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ENGINEERING MECHANICS

CHAPTER 10: SIMPLE LIFTING MACHINES

Lecture 1:

10.1 Definition and importance of Simple Machines:

Definition: A simple machine may be defined as a device, which enables us to do some useful work at some point or to overcome some resistance, when an effort or force is applied to it, at some other convenient point. They are used to modify motion and the magnitude of a force in order to perform work. They are the simplest mechanisms known that can use leverage (or mechanical advantage) to increase force.

A lifting machine is a device, which enables us to lift a heavy load (W) by applying a comparatively smaller effort (P).

Simple machines that are widely used include the wheel and axle, pulley, inclined plane, screw, wedge and lever.

Importance: Simple machines are useful because they reduce effort or extend the ability of people to perform tasks beyond their normal capabilities. While simple machines may magnify or reduce the forces that can be applied to them, they do not change the total amount of work needed to perform the overall task. A simple machine uses a single applied force to do work against a single load force. Ignoring friction losses, the work done on the load is equal to the work done by the applied force.

Note: Input of a machine: The input of a machine is the work done on the machine. In a lifting machine, it is measured by the product of effort and the distance through which it has moved.

Output of a machine: The output of a machine is the actual work done by the machine. In a lifting machine, it is measured by the product of the weight lifted and the distance through which it has been lifted.

Ideal machine: If the efficiency of a machine is 100% i.e., if the output is equal to the input, the machine is called as a perfect or an ideal machine.

10.4 Definition M.A, V.R and efficiency and their relationship. Simple problems

Mechanical Advantage: The mechanical advantage (briefly written as M.A.) is the ratio of weight lifted (W) to the effort applied (P) and is always expressed in pure number.

Mathematically, mechanical advantage, $\mathbf{M.A.} = \frac{W}{P}$.

Velocity Ratio: The velocity ratio (briefly written as V.R.) is the ratio of distance moved by the effort (y) to the distance moved by the load (x) and is always expressed in pure number.

Mathematically, velocity ratio, $\mathbf{V.R.} = \frac{y}{x}$

Efficiency of a machine: It is the ratio of output to the input of a machine and is generally expressed as a percentage.

Mathematically, Efficiency , $\eta = \frac{Output}{Input} \times 100$

Relation between efficiency, mechanical advantage and velocity ratio of a lifting machine:

It is an important relation of a lifting machine, which throws light on its mechanism. Now consider a lifting machine, whose efficiency is required to be found out.

Let W = Load lifted by the machine,

P = Effort required to lift the load,

Y = Distance moved by the effort, in lifting the load, and

x = Distance moved by the load.

We know that $\text{M.A.} = \frac{W}{P} = W/P$ and $\text{V.R.} = \frac{y}{x} = y/x$

We also know that input of a machine

= Effort applied × Distance through which the effort has moved

$= P \times y$ ...(*i*)

and output of a machine

= Load lifted × Distance through which the load has been lifted

$= W \times x$ ...(*ii*)

∴ Efficiency, $\eta = \frac{\text{Output}}{\text{Input}} = \frac{W \times x}{P \times y} = \frac{W/P}{y/x} = \frac{\text{M.A.}}{\text{V.R.}}$

Note: It may be seen from the above relation that the values of M.A. and V.R. are equal only in case of a machine whose efficiency is 100%. But in actual practice, it is not possible.

Example 10.1 *In a certain weight lifting machine, a weight of 1 kN is lifted by an effort of 25 N. While the weight moves up by 100 mm, the point of application of effort moves by 8 m. Find mechanical advantage, velocity ratio and efficiency of the machine.*

Solution. Given: Weight (W) = 1 kN = 1000 N ; Effort (P) = 25 N ; Distance through which the weight is moved (x) = 100 mm = 0.1 m and distance through which effort is moved (y) = 8 m.

Mechanical advantage of the machine.

We know that mechanical advantage of the machine

$$\text{M.A.} = \frac{W}{P} = \frac{1000}{25} = 40 \qquad \textbf{Ans.}$$

Velocity ratio of the machine

We know that velocity ratio of the machine

$$\text{V.R.} = \frac{y}{x} = \frac{8}{0.1} = 80 \qquad \textbf{Ans.}$$

Efficiency of the machine

We also know that efficiency of the machine,

$$\eta = \frac{\text{M.A.}}{\text{V.R.}} = \frac{40}{80} = 0.5 = 50\% \qquad \textbf{Ans.}$$

Reversibilty of a machine: Sometimes, a machine is also capable of doing some work in the reversed direction, after the effort is removed. Such a machine is called a reversible machine and its action is known as reversibility of the machine.

Condition for reversibilty of a machine:

Let W = Load lifted by the machine,
P = Effort required to lift the load,
y = Distance moved by the effort, and
x = Distance moved by the load.

We know that input of the machine = P × y ...(i) and

output of the machine = W × x ...(ii)

We also know that machine friction = Input – Output = (P × y) – (W × x) ...(iii)

In a reversible machine, the output of the machine should be more than the machine friction, when the effort (P) is zero. i.e.

$$W \times x > P \times y - W \times x$$

or $$2\,W \times x > P \times y$$

or $$\frac{W \times x}{P \times y} > \frac{1}{2}$$

or $$\frac{\frac{W}{P}}{\frac{y}{x}} > \frac{1}{2}$$

or $$\frac{\text{M.A.}}{\text{V.R.}} > \frac{1}{2}$$

$$\ldots\left(\because \frac{W}{P} = \text{M.A.} \quad \text{and} \quad \frac{y}{x} = \text{V.R.}\right)$$

$\therefore$ $$\eta > \frac{1}{2} = 0.5 = 50\%$$

Hence the condition for a machine, to be reversible, is that its efficiency should be more than 50%.

Self-locking machine: Sometimes, a machine is not capable of doing any work in the reversed direction, after the effort is removed. Such a machine is called a non-reversible or self-locking machine. The condition for a machine to be non-reversible or self-locking is that its efficiency should not be more than 50%.

Example 10.2. *A certain weight lifting machine of velocity ratio 30 can lift a load of 1500 N with the help of 125 N effort. Determine if the machine is reversible.*

Solution. Given: Velocity ratio (V.R.) = 30; Load (W) = 1500 N and effort (P) = 125 N.

We know that $\text{M.A.} = \frac{W}{P} = \frac{1500}{125} = 12$

and efficiency, $$\eta = \frac{\text{M.A.}}{\text{V.R.}} = \frac{12}{30} = 0.4 = 40\%$$

Since efficiency of the machine is less than 50%, therefore the machine is non-reversible. **Ans.**

Example 10.3. *In a lifting machine, whose velocity ratio is 50, an effort of 100 N is required to lift a load of 4 kN. Is the machine reversible ? If so, what effort should be applied, so that the machine is at the point of reversing ?*

Solution. Given: Velocity ratio (V.R.) = 50 ; Effort (P) = 100 N and load (W) = 4 kN = 4000 N.

Reversibility of the machine

We know that M.A. $= \frac{W}{P} = \frac{4000}{100} = 40$

and efficiency, $\eta = \frac{\text{M.A.}}{\text{V.R.}} = \frac{40}{50} = 0.8 = 80\%$

Since efficiency of the machine is more than 50%, therefore the machine is reversible. **Ans.**

Effort to be applied

A little consideration will show that the machine will be at the point of reversing, when its efficiency is 50% or 0.5.

Let P_1 = Effort required to lift a load of 4000 N when the machine is at the point of reversing.

We know that $\text{M.A.} = \frac{W}{P_1} = \frac{4000}{P_1} = 4000 / P_1$

and efficiency, $0.5 = \frac{\text{M.A.}}{\text{V.R.}} = \frac{4000/P_1}{50} = \frac{80}{P_1}$

$\therefore \quad P_1 = \frac{80}{0.5} = 160 \text{ N}$ **Ans.**

Example 10.4. *In a certain machine, an effort of 100 N is just able to lift a load of 840 N, Calculate efficiency and friction both on effort and load side, if the velocity ratio of the machine is 10.*

Solution. Given: Effort (P) = 100 N ; Load (W) = 840 N and velocity ratio (V.R.) = 10.

Efficiency of the machine

We know that M.A. $= \frac{W}{P} = \frac{840}{100} = 8.4$

and efficiency, $\eta = \frac{\text{M.A.}}{\text{V.R.}} = \frac{8.4}{10} = 0.84 = 84\%$ **Ans.**

Friction of the machine

We know that friction of the machine in terms of effort,

$$F_{(\text{effort})} = P - \frac{W}{\text{V.R.}} = 100 - \frac{840}{10} = 16 \text{ N} \quad ...(i)$$

and friction of the machine in terms of load,

$$F_{(\text{load})} = (P \times \text{V.R.}) - W = (100 \times 10) - 840 = 160 \text{ N} \quad ...(ii)$$

It may be noted from equations (*i*) and (*ii*) that an effort of 16 N is required to overcome the friction. Or in other words, this effort can lift an additional load of 160 N **Ans.**