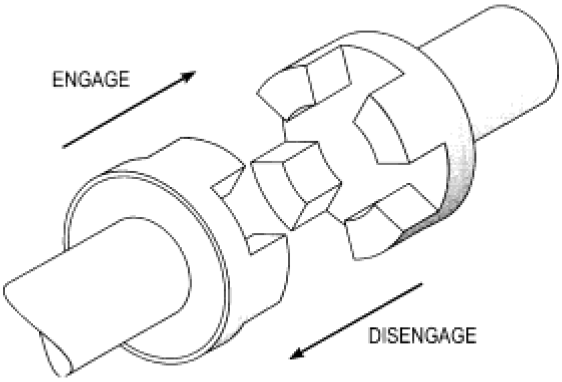
Higher Engineering Science

Mechanisms



Name: ________________________

Teacher: ______________________

Class: ________________________

PERTH ACADEMY

Mrs Gault

Learning Intentions

- Simple and compound gear trains
- Belt and chain drives
- Couplings - rigid and flexible
- Bearings - radial and thrust (plain, roller, ball journal)
- Joints in shafts
- Friction in brakes and clutches
- Torque T = Fr

Success Criteria

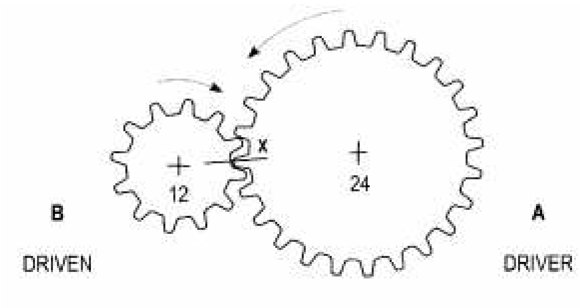
- I know the difference between simple and compound gear trains plus their advantages and disadvantages and can draw them.
- I know the advantages and disadvantages of belt and chain drives and can draw them.
- I can describe different types of couplings and know their advantages and disadvantages.
- I know how to join shafts and can select and appropriate method.
- I know about the effects of friction in brakes and clutches.
- I can complete Torque calculations.

In this unit we will build on the skills learned in National 5 Engineering Science.

Mechanisms

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) 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.

Simple Gear Train

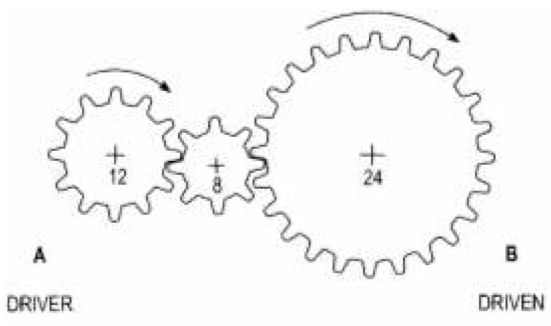


Gears work by interlocking or meshing the teeth of the gears together as shown. When 2 or more gears are meshed they form a **gear train**. The **input** gear which causes the system to move is called the **driver** and the **output** gear is called the **driven**.

The **Multiplier Ratio** is used to calculate speed, torque and size of gears.

$$M.R. = \frac{Driven}{Driver} = \frac{OutputSpeed}{InputSpeed} = \frac{OutputTorque}{InputTorque}$$

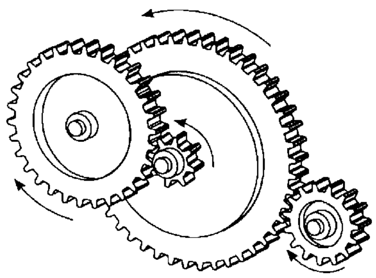
Idler Gear

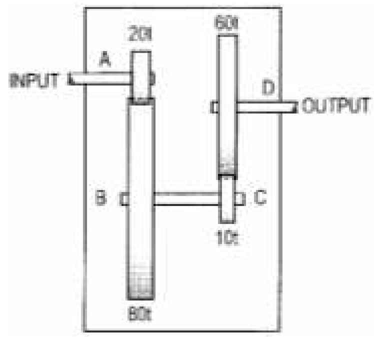


To get the driven gear to rotate in the same direction as the driver a third gear is inserted in the system. The idler gear has no effect on the speed of the driven gear wheel.

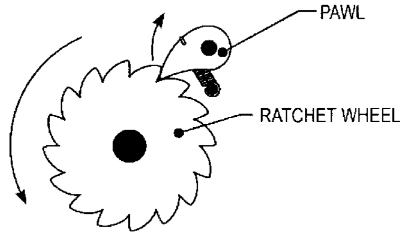
Compound Gear Trains

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

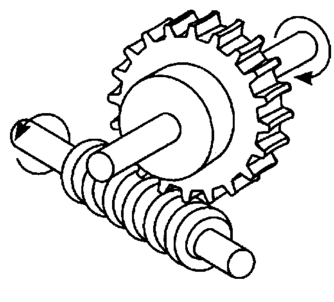




Ratchet and Pawl



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.**

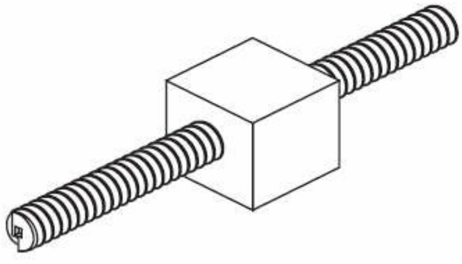


Worm and wheel

Another way of making larger speed reductions is to use a worm and wheel. The worm, which looks rather like a screw thread, is fixed to the driver shaft (sometimes directly onto the motor shaft). It meshes with a worm wheel, which is fixed to the driven shaft. The driven shaft runs at 90' to the driver shaft.

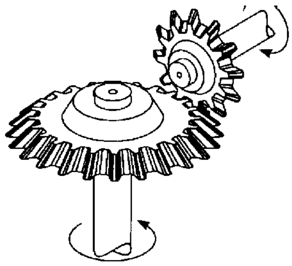
You should think of the worm wheel as a gear with only 1 tooth. This allows a huge reduction in speed which takes up very little space.

Worm and Nut



The worm gear is fixed so that when it spins, it moves the block. This transmits the motion through the gear. This allows for a big change in speed and increased torque

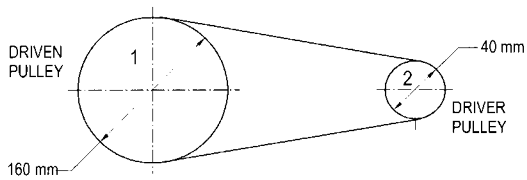
Bevel gears



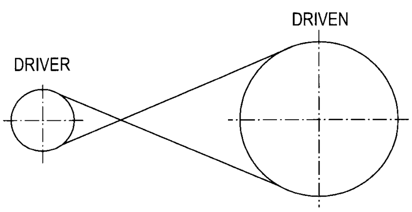
Bevel gears, like worm wheels, use shafts at 90' to each other. A whisk which uses bevel gears to change the direction motion through 90' as does the gears in a wind turbine.

Belt Drives

To make rotary motion useful it has to be transmitted from one part of a machine to another, often with a change in speed. **Connecting too many gears together can result in large efficiency losses through friction.**

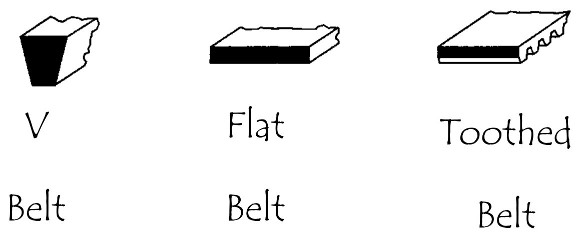


A simple way of transmitting this motion would be to use a belt wrapped around 2 pulleys, the belt can be tightened or tensioned by pulling one of the pulleys out and locking it in place. The belt should be angled to give better grip to prevent the belt from slipping.



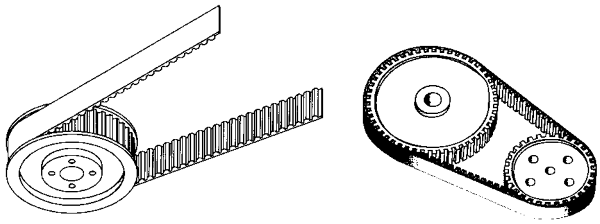
Changes in direction can be achieved by crossing over the belts.

An advantage of using a belt drive is that it allows slippage in machines where you wouldn't want for example a motor to stop or possibly cease because the belt won't turn.



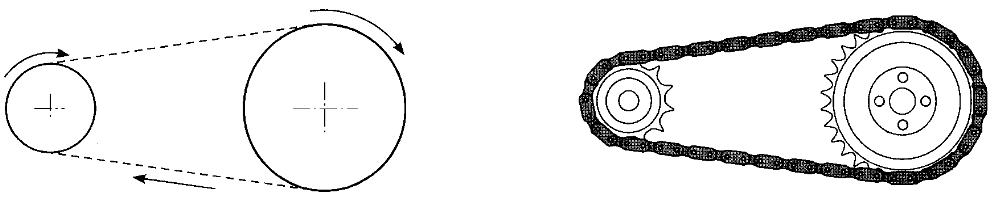
Toothed belts

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.



Chain belts

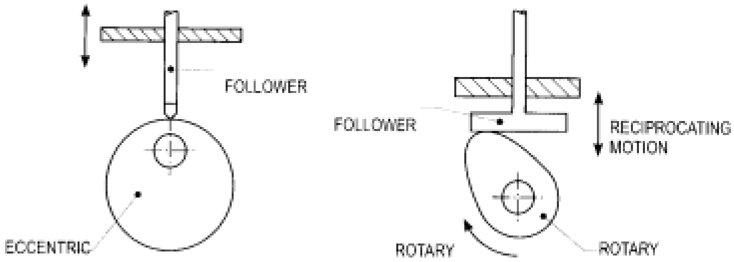
Where large forces have to be transmitted and there can be no slippage allowed chain drives are used. Instead of a pulley a toothed wheel known as a sprocket is used to drive a chain.



CAMS

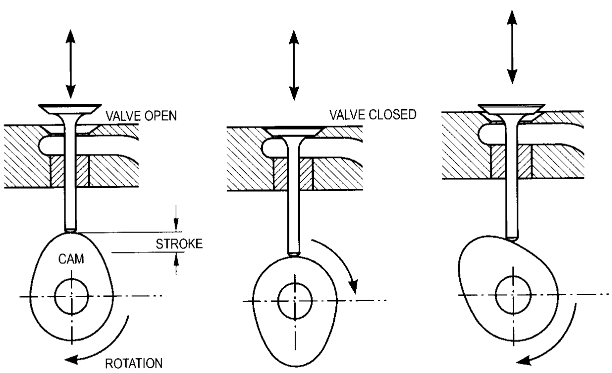
A cam is a specifically shaped piece of material, which can be used to change an input rotary motion to an output motion that is oscillating or reciprocating.

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 depends on the cam's shape and dimensions.

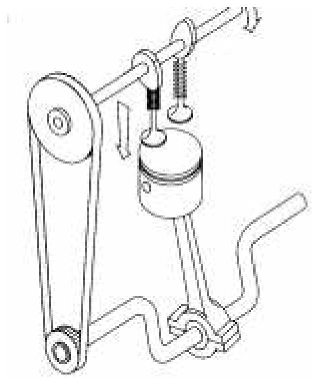


Cam Motion

Pear-shaped cams are often used for controlling valves. For example they are often used on motor-car cam shafts to operate the engine valves.



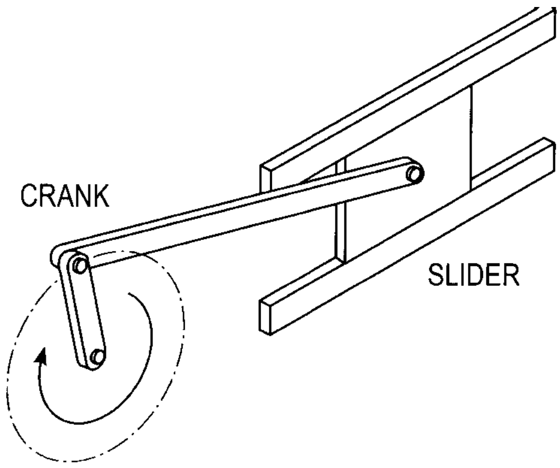
A follower controlled by a pear-shaped cam remains motionless for about half a revolution; during the other half revolution of the cam the follower rises and falls. As the pear-shaped cam is symmetrical, the rising motion is the same as the falling motion. When the follower is not moving we call this the dwell part 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.

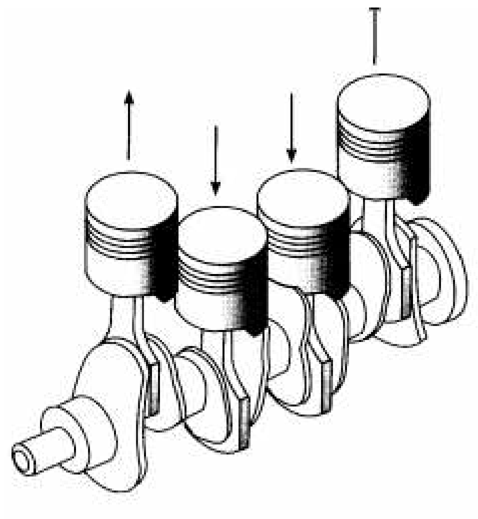
Crank & Slider

Crank & slider mechanisms involve changes between rotary and reciprocating motion. The crank rotates while the slider reciprocates. The longer the crank the further the slider will move.



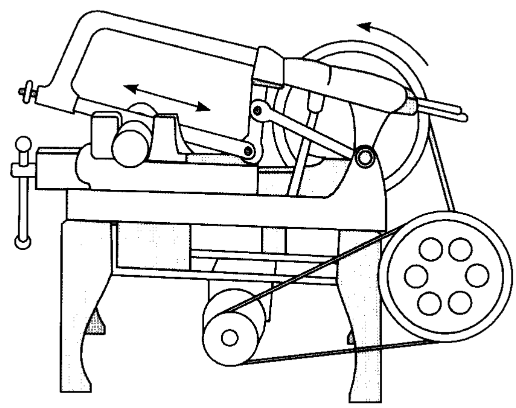
Reciprocating motion to rotary motion

Car engines use reciprocating pistons, which are connected to a crankshaft by connecting rods. As the piston moves up and down the connecting rods push the crankshaft round. Each piston moves down in turn so keeping the crankshaft turning.



Rotary motion to reciprocating motion

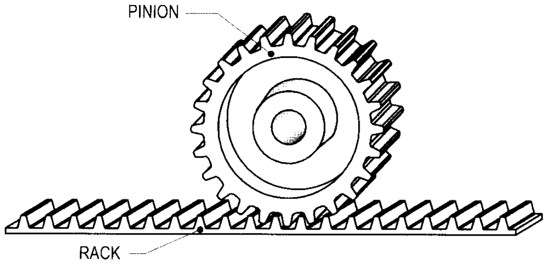
A power hacksaw uses an electric motor to power a crank, which is connected to a saw frame. The saw frame is free to slide on the arm. As the crank rotates it causes the frame to slide backwards and forwards on the arm. The longer the crank the further the saw frame will move.



Rack & Pinion

A rack & pinion mechanism is used to transform rotary motion into linear motion, or linear motion 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.

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



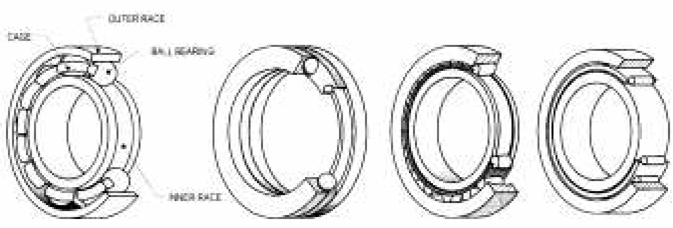
Couplings

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. To connect shafts we can use two types of couplings, flange and muff. If shafts are not aligned (centres do not match up) we can use flexi-coupling or universal joints.

Bearings

Parts of mechanisms that slide over each other use flat bearings, which can be made from brass or bronze and replaced when they are worn.

Split bearings are designed to wear, it stands to reason that they must be able to be removed and replaced.

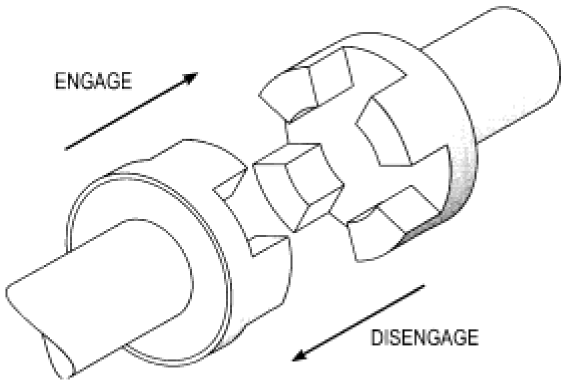


Ball Thrust ball Roller Needle roller

Ball and roller bearings change the action of rubbing to that of rolling. These bearings are used in high speed, high force applications.

Clutches

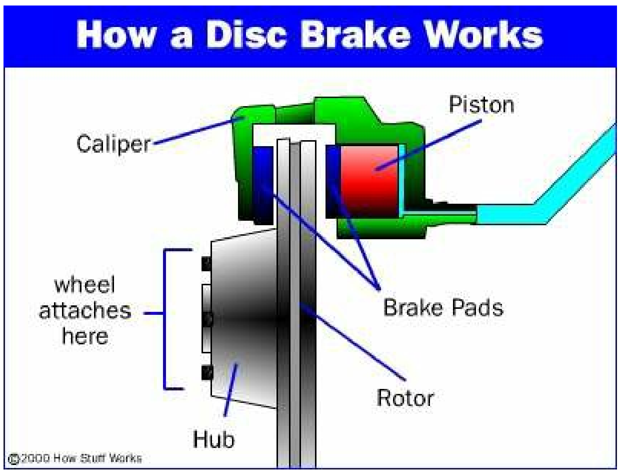
Clutches are devices that allow two rotating shafts to be connected and disconnected. There are two types of clutch, the positive clutch and the friction clutch. A dog clutch is a positive clutch and has four interlocking block on one shaft that can be interlocked with 4 on the other shaft. A simple friction clutch relies on two plates to transmit the power from one shaft to another.



Brakes

There are two main types of brakes disc and drum.

Disk brakes



The main components of a disc brake are:

The **brake pads**

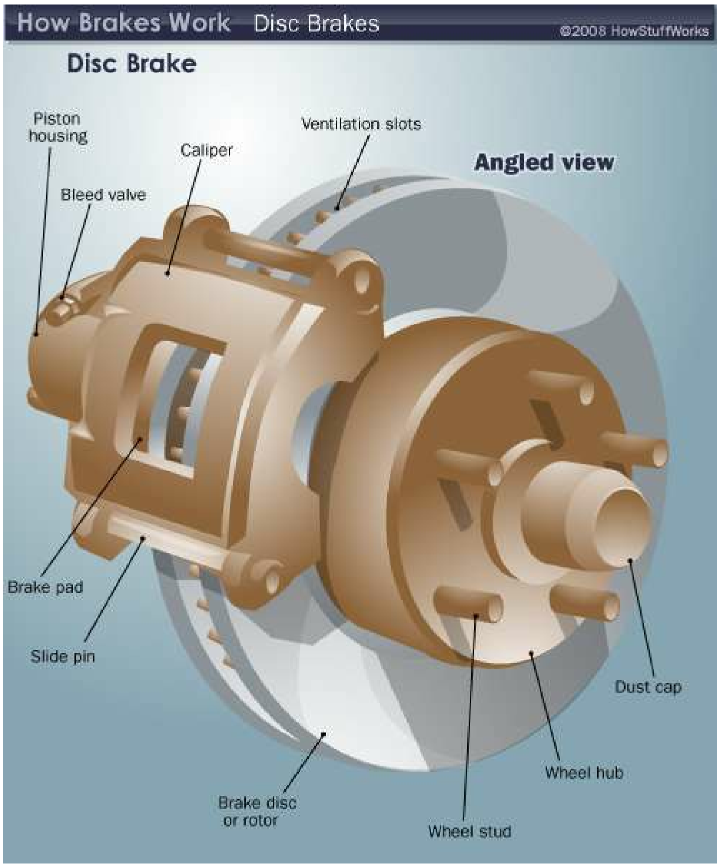
The **calliper**, which contains a piston

The **rotor**, which is mounted to the hub

Parts of a disc brake

The disc brake is a lot like the brakes on a bicycle. Bicycle brakes have a caliper, which squeezes the brake pads against the wheel. In a disc brake, the brake pads squeeze the rotor instead of the wheel, and the force is transmitted hydraulically instead of through a cable. Friction between the pads and the disc slows the disc down.

A moving car has a certain amount of kinetic energy, and the brakes have to remove this energy from the car in order to stop it. How do the brakes do this? Each time you stop your car, your brakes convert the kinetic energy to heat generated by the friction between the pads and the disc. Most car disc brakes are vented.



Disc brake vents

Vented disc brakes have a set of vanes, between the two sides of the disc, that pump air through the disc to provide cooling.

Self-Adjusting Brakes

The single-piston floating-caliper disc brake is self-centering and self-adjusting. The caliper is able to slide from side to side so it will move to the center each time the brakes are applied. Also, since there is no spring to pull the pads away from the disc, the pads always stay in light contact with the rotor (the rubber piston seal and any wobble in the rotor may actually pull the pads a small distance away from the rotor). This is important because the pistons in the brakes are much larger in diameter than the ones in the master cylinder. If the brake pistons retracted into their cylinders, it might take several applications of the brake pedal to pump enough fluid into the brake cylinder to engage the brake pads.

Self-adjusting disc brake

Older cars had dual or four-piston fixed-caliper designs. A piston (or two) on each side of the rotor pushed the pad on that side. This design has been largely eliminated because single-piston designs are cheaper and more reliable.

Emergency Brakes

In cars with disc brakes on all four wheels, an emergency brake has to be actuated by a separate mechanism than the primary brakes in case of a total primary brake failure. Most cars use a cable to actuate the emergency brake.

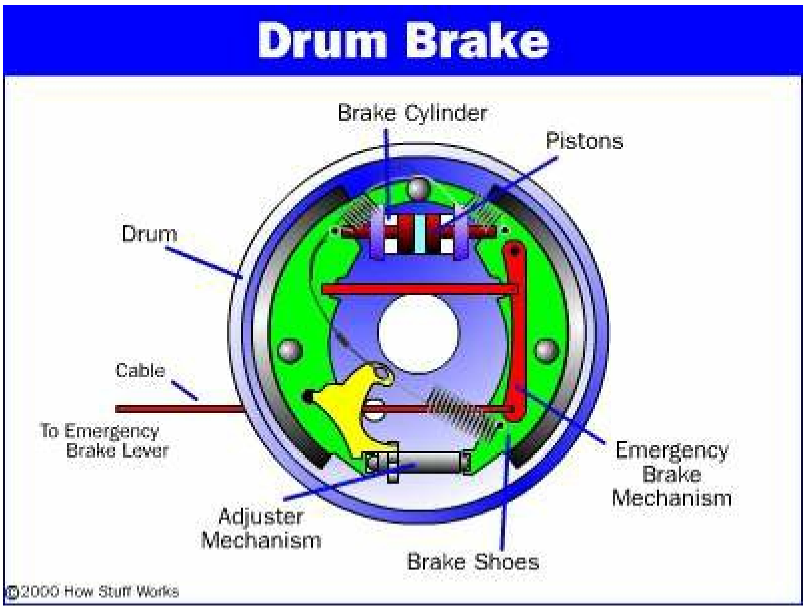
Some cars with four-wheel disc brakes have a separate drum brake integrated into the hub of the rear wheels. This drum brake is only for the emergency brake system, and it is actuated only by the cable; it has no hydraulics.

Other cars have a lever that turns a screw, or actuates a cam, which presses the piston of the disc brake.

Drum brakes

Drum brakes work on the same principle as disc brakes: Shoes press against a spinning surface. In this system, that surface is called a drum.

Many cars have drum brakes on the rear wheels and disc brakes on the front. Drum brakes have more parts than disc brakes and are harder to service, but they are less expensive to manufacture, and they easily incorporate an emergency brake mechanism.

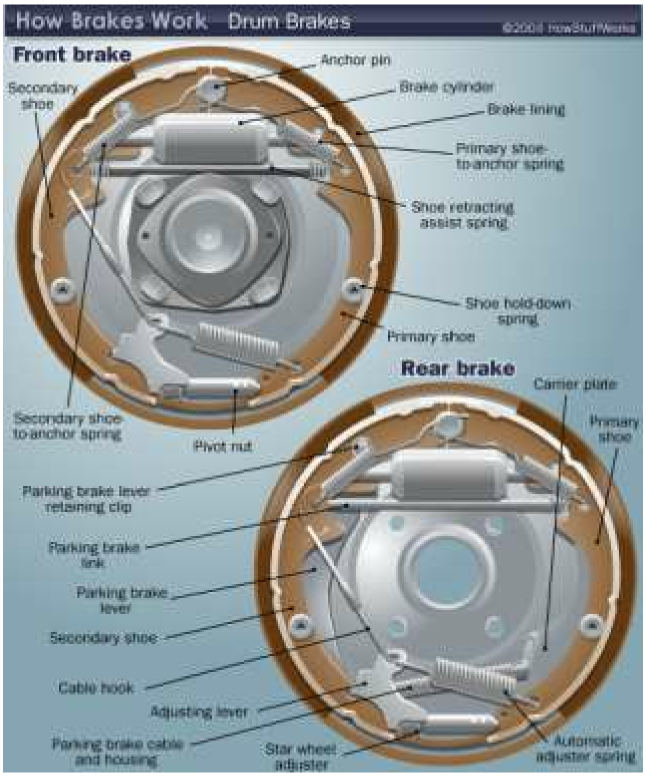


Like the disc brake, the drum brake has two brake shoes and a piston. But the drum brake also has an adjuster mechanism, an emergency brake mechanism and lots of springs.

When you hit the brake pedal, the piston pushes the brake shoes against the drum. That's pretty straightforward, but why do we need all of those springs?

This is where it gets a little more complicated. Many drum brakes are self-actuating. As the brake shoes contact the drum, there is a kind of wedging action, which has the effect of pressing the shoes into the drum with more force.

The extra braking force provided by the wedging action allows drum brakes to use a smaller piston than disc brakes. But, because of the wedging action, the shoes must be pulled away from the drum when the brakes are released. This is the reason for some of the springs. Other springs help hold the brake shoes in place and return the adjuster arm after it actuates.

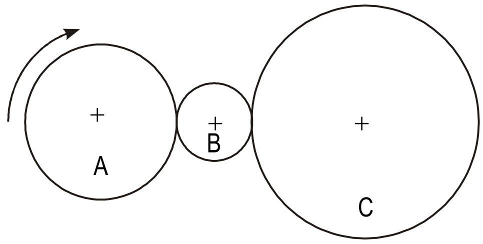


When you step on your brake pedal the two curved brake shoes, which have a friction material lining, are forced by hydraulic wheel cylinders against the inner surface of a rotating brake drum. This contact produces friction causing the drum and the wheel to slow down or stop.

Gears task 1

Calculate the multiplier ratio for the simple gear train below and then find the output speed and direction if gear A rotates at 250 revs min^{-1} in a clockwise direction. Show all your working.

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



Gears task 2

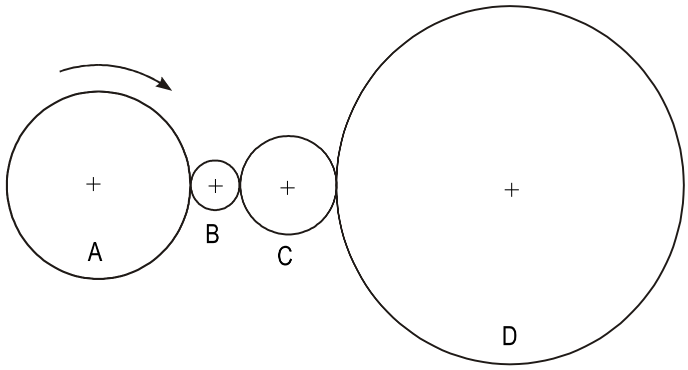
For the simple gear train shown below, find the following.
(a) The gear that rotates in the same direction as A.
(b) The multiplier ratios of A to B, A to C and A to D.
(c) The speed of B, C and D if A rotates at 500 revs min $^{-1}$.

A = 50 teeth

B = 10 teeth

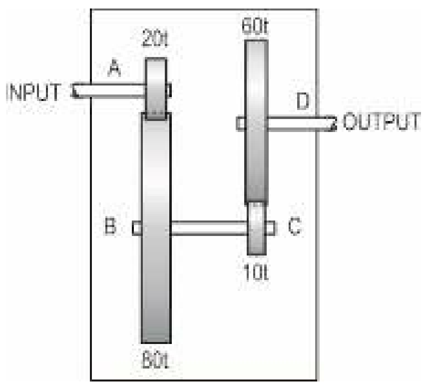
C = 25 teeth

D = 100 teeth



Gears task 3

Calculate the output speed of the compound gear system if the input speed is 200 revs min $^{-1}$.



Gears task 4

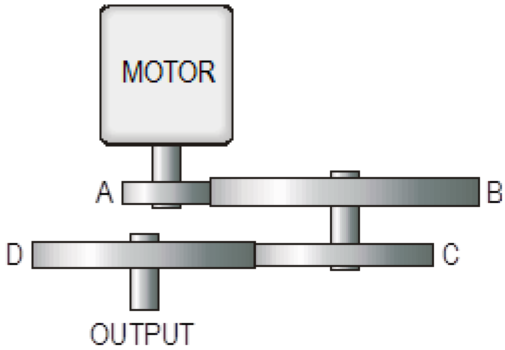
The compound gear train shown is driven by a motor that runs at 1000 revs min $^{-1}$. Calculate the multiplier ratio of the motor to the output shaft and then the output speed. Show all your working.

A = 20 teeth

B = 60 teeth

C = 40 teeth

D = 50 teeth



Gears task 5

A motor with a single worm wheel output rotates at 500 revs min $^{-1}$. You are given the following sizes of worm gears from which to select.

(a) = 10 teeth

(b) = 25 teeth

(c) = 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 6

The motorised winch shown below runs at a speed of 1200 revs min $^{-1}$. The drum is to rotate at 25 revs min $^{-1}$. Calculate:

(a) the multiplier ratio required to produce the speed reduction

(b) the number of teeth gear A must have to meet this requirement.

A = ?

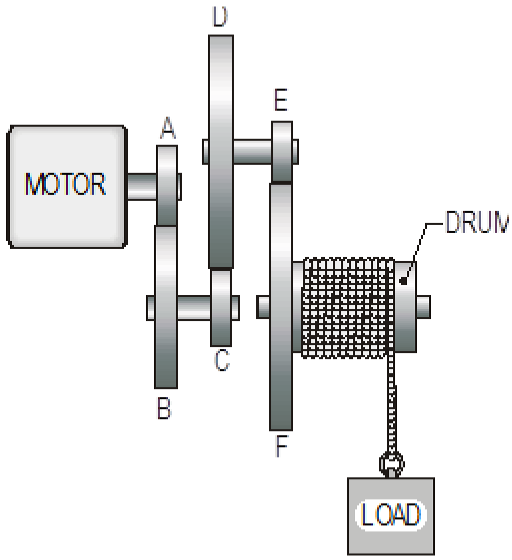
B = 32 teeth

C = 15 teeth

D = 45 teeth

E = 12 teeth

F = 48 teeth



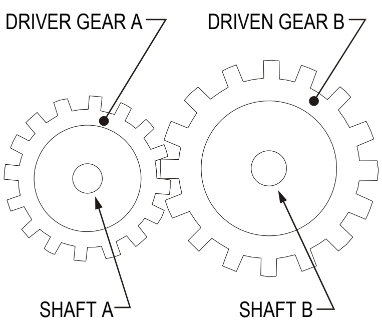
Also calculate for the above system the following:

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

Gears task 7

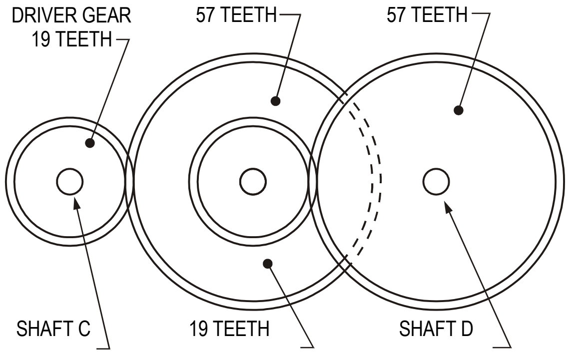
A simple gear train is shown. The driver gear A has 20 teeth. When shaft A is rotated 10 times, shaft B rotates five times.

(a) How many teeth has gear B?
(b) What is the gear ratio of the system?
(c) If shaft A rotates at 60 revs min $^{-1}$, at what speed does shaft B rotate?
(d) If shaft A rotates anti-clockwise, in which direction does shaft B rotate?

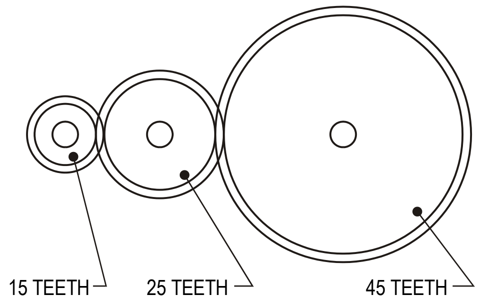


Gears task 8
What is the name of the transmission system shown below?

a) What is the gear ratio of the system?
b) If shaft C rotates at 36 revs min $^{-1}$, at what speed will shaft D rotate?



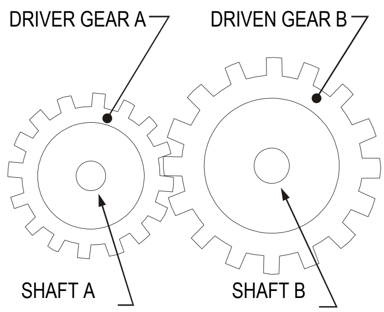
Gears task 9
What is the movement ratio of the gear system shown below?



Gears task 10

In the simple gear train shown below, driver A has 20 teeth. When shaft A rotates 10 times, shaft B rotates five times.

(a) What is the movement ratio of the system?
(b) How many teeth does gear B have?
(c) If shaft A rotates at 600 revs min $^{-1}$, at what speed will shaft B turn?
(d) If A rotates clockwise, what direction will B rotate?

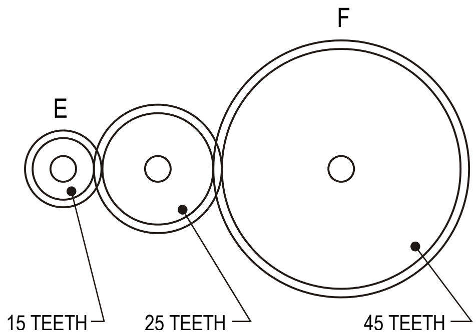


Gears task 11

The names following are all associated with gears. Pick two and explain what they mean. Simple gear train, mesh, idler, compound gear train

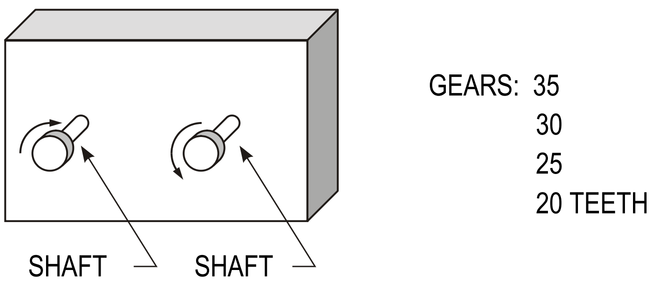
Gears task 12
What is the gear ratio of the transmission system shown?

(a) If gear E rotates clockwise, in which direction will gear F rotate?



Gears task 13

The black box system below contains a simple gear train.



(a) When shaft G is rotated 60 times, shaft H rotates 40 times. Using two gears chosen from those listed above sketch the transmission system that the box contains.
(b) Do the same for the shaft G being rotated 10 times, and shaft H rotated eight times.

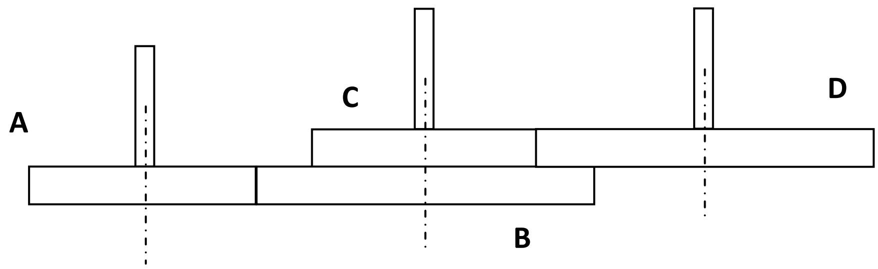
Gears task 14

A compound gear train consists of a driver gear A having 40 teeth, engaging with gear B, having 160 teeth. Attached to the same shaft as B, gear C has 48 teeth and meshes with gear D on the output shaft, having 96 teeth.

(a) Draw a diagram to show the arrangement.
(b) Determine the movement ratio of the gear train. [8]

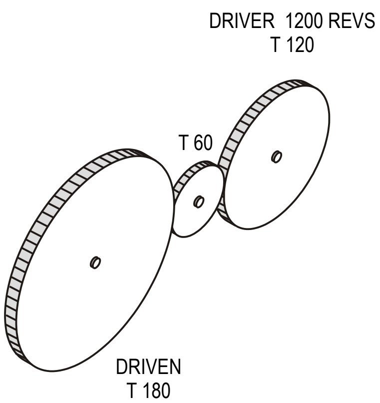
Gears task 15

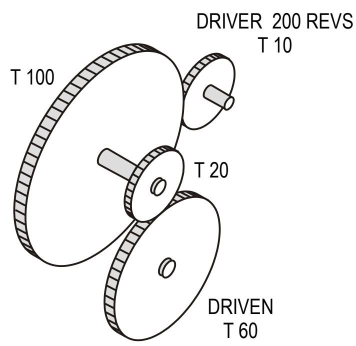
In the compound train shown below (figure 1) wheel A is rotating at 100 revs min $^{-1}$. If the numbers of teeth in the gear wheels A, B, C and D are 25, 50, 25, and 50 respectively, determine the speed of rotation of wheel D.



Gears task 16

Calculate the output speed in the two examples of gear systems.





Gears task 17

Four parallel shafts A, B, C, and D are connected by a simple gear train. The number of teeth in each wheel is as follows.

A = 40

B = 25

C = 30

D = 60

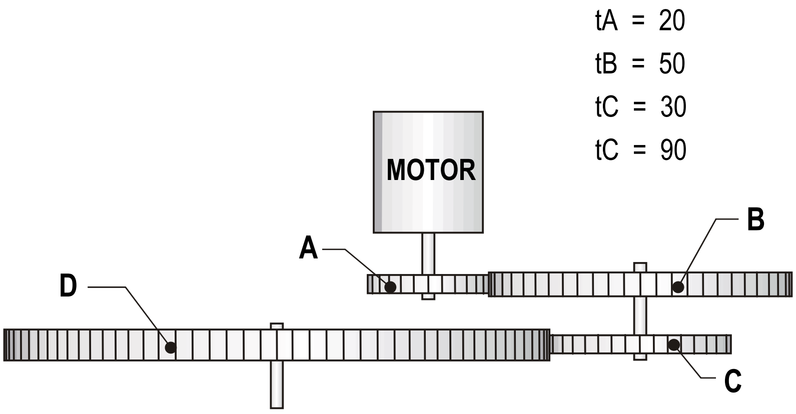
If wheel A is rotating at 200 revs min $^{-1}$ in a clockwise direction, determine the speed and direction of rotation of the other gear wheels.

Gears task 18

The compound gear train shown below is driven by a motor that runs at 750 revs min $^{-1}$. Calculate:

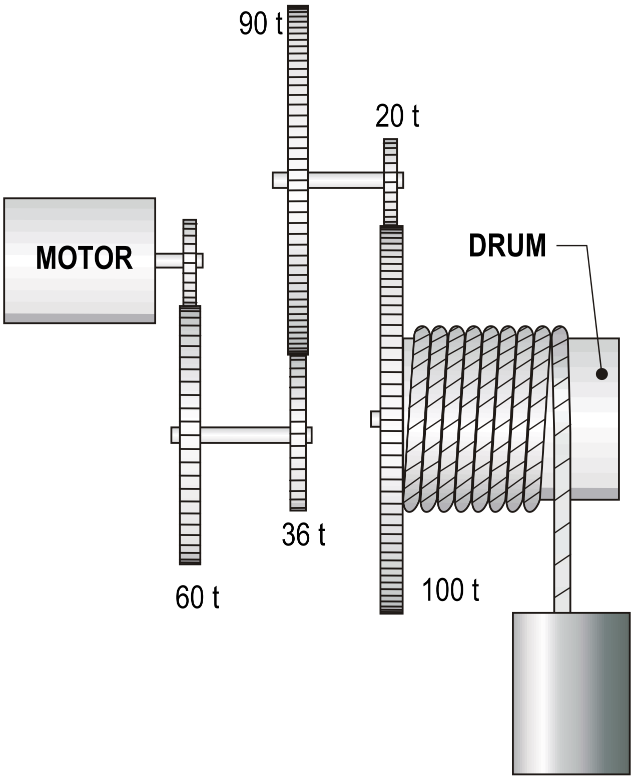
(a) The output shaft speed.

(b) The ratio of the motor spindle speed to the output speed.



Gears task 19

A motorised winch is shown below. The motor runs at 1350 revs min $^{-1}$ and the drum is to rotate at 54 revs min $^{-1}$. Find the number of teeth that the motor drive gear must have to satisfy this requirement.



Gears task 20

A compound gear train consists of an input gear A with 30 teeth that meshes with gear B having 60 teeth. Gear C is attached to gear B and has 30 teeth. Gear D is in mesh with gear C. Determine the number of teeth in gear D to give a movement ratio between A and D of 5.33.

Gears task 21

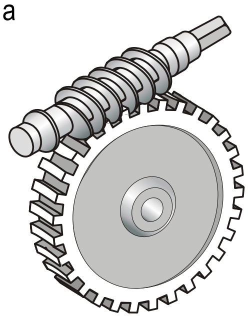
Two gear wheels A and B are in mesh. Wheel A has 20 teeth and wheel B 60 teeth. Attached to wheel A is a pulley of diameter 30 mm and to wheel B a pulley of diameter 120 mm. If an effort of 50 N is applied through a rope wrapped around pulley B, what load attached to a rope wrapped around pulley A would be moved? Assume the machine to be 100 per cent efficient.

Gears task 22

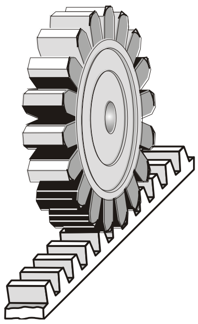
Three different mechanisms are shown below. Name each and describe the change in movement produced.

Example: gear train = rotational to rotational motion.

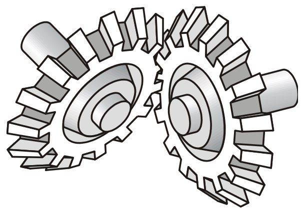
a



b

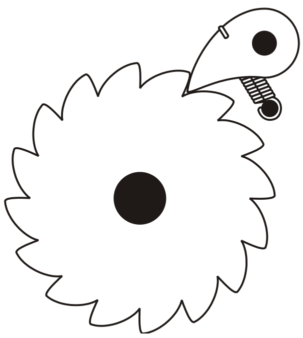


c



Gears task 23

Below is a mechanical device that allows rotation only in one direction.

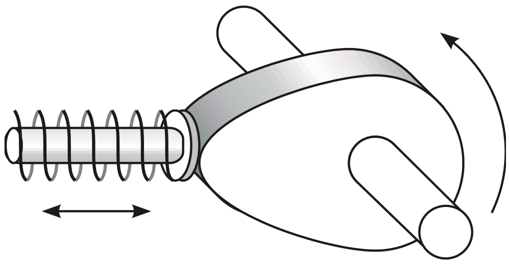


(a) Name the device.
(b) Using an arrow on the diagram show the direction in which the device will turn.

Gears task 24

A cam and follower is shown below.

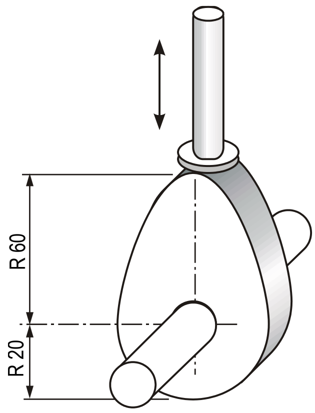
(a) Label the following parts: cam, follower, stroke

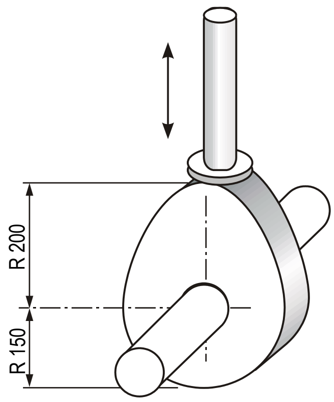


(b) Describe the change in motion that the cam and follower produces.
(c) What is the purpose of the spring?

Gears task 25

In the two examples below, how far will the rod move?





Gears task 26

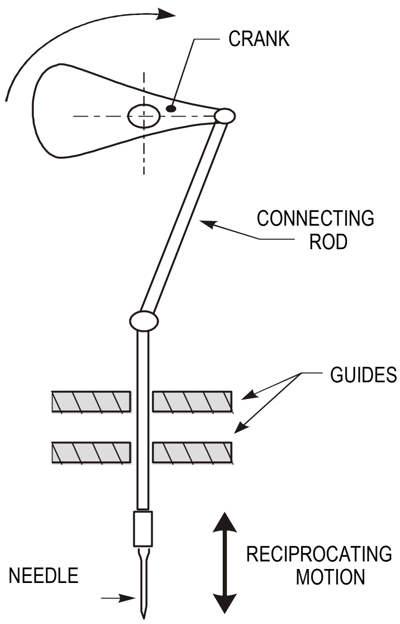
A single start worm and wheel similar to the one shown below has an effort wheel of 140 mm diameter, and a load drum diameter of 125 mm. If the worm has 40 teeth calculate:

(a) The movement ratio for the machine.
(b) The effort required to raise a load of 390 N if the efficiency of the machine is 67 per cent.

Gears task 27

The following diagram shows a domestic sewing machine. The diagram shows the crank and slider mechanism that is used to produce reciprocating motion at the needle.

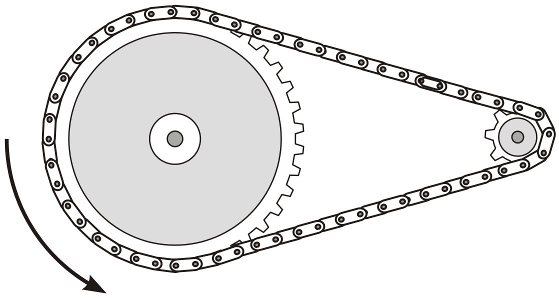
At its slowest operating speed, the needle moves down 120 times per minute. At what speed does the crank rotate?



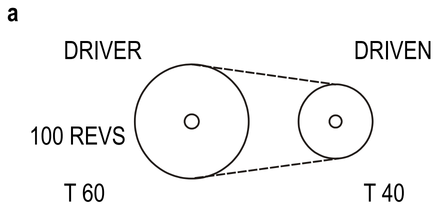
Gears task 28

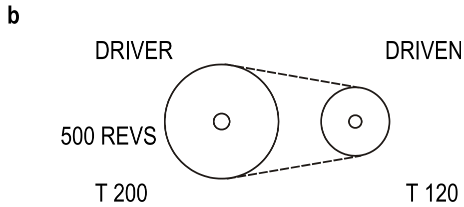
A chain and sprocket is shown below. Label the following parts.

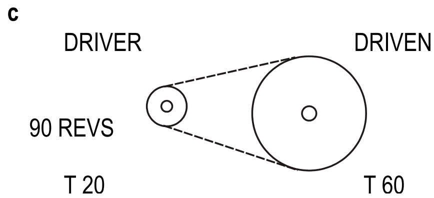
Driver, driven, chain, sprockets

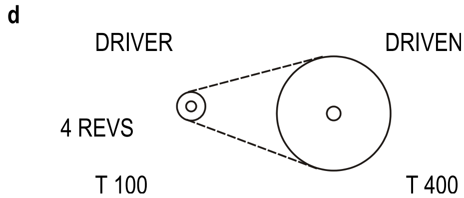


1. Describe one advantage and one disadvantage in using a chain and sprocket system.
2. Write down the formula for movement ratio.
3. Determine the speed of sprocket B in this chain drive if sprocket A rotates at 150 revs min $^{-1}$.
4. Four chain drive systems are shown below. Calculate the output speed for each.



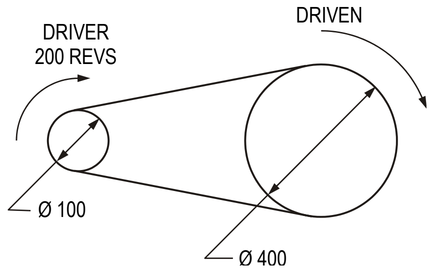






Gears task 29

1. A belt and pulley system is shown below.



(a) Calculate the output speed of the driven pulley.
(b) Describe one advantage of a belt and pulley over other drive systems.
(c) Show with a sketch how a belt and pulley system could be joined to make the input and output turn in different directions. Label the driver (input) and the driven (output).

2. Write down why/where you would use the following types of drive belts.

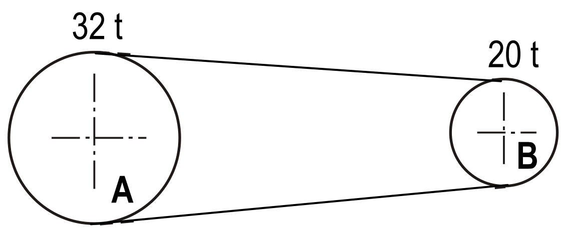
V-belt

Linked belt

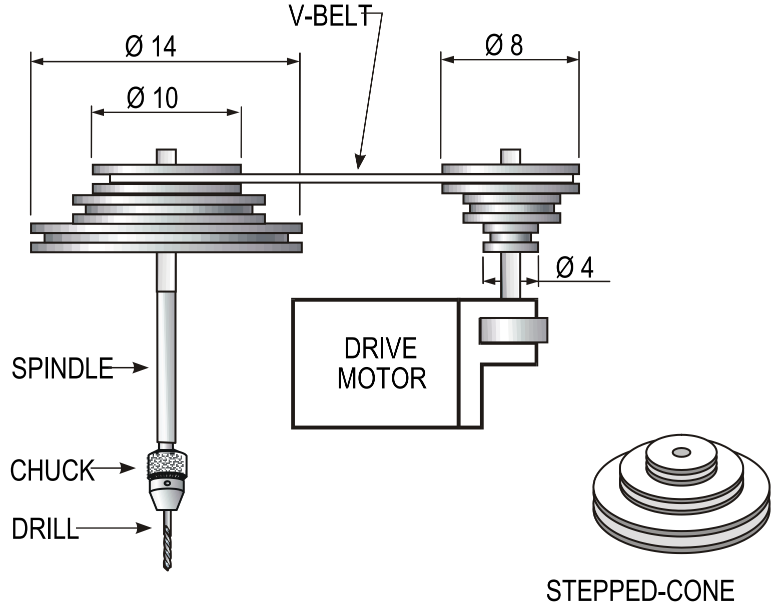
Round belt

Toothed belt

3. Determine the speed of the pulley B in this belt drive if pulley A rotates at 150 revs min $^{-1}$.



4. The diagram shows a stepped-cone pulley system as used on some pillar drills. By changing the position of the V-belt, three different shaft speeds can be obtained.



(a) In which position must the belt be engaged to provide the highest drill speed?
(b) If the drive motor runs at 1400 revs min $^{-1}$, what is the maximum drill speed?
(c) What is the lowest speed at which the drill will run?

Gears task 30

1. Determine the torque when a pulley wheel of diameter 300 mm has a force of 80 N applied at the rim.

2. Determine the force applied tangentially to a bar of a screwjack at a radius of 800 mm, if the torque required is 600 N/m.

3. A constant force of 150 N is applied at a tangent to a wheel of diameter 140 mm. Determine the work done in 12 revolutions of the wheel. Your answer should be in joules and watt-hours.

4. Calculate the torque developed by a motor whose spindle is rotating at 1000 rpm and developing a power of 2.5 kW.

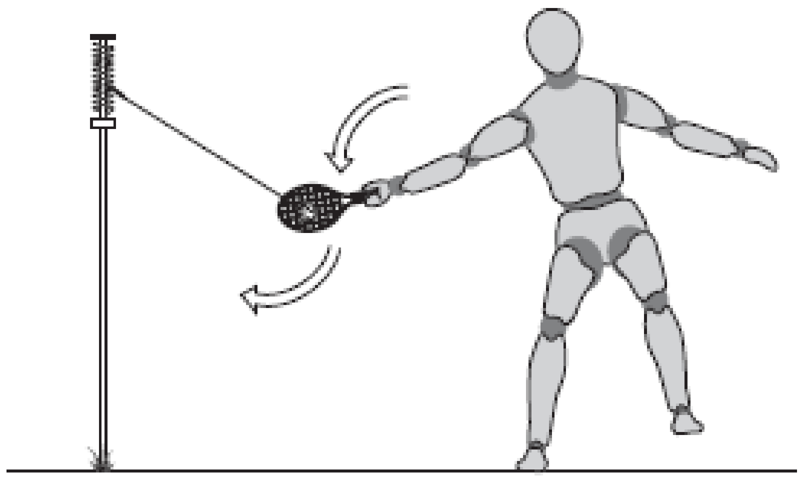
5. An electric motor develops a power of 3.75 kW and a torque of 12.5 N/m. Determine the speed of rotation of the motor in rpm.

6. A pulley is 600 mm in diameter and the difference in tension on the two sides of the driving belt is 1.5 kN. If the speed of the pulley is 500 revs min $^{-1}$, determine:
   (a) the torque developed
   (b) the work done in three minutes.

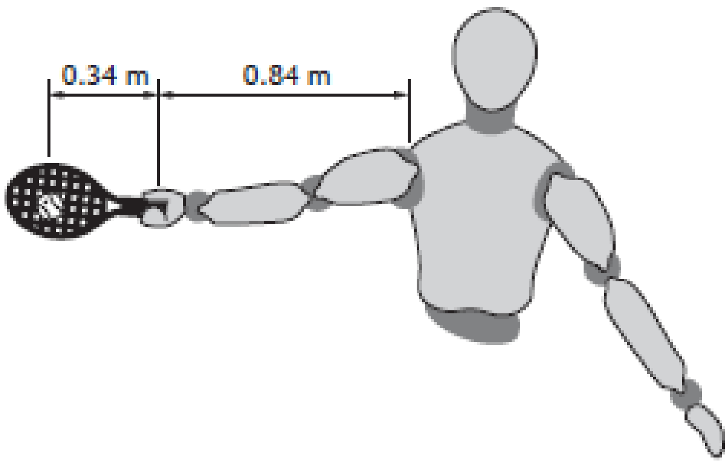
7. A 15 kW motor is driving a shaft at 1150 revs min $^{-1}$ by means of pulley wheels and a belt. The tensions in the belt on each side of the driver pulley are 400 N and 50 N and the diameters of the driver and driven pulley wheels are 500 mm and 750 mm respectively. Calculate:
   (a) the power output
   (b) the efficiency of the motor.

2023 Past Paper

3. In a popular garden game, a tennis ball attached to a pole by a length of rope is hit with a racquet to swing around for another player to hit back.

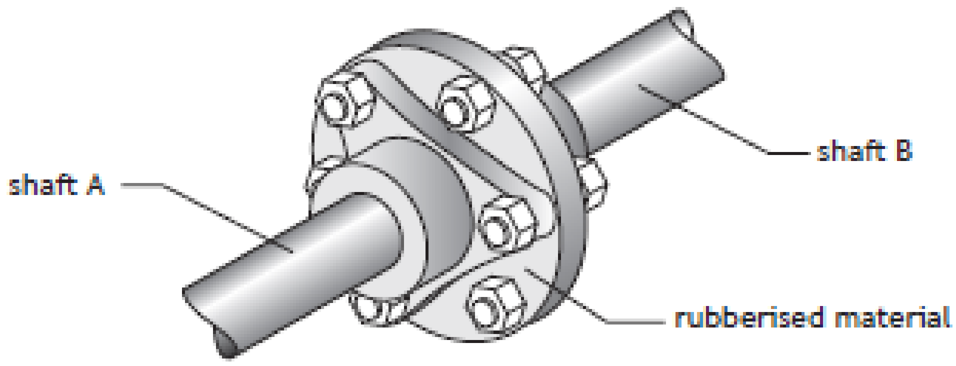


One player has an arm length of 0.84 m and the ball hits the racquet at a further distance of 0.34 m as shown below.



(a) Calculate the force that this player strikes the ball with to produce a torque of 295 Nm. 2

4. Flexible couplings can be used rather than rigid couplings to connect two shafts. An example of a flexible coupling is shown.



(a) Describe two advantages of using flexible couplings rather than rigid couplings to connect shaft A and shaft B. **2**

Advantage 1 ______________________________

____

____

Advantage 2 ______________________________

____

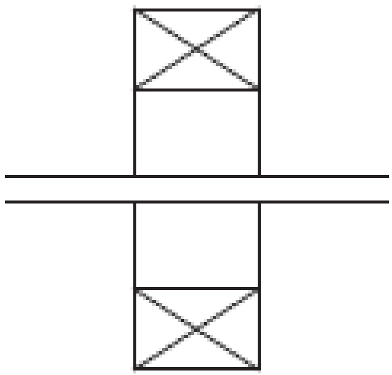
____

(b) State the name of another mechanical method of joining two shafts together to transmit rotational motion. **1**

____

4. (continued)

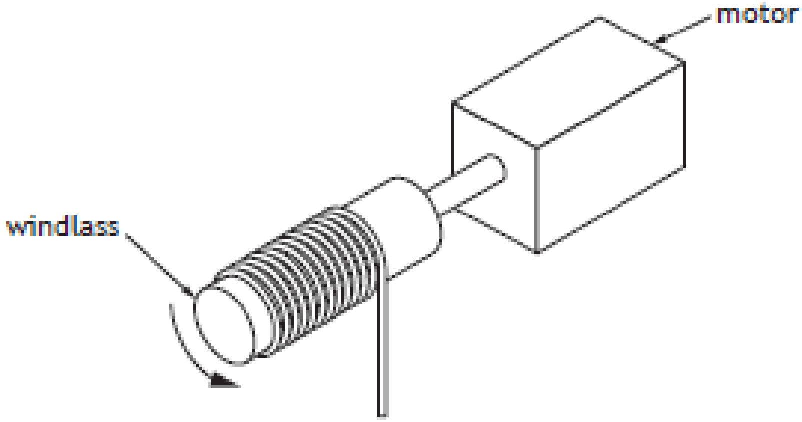
A typical graphic symbol used by engineers to represent a bearing is shown below.



(c) Describe one function of a bearing in a drive system. 1

11. (continued)

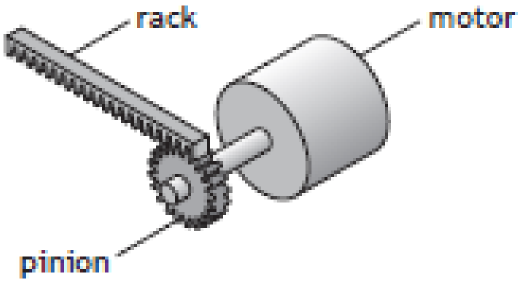
A motor-driven winch system is used for lifting construction materials with up to 12,000 kg of mass. The windlass, with 320 mm diameter, rotates at 12 revolutions per minute.



(b) Calculate the mechanical power required by this motor. **5**

12. (continued)

Part of the design involves rotary motion, from a motor, transforming into linear motion.



The pinion gear has 24 teeth and the pitch of the teeth on the rack is 3·0 mm.

The rack is required to move 2·75 m in three seconds.

(d) Calculate the required speed of the motor. **3**