National 4/5 Engineering Science

Mechanisms and Structures

Book 3 of 5 - Mechanisms

Name: 

Class:
Introduction to Mechanisms

A mechanism is a system of moving parts that changes an input motion and force into a desired output motion and force. Mechanisms are a large part of modern society. Most of the mechanisms are that we use everyday are so familiar that we never think twice about them, for example door handles, light switches, scissors.

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 provide the forces to press sheet steel into shapes of car body panels, to lift large components from place to place and to force power hacksaws to cut through metal bars – the list is endless. It is only by using mechanisms that industry can make products you use every day.

All mechanisms must:
- Transfer force from one point to another
- Transfer motion from one point to another

Types of motion

<table>
<thead>
<tr>
<th>Rotary</th>
<th>Linear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion in a circle is called rotary motion. The number of complete revolutions per minute (rpm) is called rotary velocity.</td>
<td>Linear motion is motion in a straight line. Steady linear motion is known as velocity.</td>
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</tbody>
</table>

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<tr>
<th>Oscillating</th>
<th>Reciprocating</th>
</tr>
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<tbody>
<tr>
<td>Oscillating motion is motion backwards and forwards in a circular arc. A swinging pendulum is an example of oscillating motion.</td>
<td>Reciprocating motion is linear motion backwards and forwards in a straight line. Jigsaws which are often used in school workshops make use of reciprocating motion.</td>
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Levers

One of the simplest mechanisms is a lever. The purpose of a lever is to transfer input motion and force to create output motion and force. Often, this means that the output force will be significantly larger than the input force which allows heavy loads to be lifted with relatively little force required.

Classes of Levers

Class 1
This is the easiest lever to understand. A force (effort) applied on one side is used to move a load on the other side. The lever pivots about a fulcrum in between the load and effort. Scissors and crowbars are class 1 levers.

Class 2
A class 2 lever has a fulcrum positioned at one end, with the effort force being applied to the other. The load is positioned between the effort and fulcrum. A wheelbarrow is an example of a class 2 lever.

Class 3
A class 3 lever has a fulcrum at one end, whilst the load is at the other end. The effort applied to move the load is positioned between the load and fulcrum.

More information on levers can be found in the Focus on Mechanisms software.
Belt Drive Systems - Pulleys

A belt drive system, or pulley, is used to transmit rotary motion from one part of a mechanism to another. In doing so power, torque (twisting force) and speed are also transferred and can be stepped up or stepped down by adjusting the sizes of the pulley wheels.

Velocity Ratio

As can be seen pulleys change the speed of rotation. The amount by which the speed is stepped up or down is called the velocity ratio, which can be calculated using the following equation:

\[ VR = \frac{\text{Output size}}{\text{Input size}} \]

Changing Speed in a Pulley System

To calculate the output speed from a simple pulley system it is easiest to think of the systems diagram below.

\[ \text{Input speed} \rightarrow \text{Divide by VR} \rightarrow \text{Output speed} \]

\[ \text{VR} = \frac{\text{output size}}{\text{input size}} \]
\[ = \frac{120}{200} \]
\[ = 0.6 \]

Output speed = input speed / VR
\[ = \frac{300}{0.6} \]
\[ = 500\text{rpm} \]

This equation is particularly useful:
\[ \text{Input speed x input size} = \text{Output speed x output size} \]
Assignment 1 - Pulleys

1. Copy the diagram of a belt drive system into your jotter, adding labels to show the driver, driven, and belt.

2. In this belt drive system does the output rotate faster or slower than the input?

3. If the diameter of the input pulley is 40mm and the diameter of the output pulley is 10mm, what is the velocity ratio?

4. If the input pulley is coupled to a motor spinning at 1800rpm what is the rotational speed of the output?

Remember:

\[
\text{Input speed} \times \text{Input size} = \text{Output speed} \times \text{Output size}
\]

5. Copy each of the diagrams into your jotter, adding arrows to show the direction of rotation. In each case A rotates clockwise.
Assignment 1 continued

6. For each of the systems in question 5, calculate the output speed if the input speed is 50rpm.

7. Investigate pulleys using the “Focus on Mechanisms” software. In your jotter sketch 3 ways in which slip can be reduced.

8. In your jotter sketch a method a varying speed in a belt drive system.

9. Give three examples of where jockey wheels are used in drive systems.
Chain Drives

Like pulleys, chain drives are used to transmit rotary motion from one part of a mechanism to another. In doing so power, torque (twisting force) and speed are also transferred and can be stepped up or stepped down by adjusting the number of teeth on the gear wheels. Chain drives are usually used where large forces have to be transmitted and no slip is allowed.

Velocity Ratio

As can be seen chain drives change the speed of rotation. The amount by which the speed is stepped up or down is called the velocity ratio, which can be calculated using the following equation:

VR = output size / input size

Changing Speed in a Chain Drive

To calculate the output speed from a chain drive it is easiest to think of the systems diagram below.

Input speed $\xrightarrow{\text{Divide by VR}}$ Output speed

VR = output size / input size

= 20 / 68

= 0.29

Input driver
68 teeth
Speed = 300rpm

Output driven
20 teeth

Output speed = input speed / VR

= 300 / 0.29

= 1034.48rpm

This equation is particularly useful:

Input speed x input size = Output speed x output size
Assignment 2 - Chain Drives

1. Copy the diagram of a chain drive system into your jotter, adding labels to show the driver, driven, and chain.

   ![Diagram of a chain drive system]

   In this chain drive does the output rotate faster or slower than the input?

2. If the number of teeth on the input sprocket is 46 and the number of teeth on the output is 10, what is the velocity ratio?

3. If this system was part of a BMX, with the input sprocket connected to the pedals being rotated at 29rpm, what would be the output speed of the BMX wheel?

4. What is lubrication and why is it important to keep the chain well lubricated?

5. Copy the following chain drives into your jotter and calculate the velocity ratio for each.

   ![Chain drive diagrams]

6. For each of the chain drives above calculate the output speed if the input speed is 50rpm
Simple Gear Trains

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.

Velocity Ratio

As can be seen gear trains change the speed of rotation and the direction of rotation. The amount by which the speed is stepped up or down is called the velocity ratio, which can be calculated using the following equation:

\[
VR = \frac{\text{Output size}}{\text{Input size}}
\]

Changing Speed in a Gear Train

To calculate the output speed from a gear train it is easiest to think of the systems diagram below.

\[\text{Input speed} \rightarrow \text{Divide by VR} \rightarrow \text{Output speed}\]

Multiple Velocity Ratios

Consider the simple gear train shown to the left which has 3 velocity ratios:

- A to B
- B to C
- C to D

You should notice that there is a velocity ratio wherever two gears mesh together.

To calculate the overall velocity ratio simply calculate each velocity ratio stated above then multiply them all together.
Assignment 3 - Simple Gear Trains

1. 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

![Diagram of gear train A-B-C]

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

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

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

![Diagram of gear train A-B-C-D]

3. A simple gear train used in a food processor is shown.

   (a) Draw, using the correct symbols, this simple gear train into your jotter.

   ![Diagram of gear train]

   (b) What is the correct name for gear A and what is its purpose? You will be able to find the answer on Focus on Mechanisms.
Compund 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. In these occasions simple gear trains are simply too bulky.

The problem can be overcome by mounting pairs of gears on the same shaft as shown. This is called a compound gear train.

Example
The velocity ratio for this gear system would be...

The velocity ratio for the first pair of meshing teeth is:

\[
\text{Ratio of AB} = \frac{\text{driven}}{\text{driver}} = \frac{80}{4} = 4:1
\]

Driver 20 1

The velocity ratio for the second pair of meshing teeth is:

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

Driver 10 1

The total velocity ratio is calculated by multiplying both ratios:

\[
\text{Total ratio} = 4 \times 6 = 24 = 24:1
\]

1 1 1

For an input speed of 100 rpm, the output speed would be 4.17 rpm

\[
\frac{100}{24}
\]
Assignment 4 - Compound Gear Trains

1. A motorised towel dispenser uses a compound gear train as shown.
   (a) Calculate the velocity ratio for the gear system.
   (b) Describe the difference between the input and output speeds.
   (c) Explain the difference between the input and output rotational directions.

2. A conveyor is operated using the compound gear train shown below.
   (a) Describe an advantage of using a compound gear train.
   (b) Calculate the speed of the output gear if the input rotates at 250rpm.
   (c) Describe how friction in this compound gear train could be reduced.
Specialist Gears

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 do the gears in a wind turbine.
Assignment 5 - More Gear Systems

1. The compound gear train shown below is driven by a motor that runs at 1000 rpm. Calculate the gear 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

2. 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.

   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?

3. The motorised winch shown below runs at a speed of 1200 rpm. The drum is to rotate at 25 rpm. Calculate:
   (a) The velocity 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
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.