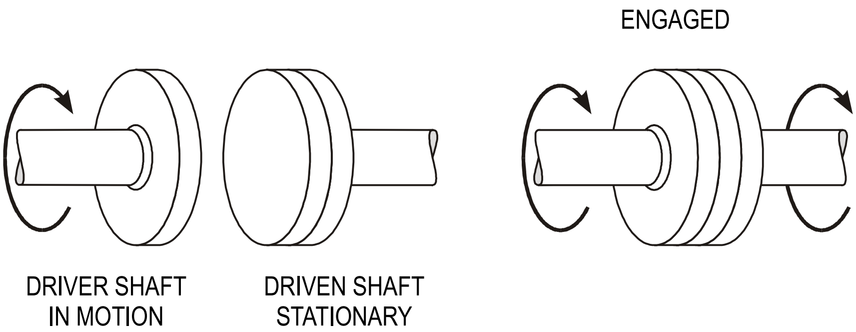


Figure 2: a simple friction clutch

Figure 3 shows a multi-plate system used for large transmission forces or limited-space applications.

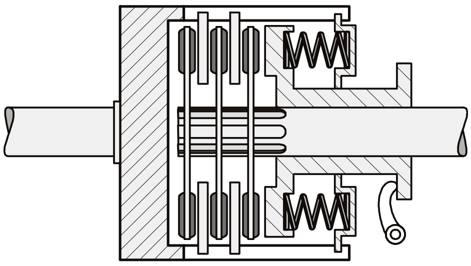


Figure 3: a multi-plate clutch

Couplings: task 1

1. Why are couplings used in mechanical systems?

2. What term is used in making sure that a coupling has a positive drive?

3. When alignment is a problem in shafts what mechanical device can be fitted?

4. Why can friction be a problem in mechanical devices?

5. What consequences may occur if friction is not overcome?

6. Thrust bearings are often used in rotating systems. What is the main advantage in using this type of bearing?

7. If a bearing is required in the middle of a long shaft, how can the problem of changing it be overcome?

8. How does lubrication work within the bearing housing?

9. Some shafts require to run at high speeds with limited friction. How can this be done?

10. Explain the term ‘dog clutch’.