Mechanical Systems – Levers and Forces

Mechanisms and Structures

Mechanical Systems

Levers

Basic Forces

Pupil Name

Teacher

Class
MECHANICAL SYSTEMS

Our every day lives are made much easier by a variety of mechanical systems that help us do jobs of work and leisure. Most of the mechanisms you use are so familiar you take them for granted.

In the home for example, from simple mechanical mechanisms such as scissors and those in vacuum cleaners, to more complex mechanisms such as sowing machines, all help us do work in the house.

Mechanisms at home
fig1.1

Mechanisms play a vital role in transporting people to school, college or work and mechanical systems included in bicycles, cars, buses, aeroplanes and ships make all this possible.

Mechanisms in transportation
fig1.2
In the factories, the work involved in making all these consumer products so necessary for our modern society is made easier by the large and complex machines using mechanical systems in their manufacture.

Mechanisms in the workplace

All machines have one thing in common, to do their work they require energy. Mechanical Systems within Machines in fact can be considered as systems which process energy to produce useful work.

Common forms of energy you may already know:

Electrical, Heat, Chemical, Potential and Kinetic Energies.

In this unit we intend to look at that energy most closely associated with machines, called work.
MECHANICAL SYSTEMS

The main purpose of most mechanical systems is to make work easier to do.

In fact, if a mechanical system doesn’t make work easier to do then there is little point in having it.

Just think what hard work it must have been to wash clothes before washing machines were invented.

fig 2.1

Modern machines like washing machines are made up from many different parts or subsystems such as electronic devices to control their operation. However, the parts of the machine which do the hard work of washing clothes, such as turning the drum and pumping out the water, are mechanical systems, the simplest of which are called mechanisms.

fig 2.2

In your project work in this subject you will require to know about a range of mechanical subsystems and be able to use them to solve problems.

Through completing this learning outcome you will be introduced to the most
common of mechanical subsystems.
Although different mechanical systems or mechanisms are all designed to perform different jobs, they all have two similar functions. Mechanisms are systems, which transmit force and transmit and/or convert motion.

**fig 3.1**

Common place items such as bicycles, door handles and kitchen taps all involve some form of motion and force. This force and motion is transmitted to provide a desired output force and motion.

**Motion**
The four types of motion most basic to machines are:

- **Rotary; Linear; Oscillating and Reciprocating**

An example of a device, which uses each of these types of motion, is shown.

**Rotary motion**
Rotary motion is motion through a circular path, such as is produced when a sharpener handle rotates.

**fig 3.2**
**Linear Motion**
Linear motion is motion in straight line, such as is produced when a person bowls a bowling ball.

![Image of bowling motion](image-url)

**fig 3.3**

**Oscillating Motion**
Oscillating motion is motion back and forward through the arc of a circle, as can be produced by the gymnast.

![Image of gymnast motion](image-url)

**fig 3.4**

**Reciprocating Motion**
Reciprocating motion is motion back and forward through a straight line, such as is produced by jigsaw.
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fig 3.5
**Conversion of Motion**

Most mechanisms are used to convert one of these types of motion into another.

An example of this is in an electric sewing machine.

**fig 4.1**

The input motion from the electric motor, which drives the machine, is rotary. This rotary motion is converted by a mechanism called a crankshaft to produce the reciprocating motion required by the sewing machine needle.

**fig 4.2**
**Levers**

The main factor that has led to mankind dominating the world in which we live has been the ability to harness energy to do work through developing machines and mechanical systems.

An early example of this was demonstrated in the ability to lift and move heavy objects using a simple mechanism called a **Lever**.

![Diagram of a lever](image)

**fig 5.1**

The idea behind a lever is simple enough. It is a system which will produce a large output force from a smaller input force.

![Diagram of a lever with forces](image)

**fig 5.2**

For this to happen a rigid beam is required to act as the lever which **must pivot** about a point closer to the output force than the input force.

![Diagram of a lever with pivot](image)

**fig 5.3**
**Mechanical Advantage (MA)**

There is an obvious advantage in using a lever for this purpose, in that it increases the effect of the small input force to produce a larger output force to lift the load.

The advantage gained from using a lever mechanism for this purpose is called **Mechanical Advantage**.

Mechanical Advantage is the ratio of the output force to the input force.

\[
MA = \frac{\text{Force out (Fo)}}{\text{Force in (Fi)}}
\]

**Example**

The lever shown in the diagram requires a 10 N force to raise a load weighing 100 N. Calculate the mechanical advantage of the lever.

\[
\begin{align*}
\text{MA} &= \frac{\text{Fo}}{\text{Fi}} \\
\text{MA} &= \frac{100}{10} \\
\text{MA} &= 10 \text{ or } 10:1
\end{align*}
\]

(i.e. the input force is **ten** times smaller than the output force.)
Velocity Ratio (VR)
Most mechanical systems are designed to produce a mechanical advantage (i.e. a small input force producing a large output force). There is, however, a price to pay for this advantage because the smaller input force has to be moved through a much larger distance than the large output force.

Just as there is a name given to the ratio between the input and output forces, i.e. mechanical advantage, there is a name given to the ratio between the distances moved by the input and output force.

This ratio is called the **Velocity Ratio**.

\[
\text{Velocity Ratio} = \frac{\text{Distance moved by the input (di)}}{\text{Distance moved by the output (do)}}
\]

\[
VR = \frac{di}{do}
\]

For our lever then:

\[
VR = \frac{1000}{10} = 10 \text{ or } 101
\]

i.e. the input force has to be moved ten times further than the output force.

**Efficiency**
The efficiency of a mechanism is a measure of how effectively it does its work.

\[
\text{Efficiency} = \frac{\text{Work out} \times 100\%}{\text{Work in}}
\]

For our lever then:

\[
\text{Efficiency} = \frac{Wo}{Wi} = \frac{10 \times 100}{10} = 100\%
\]
The efficiency of a mechanical system can also be calculated from the ratio of the MA to the VR.

\[
\text{Efficiency} = \frac{\text{Mechanical Advantage (MA)}}{\text{Velocity Ration (VR)}}
\]
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Again for the lever:

\[
\text{Efficiency} = \frac{MA}{VR} \times 100
\]

\[
= \frac{10 \times 100}{10}
\]

\[
= 100\%
\]
Friction

From our calculations it would appear that our lever is an ideal mechanism. It converts all the energy input to do the work at the output. In reality however this would not be the case.

Probably the lever would bend slightly as the input force was applied. Therefore the distance which this force would have to be moved would be greater thus increasing the VR and reducing the efficiency.

Even if the lever was perfectly rigid it still could not be 100% efficient because of friction.

Friction occurs when any two surfaces come into contact. In the case of the lever, friction between the pivot and the underside of the lever will generate heat energy. This means that some of the input energy will be ‘lost’ at the pivot and the amount of work done at the output will be less.

In more complex systems friction can be a major problem and engineers have developed various methods of reducing friction.

The simplest way to reduce friction is to use a lubricant such as oil or grease.
In moving parts such as at the hub of a wheel, ball bearings get over the problem of surfaces rubbing together.

fig 8.3

The bearing consists of an outer and an inner ‘race’ which have grooves machined in them. Hardened steel spheres, or ‘balls’, are fitted between the outer and inner race which can then rotate freely. To work effectively the ball bearing must be well lubricated.

Friction is not all bad however and without friction many mechanical systems would not work.

It is friction between the soles of our shoes and the pavement, which allows us to walk. If it were not for friction it would feel a bit like walking on ice and we would find it impossible to get about. Tyres on cars are designed to increase friction with the road surface to ensure that the force from the engine can be transmitted effectively.
Without friction it would be impossible to stop our cars or bicycles because the brakes also rely on friction.
Moments
With the lever we saw that applying it further away from the pivot point can increase the effect of a force.

This effect is used when tightening a bolt with a spanner. To get the bolt really tight the force must be applied at the end of the spanner.

The effect of producing a large output force from a small input force is called a moment.

The moment of a force is dependent on the size of the force and the distance at which it is applied from the pivot point.

\[ \text{MOMENT} = \text{FORCE} \times \text{DISTANCE} \]

\[ M = F \times d \]
**Example**
The spanner shown in the diagram is 250 mm long. If a force of 40 N is exerted at its end, find the moment of the force.

\[ M = F \times d \]

\[ M = 40 \times 250 = 10,000 \text{ Nmm} = 10 \text{ Nm} \]

**Equilibrium**
Moments are very important in the design of some mechanisms. Large and complex mechanical systems such as cranes use moments to balance either side of the arm, otherwise the crane would topple over.

\[ \text{COUNTER BALANCE MOMENT} = \text{LOAD MOMENT} \]

\[ 10 \times 3 = 6 \times 5 \]

\[ 30 = 30 \text{ Nm} \]
Linkages
Linkages are mechanical systems which transmit force and movement. Like levers they can be used to increase the effect of an input force.

![Diagram of Linkage]

Some common types of linkage are shown in the diagrams.

Bell Crank Linkage

Reverse Motion Linkage

Bell cranks and reverse motion linkages can be used to alter the direction of transmission of the input force.

If the pivot point on the reverse motion linkage is changed a larger output force is transmitted.

![Diagram of Reverse Motion Linkage]
The mechanism that operates calliper brakes on bicycles uses two bell cranks to transmit braking force. These mechanisms transmit the force from the brake cable at right angles onto the wheel rim.

Parallel linkages are used to make two or more parts of a mechanical system move together in parallel. These systems are based on a parallelogram and are used in folding devices such as extension mirrors and tool boxes.

A common application of a parallel linkage can be seen in some car windscreen wipers. The diagram shows how this is achieved using a rotating linkage to drag a parallel linkage back and forth.
Windscreen Wipe
Build and test a model which shows the action of a windscreen wiper linkage.

fig 9.8

1. (a) Draw a systems diagram which shows the input and output motion to the mechanism.

(b) Draw a line diagram of the device and explain how it operates.

2. (a) Develop an electronic control system which would switch on the wipers automatically when it rains and can also be operated manually.

(b) Draw a systems diagram for the control system.

(c) Build and test the control system and draw a block diagram explaining how it operates.
Assignment
A hand operated crusher for aluminium cans is shown below. A schematic diagram of the lever system is also shown.

(a) Write a few sentences to explain why a lever is useful for this application.

(b) In the situation above, if the operator applies a force of 100N on the handle at A, calculate the size of the total force applied to the can at D.

(c) Identify one part of the mechanism which is in tension.
Assignment

Waste material is transported to a site by a cab with a trailer supported on a ball joint tow bar at P as shown on the diagram. The centre of gravity of the cab acts through point A and the centre of gravity of the loaded trailer acts through point B.

![Diagram of the system](image)

**fig 9.10**

A line diagram of the system is shown below.

![Line diagram](image)

**fig 9.11**

(a) By considering the trailer, calculate the force acting at the ball joint at P.

(b) Calculate the reaction forces between the wheels of the cab and the ground at R1 and R2.
ASSIGNMENTS: MOMENTS AND LEVERS

1. Explain in your own words what the term Moment means?

2. A garage door is 2 metres high and is hinged at the top. The door begins to open when a force of 65 newtons is applied to the door handle at right angles, which is 1.5 meters down from the hinge. Find the least amount of force which, when applied to the middle of the door, will open it?

MS. Int2 02 Fig 9.16

3. In a theatre stage a horizontal aluminum beam 5 metres long carries lighting weighing 70 newtons at one end and a counter balance of 80N at the other end. Calculate the position of a single pivot support to allow the system to balance?

MS. Int2 02 Fig 9.17

4. In the wheelbarrow shown a load of 500 newtons is to be removed. Calculate the amount of force that is needed to lift the handle to transport the load.
5. During a cross-country rally the jacking system to remove a punctured tyre could not be placed on a level surface. A new arrangement using a lever to change the tyre was attempted. If the weight of the car was 4,800 newtons, calculate the position of the pivot from the car if the effort applied is 600 newtons.

6. A clawhammer was used to extract a nail from a piece of wood. The necessary force was 45 newtons applied at 300mm from the back of the hammer. Find the resistance force offered by the nail, which was 40mm away from the pivot point of the hammer.

7. A pneumatic clamp is used to hold a workpiece in place during a machining process. The double acting cylinder has an upward thrust of 100 newtons.
a) Calculate the force exerted on the workpiece by the clamp when the cylinder is positive?

MS. Int2 02 Fig 9.21

8. A truck weighs 60kN with its weight acting as shown. If the pivot point is the rear wheels,
a) Calculate the weight of the skip (W)
b) What effect would a loaded skip have on the lifting process?

MS. Int2 02 Fig 9.22

9. The diagram below shows part of a tractor handbrake system. The line diagram indicates dimensions and forces within the system; a spring and a force of 120N will return the brake handle.

For the position shown, calculate the force F required at the brake handle.
MS. Int2 02 Fig 9.23