ENGINEERING MECHANICS LAB MANUAL

DEPARTMENT OF CIVIL ENGINEERING

CENTRAL UNIVERSITY OF JHARKHAND

LIST OF EXPERIMENTS

EXPERIMENT NO.: 01

VERIFICATION OF TRIANGLE LAW OF FORCES

OBJECTIVE: To verify triangle law of forces with the help of Gravesand's apparatus

THEORY: The "triangle law of force" states that if three coplanar forces acting on a particle can be represented in magnitude and direction by the three sides of the triangle taken in order, the force will be in equilibrium. This law can also be stated as: If two forces acting on a particle represented in magnitude and direction by the two sides of the triangle taken in order then their resultant will be given by the third side of the triangle taken in opposite direction.

"Parallelogram law of forces" states that if a particle is acted by the two forces represented in magnitude and direction by the two sides of a parallelogram drawn from a point then the resultant is completely represented by the diagonal passing through the same point.

APPARATUS: Gravesand's apparatus, paper sheet, weight, thread, pans, set square, pencil, drawing pin etc. .

PROCEDURE:

Refer to fig. 1.1

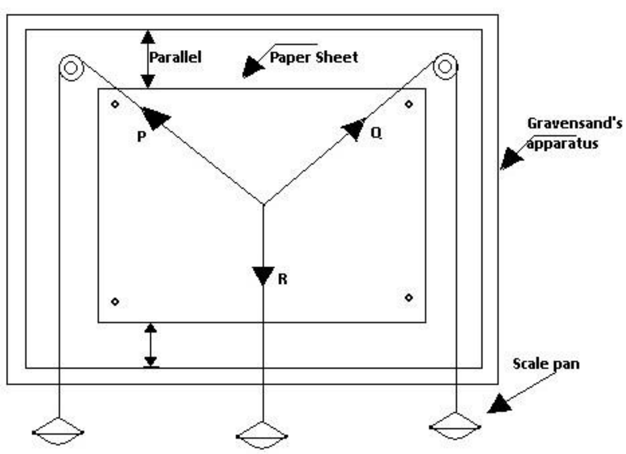


Fig. 1.1

1. Fix the paper sheet with drawing pin on the board set in a vertical plane such that it should be parallel to the edge of board.
2. Pass one thread over the pulleys carrying a pan at its each end. Take a second thread and tie its one end at the middle of the first thread and tie a pan at its other end.
3. Add weights in the pan in such a manner that the small knot comes approximately in the centre.
4. Displace slightly the pans from their position of equilibrium and note if they come to their original position of rest. This will ensure the free movement of the pulleys.
5. Mark lines of forces represented by thread without disturbing the equilibrium of the system and write the magnitude of forces i.e. **Pan Weight + Added Weight**.
6. Remove the paper from the board and produce the line to meet at O.
7. Use Bow's notation to name the force P, Q, R as AB, BC, and CA.
8. Select a suitable scale and draw the line *ab* parallel to force P and cut it equal to the magnitude of P. From *b* draw the line *bc*parallel to force Q and cut it equal to the magnitude of Q (Fig. 1.2). Calculate the magnitude of *ca* i.e., R_1 which will be equal to the third force R which proves the triangle law of forces.

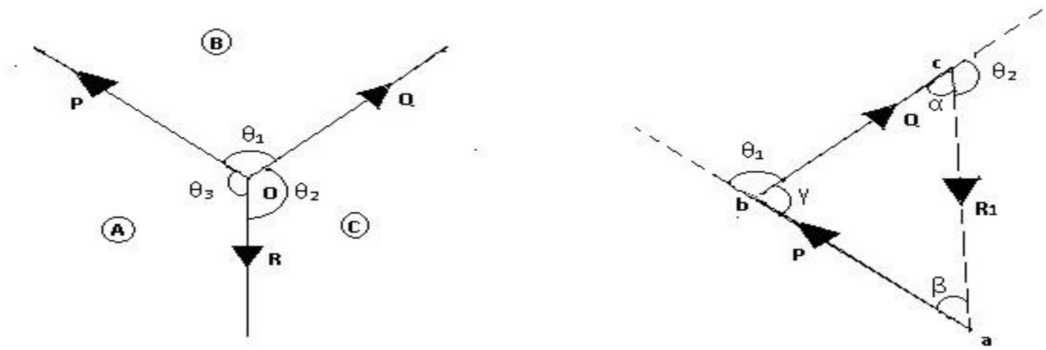
   If R_1 differs from original magnitude of R, the percentage error is found as follows:

$$\text{Percentage error} = \frac{R-R1}{R} * 100$$

1.1TRIANGLE LAW OF FORCES

Graphical Method

Fig. 1.2(b), draw *ab* parallel to force P in suitable scale with the use of set square and then from *b* draw *bc*parallel to force Q. The closing side of triangle represents the force R_1 which should be equal to force R. Note, the difference in R_1 and R shows the graphical error.



(a)Space diagram (b) Vector diagram

Fig. 1.2

Analytical Method

Measure angles α, β and γ and by using Lami's theorem check the following relation

$$\frac{P}{Sin\ \alpha} = \frac{Q}{Sin\ \beta} = \frac{R2}{Sin\ \gamma}$$

1.2 PARALLELOGRAM LAW OF FORCES

Graphical Method

Fig. 1.3, cut OA=P and OB=Q in suitable scale. From A draw AC' parallel to OB and BC' parallel to OA.

R_1 represents the resultant of force P and Q. As the system is in equilibrium it must be equal to R.

Note that R and R_1 are in opposite direction.

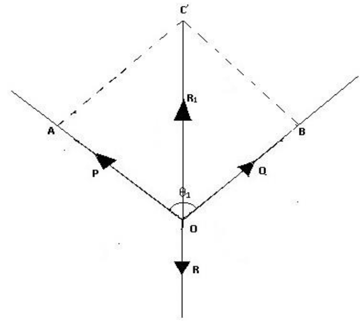


Fig. 1.3

Analytical Method

Measure angles θ_1 and by using resultant formula, calculate R_1

$$R_2=\sqrt{(P^2+Q^2+2\,PQ\,\text{cosine}\,\theta_1)}$$

OBSERVATIONS

Scale ……….N: …….mm

Law	Total Weight of pan P	Total Weight of pan Q	Total Weight of pan R	Calculate Resultant	%age error =
Triangle Law					**Graphical** $\frac{R-R1}{R}*100$ **Analytical** $\frac{R-R2}{R}*100$
Parallelogram Law					$\frac{R-R1}{R}*100$ **Graphical**
					$\frac{R-R2}{R}*100$ **Analytical**

PRECAUTIONS

A. Pans/weights should not touch the vertical board

B. There should be only one central knot on the thread which should be small

C. While calculating the total force in each case the weight of the pan should be added to the weight put into the pan

D. Make sure that all the pans are at rest when the lines of action of forces are marked

E. All the pulleys should be free from friction

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EXPERIMENT NO.: 02

VERIFICATION OF POLYGON LAW OF FORCES

AIM: To verify polygon law of forces with the help of Gravesand's apparatus

THEORY: "Polygon law of force" states that if a number of coplanar concurrent forces acting on a particle are represented in magnitude and direction by sides of a polygon taken in same order, then their resultant is represented in magnitude and direction by the closing side of the polygon taken in the opposite direction.

APPARATUS: Gravesand's apparatus, paper sheet, weight, thread, pans, set square, pencil, drawing pin etc. .

PROCEDURE:

Refer to fig. 2.1

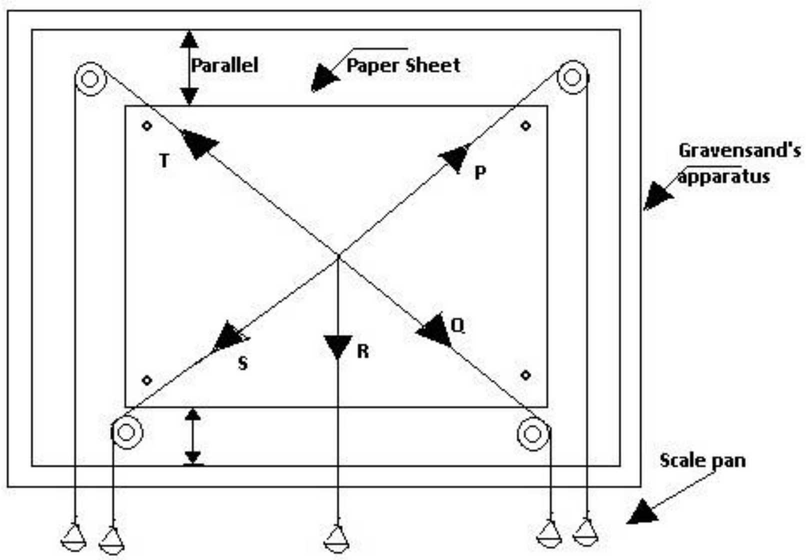


Fig. 2.1

1. Fix the paper sheet with drawing pin on the board set in a vertical plane such that it should be parallel to the edge of board.
2. Pass a thread over two pulleys. Take a second thread and tie the middle of this thread to the middle of first thread. Pass the ends of the second thread over the other set of two pulleys.
3. C.Take a third thread and tie its one end to the point of first two threads.

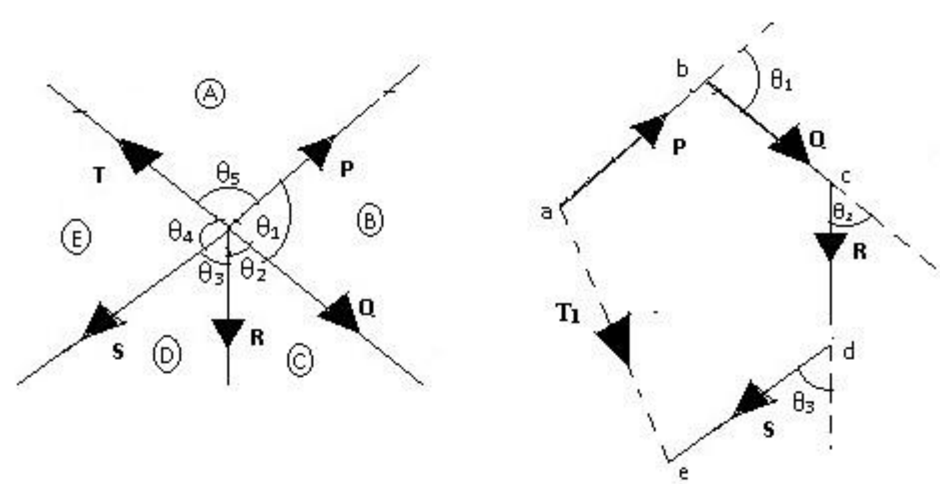
4. Attach pans to the free ends of the threads as shown in Fig. 2.1.
5. Add weights in the pan in such a manner that the knot comes approximately in the centre.
6. Mark lines of forces represented by thread without disturbing the system and write the magnitude of forces i.e. **Pan Weight + Added Weight**.
7. Remove the paper from the board and produce the line to meet at O.
8. Select a suitable scale and draw the vector diagram (Fig. 2.2) by moving in one direction (i.e. clockwise or counter clockwise). Draw ab parallel to AB and cut it equal to force P; draw bc parallel to BC and cut it equal to Q; Draw cd parallel to CD and cut it equal to force R; draw de parallel to DE and cut it equal to S. Vector ae will be the resultant force T_1 taken in opposite direction and should be equal to force T which proves the law of polygon forces. If ae is not equal to T then percentage error is found as follows:

$$\text{Percentage error} = \frac{T - T1}{T} * 100$$

1.1POLYGON LAW OF FORCES

Graphical Method

Fig. 2.2(b), draw *ab* parallel to force P in suitable scale with the use of set square and then from *b* draw *bc*parallel to force Q. From c draw cd parallel to R and then draw de parallel to S. The closing side of polygon represents the force T_1 which should be equal to force T. Note, the difference between T_1 and T shows the graphical error.



(a)Space diagram (b) Vector diagram

Fig. 2.2

Analytical Method

Draw a horizontal and vertical line at the point of concurrency of all the forces in Fig.2.2 (a) with the help of set square. Resolve each force in x and y axis,

$\Sigma F_x=0;$ $P_x+Q_x+R_x+S_x+T_x=0$

$T_x= -(P_x+Q_x+R_x+S_x)$

$\Sigma Fy=0;$ $Py+Qy+Ry+Sy+Ty=0$

$T_y= -(P_y+Q_y+R_y+S_y)$

$$T_2= \sqrt{(T_x^2+ T_y^2)}$$

Note that T is resultant from the experiment, T_1 is the resultant found from graphical method and T_2 is the resultant found from analytical method.

The difference between T_2 and T shows the experimental error.

OBSERVATIONS

Scale ……….N: …….mm

Law		Force (Pan Weight + Added Weight)				Calculated Resultant	%age error
	P	Q	R	S	T		
Polygon Law							$\frac{T-T1}{T}*100$ Graphical Analytical $\frac{T-T2}{T}*100$

PRECAUTIONS

A. Pans/weights should not touch the vertical board

B. There should be only one central knot on the thread which should be small

C. While calculating the total force in each case the weight of the pan should be added to the weight put into the pan

D. Make sure that all the pans are at rest when the lines of action of forces are marked

E. All the pulleys should be free from friction

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EXPERIMENT NO.: 03

VERIFICATION OF PRINCIPLE OF MOMENT USING BELL CRANK LEVER APPARATUS

AIM: To verify the law of moment by using bell crank lever.

THEORY: The bell crank lever is an apparatus used to verify the law of moments. The bell crank is used to convert the direction of reciprocating movement. A bell crank is a type of crank that changes motion around a 90 degree angle. The name comes from its first use, changing the vertical pull on a rope to a horizontal pull on the striker of a bell, used for calling servants in upper class British households. The fixed point of the lever about which it moves is known as the fulcrum.

The bell crank consists of an "L" shaped crank pivoted where the two arms of the L meet. Moving rods (or ropes) are attached to the ends of the L arms. When one is pulled, the L rotates around the pivot point, pulling on the other arm.

Changing the length of the arms changes the mechanical advantage of the system. Many applications do not change the direction of motion, but instead to amplify a force "in line", which a bell cranks, can do in a limited space. There is a tradeoff between range of motion, linearity of motion, and size. The greater the angle traversed by the crank, the more non-linear the motion becomes (the more the motion ratio changes).

According to law of moments “the moment of a force about an axis is equal to the sum of moment of its component about the same axis.”

$$\Sigma M = \Sigma (\vec{r}\ \vec{F})$$

APPARATUS: Bell Crank Lever apparatus, slotted weight, spirit meter, spring balance and pointer

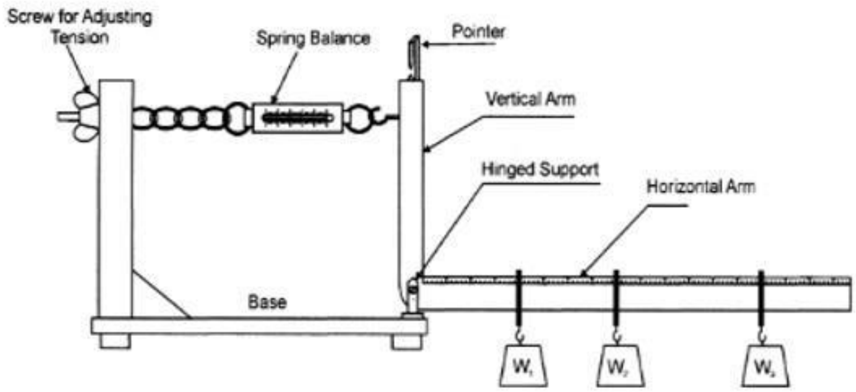

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Fig. 3.1 Bell Crank Lever Apparatus

PROCEDURE:

1. Make the longer arm of the lever horizontal by adjusting with wing nut provided at the end of spring balance longer screw, by using a spirit meter when there is no load on longer arm.
2. Adjust the initial spring balance reading as zero.
3. Hang a small weight (W) on the hook fixed in the lever. This will make the longer arm move downward and the spring balance will show some reading on balance
4. Note the final spring balance reading.
5. Change the position of load and repeat the steps B to D for different loads and calculate the moments.
6. Take at least six readings.

ANALYTICAL CALCULATION

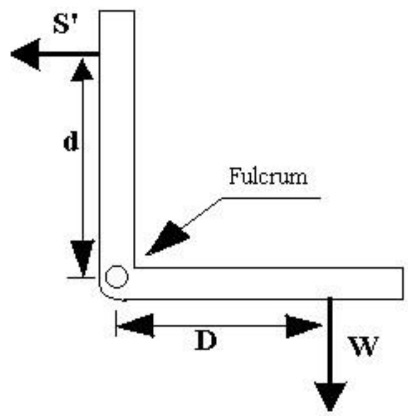

Fig. 3.2 Free Body Diagram of Apparatus

Free body diagram of bell crank lever apparatus is shown in Fig. 3.2. Here,

W - Force applied on lever

D - Varying distance on lever

S' -Theoretical spring force

S -Experimental spring force

d - Fixed distance, measure from the fulcrum of equipment

As the system is in equilibrium,

$$\Sigma M_o = 0$$

$$W*D - S'*d = 0$$

OBSERVATIONS

S No	Weight W N	Distance (D) mm	Moment (W×D) N-m	Observed Spring force (S) N	Calculated Spring force (S')= W*D/d N	%Error= $\frac{(S'-S)}{S'}*100$
1.						
2.						
3.						
4.						
5.						
6.						

RESULT

From the values obtained above, it's clear that the observed and calculated values of spring force are nearly equal and within the permissible experimental error limits.

Hence the Law of Moments stating that "the moment of a force about an axis is equal to the sum of moment of its component about the same axis" has been verified.

PRECAUTIONS

1. There should minimal disturbance as long as the pointer is concerned.
2. Only one person must take all the readings, because eye-judgment for matching the pointer with the mark on the lever will vary from individual to individual.
3. Weights should not touch the table.
4. Add weights in the hanger gently.
5. The pointer should exactly coincide with the mark on the bell crank lever.
6. The optimum starching of spring should be kept in mind.
7. The apparatus should be kept on smooth and leveled surface.
8. Proper lubrication of the joints of two arms of the lever should be done so as to reduce frictional force.
9. Zero error of spring should be properly noted.

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EXPERIMENT NO.: 04

VERIFICATION OF SUPPORT REACTION OF A SIMPLY SUPPORTED BEAM

AIM: To verify the support reactions of a simply supported beam

THEORY: This experiment is based on 'Principle of moments' which states that if a body is in equilibrium under the action of a number of coplanar forces then the algebraic sum of all the forces and their moments about any point in their plane are zero.
Mathematically: The body will be in equilibrium, if
$\sum H = 0$ i.e. the algebraic sum of all horizontal forces is zero.
$\sum V = 0$ i.e. the algebraic sum of all Vertical forces is zero.
$\sum M = 0$ i.e. the algebraic sum of all moments about a point is zero.

APPARATUS: A Graduated wooden beam, two weighing machines, weights.

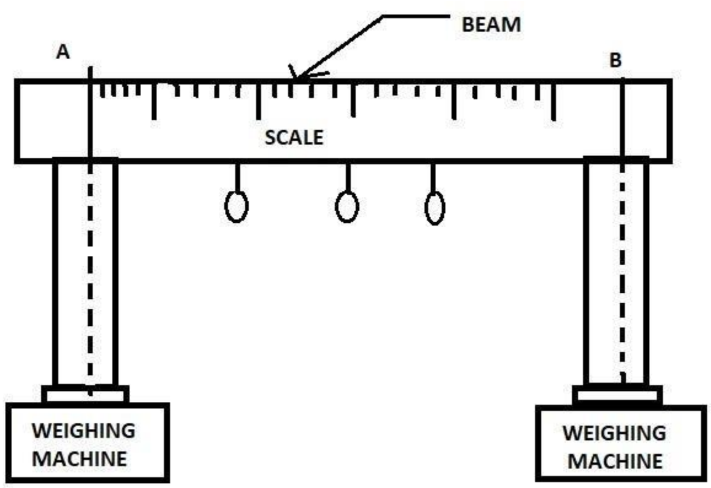

Fig. 4.1 Experimental setup for simply supported beam

PROCEDURE:

1. Place the graduated beam on the weighing machine.
2. Ensure that initial reading of weighing machine is zero, if not make it equal to zero by pressing tare button.
3. Now suspend the weights at different points on the beam

4. Note down the readings of the weighing machine which represent the observed values of support reactions at A and B.
5. Measure the distance of each weight from one support.
6. Then apply the equations of equilibrium (∑H =0, ∑V =0, ∑M =0) to calculate the support reaction at both the ends.
7. If there is any difference between observed and calculated reactions then calculate the percentage error.

OBSERVATIONS

S No	Readings from the weighing Machine (N)		Weights Suspended (N)			Distances of loads from support 'A'(m)			Sum of Moments	Calculated reactions		% error	
	RA	R_B	W1	W2	W3	L1	L2	L3	W1L1+ W2L2 + W3L 3	R_A'	R_B'	A	B

ANALYTICAL CALCULATIONS

Free body diagram of the setup is shown in Fig. 4.2

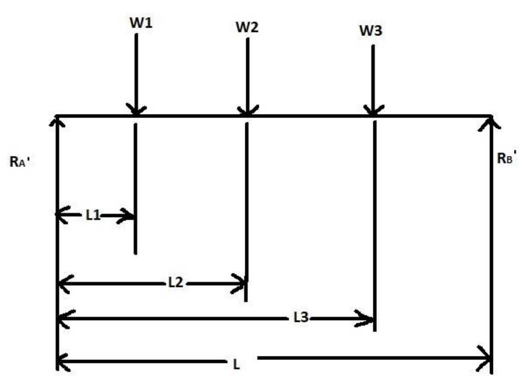

Fig. 4.2 Free body diagram

From the equation of Equilibrium , ∑V =0 i.e. the algebraic sum of all Vertical forces is zero.

∑V =0 R_A '+R_B' = $W_1 + W_2 + W_3$

$\sum M_A = 0$ R_B '* L = W_1* L_1+ W_2*L_2 + W_3*L_3

R_B' = Calculated reaction force at
BR_A '= Calculated reaction force at
AR_B = Observed reaction force at B
R_A = Observed reaction force at A

Percentage error at point A

$$= \frac{R_A - R'_A}{R_A} \; X \; 100$$

Percentage error at point B

$$= \frac{R_B - R'_B}{R_B} \; X \; 100$$

RESULT

Reactions at the supports of simply supported beam are verified successfully.

PRECAUTIONS

1. Measure the Distance accurately.
2. Beam should be kept at the centre of weighing pan.
3. The Weights Should suspended gently at hooks.
4. The readings should be taken carefully.
5. Before noting down the final readings, the beam should be slightly pressed downwards so as to avoid any friction at the support.

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EXPERIMENT NO.: 05

TO DETERMINE THE MOMENT OF INERTIA OF A FLYWHEEL ABOUT ITS OWN AXIS OF ROTATION

AIM: To determine moment intertia of flywheel

THEORY:

When a flywheel accelerates, it produces a torque. The general formula for this is given as: T= Iα,

Where T is torque, I is moment of inertia and alpha is angular acceleration.

Moment of inertia is the sum of product of masses and squared of perpendicular distances to axis of rotation.

$I = mk^2$

$I = m_1k_1^2 + m_2k_2^2 + m_3k_3^2$

K = radius of gyration

$K = r/\sqrt{2}$

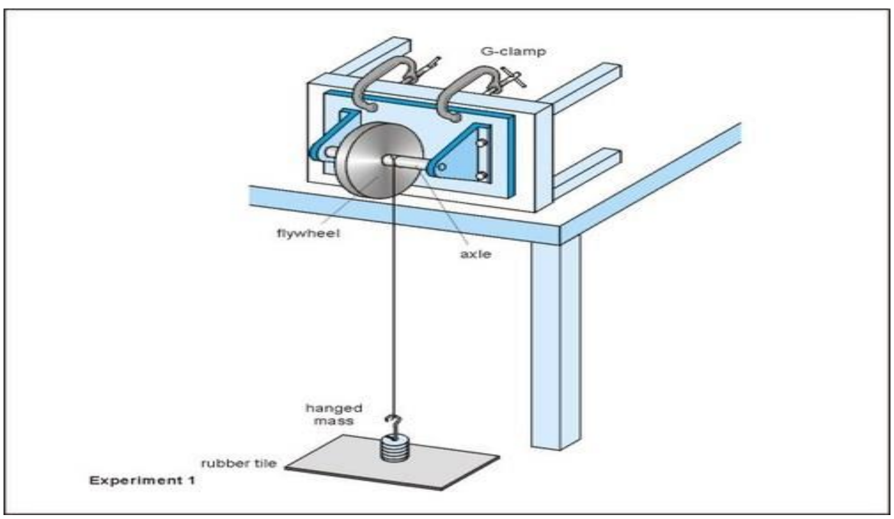

Fig 5.1

Assumption:

- Mass of string assumed to be negligible.
- Acceleration masses are assumed to have accurate mass.

- Mass of hook assumed to be negligible.
- Length of meter rod assumed to be accurate.
- It is assumed that there are no human errors.
- It is assumed that there is no air friction

APPARATUS: Mass, Stop Watch, Measuring tape

PROCEDURE:

1. The length of the cord is carefully adjusted, so that when the weight-hanger just touches the ground, the loop slips off the peg.
2. A suitable weight is placed in the weight hanger
3. A chalk mark is made on the rim so that it is against the pointer when the weight hanger just touches the ground.
4. The other end of the cord is loosely looped around the peg keeping the weight hanger just touching the ground.
5. The flywheel is given a suitable number (n) of rotation so that the cord is wound round the axle without overlapping.
6. The height (h) of the weight hanger from the ground is measured.
7. The flywheel is released.
8. The weight hanger descends and the flywheel rotates.
9. The cord slips off from the peg when the weight hanger just touches the ground. By this time the flywheel would have made n rotations.
10. A stop clock is started just when the weight hanger touches the ground.
11. The time taken by the flywheel to come to a stop is determined as t seconds.
12. The number of rotations (N) made by the flywheel during this interval is counted.
13. The experiment is repeated by changing the value of n and m.

PRECAUTIONS

1. There should be least friction in flywheel.
2. The length of string should be less than the height of axle from floor.
3. There should be no kink in string.
4. The string should be thin and should be wound evenly.
5. The stop watch should be started just after detaching the loaded string.

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EXPERIMENT NO.: 06

TO FIND THE MECHANICAL ADVANTAGE VELOCITY RATIO AND EFFICIENCY OF COMPOUND SCREW JACK

AIM: To find the Mechanical Advantage, Velocity Ratio and Efficiency of Simple Screw-Jack.

THEORY:

Screw Jack

1. It is a device used for lifting heavy loads which are usually centrally loaded by applying smaller effort.

2. It works on the principle of inclined plane. The device consists of a nut and screw. The load is carried by screw head. The body consisting of a nut is fixed and screw is rotated by means of a lever.
3. The axial distance moved by the screw when it makes one complete revolution is known as the Lead of the screw. The distance between two consecutive threads is called Pitch of the screw.
4. For single threaded screw Lead = Pitch, and for double threaded screw L = 2p

Mechanical Advantage

It is the ratio of weight lifted to effort applied. M.A. = W/ P

Velocity Ratio

It is the ratio of distance moved by the effort (y) to the distance moved by the load (x). V.R. = y/ x In one complete revolution of the lever by effort P:

Distance traveled by effort = 2 π R

And, distance traveled by the load = p

Therefore, Velocity Ratio = 2 π R / p Mechanical efficiency =M.A/V.R

i) **Parts of machine:** Simple screw jack fitted with nut

ii) **Working of machine:** Screw jack fitted with a nut works on the principle similar to as that of an inclined plane. If screw is rotated by application of an effort applied at one end of pulley, load kept on load table will be lifted.

iii) Take care, whether the string is properly wound on the circular disc or not.
iv) Different loads are applied and corresponding efforts are recorded.
v) To keep the friction constant, readings are taken at particular point.
vi) Calculation for V.R. and efficiency is done.

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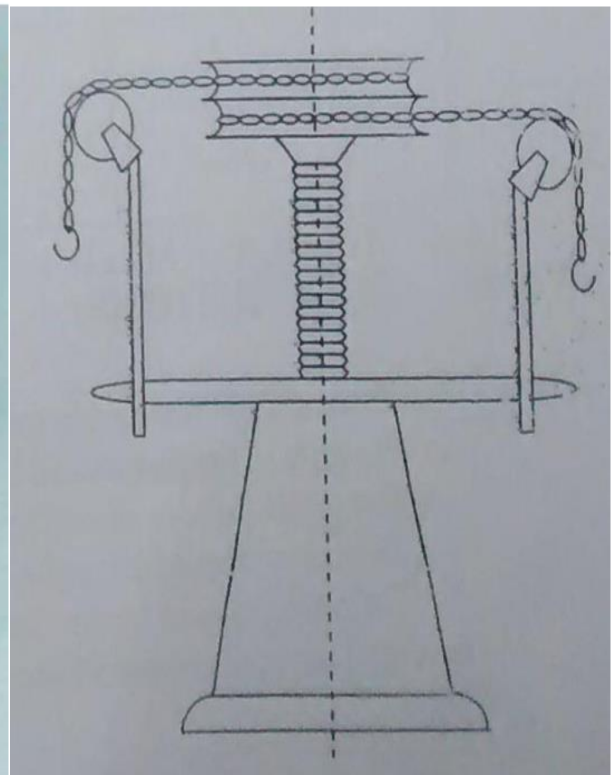
APPARATUS: Simple screw jack, Load to be lifted (W), Weights or Effort to be applied (P), Vernier caliper, Pan, Weight box.

PROCEDURE:

1. Note down the pitch ‘p’ of the screw.
2. Measure the circumference of the flanged table with an inextensible thread and meter scale or measure the diameter of flanged table with the help of outside caliper.
3. Wrap the string around the circumference of the flanged table and pass it over one pulley.

Similarly, wrap another string over the circumference of flanged table and take it over the second pulley. The free ends of both the strings be tied to two pans/hanger in which the weights are placed/hanged.

4. Place a load 'W' on the top of the flanged table and start adding weights on to the pans gradually till the load starts lifting. P1 and P2 are the weights (effort) in the pans.
5. Calculate M.A, V.R and % Efficiency.
6. Repeat the above procedure by increasing the load on flanged table and note down the corresponding efforts applied.

OBSERVATIONS:

Let, Load Lifted = W

Effort Applied = P

Effort Wheel Diameter (D) =

Diameter of the rope (d) =

Pitch of the screw (p) =

No. of teeth on the gear (N) =

Weight of the Pan (w) =

SR.NO	W(kg)	P(kg)	M.A=W/P	V.R=2ΠR/p	%ή=M.A/V.R*100

RESULT:

i. V.R. of machine = ii. Efficiency of machine
= M.A./V.R.

Conclusion:

i. Efficiency of machine is less than 50%, the machine is irreversible.

ii. VR of machine remains constant.

iii. Efficiency of machine increases with load in the beginning and then remains constant.

iv. The graph line indicates a linear motion.

v. As load on machine increases, the effort required to lift also increases

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EXPERIMENT NO.: 07

TO FIND THE MECHANICAL ADVANTAGE VELOCITY RATIO AND EFFICIENCY OF SIMPLE SCREW JACK

AIM: To study simple screw jack and find its V.R. and its various performances.

THEORY: A screw jack is used to lift and support heavy loads. Jacks used for lifting trucks or cars for repairs are screw jack. To lift such heavy loads, comparatively very small effort is applied at the end of the handle.

Screw jack consists of a screw & a drum is mounted at its head. Load is kept on the drum therefore it is called as Load drum. Load drum is rotated with the help of the thread passing over the pulley and having effort applied at its end.

When screw jack completes on the rotation load drum will also complete one rotation. Distance moved by effort is equals to the circumference of the load drum at the same time load is lifted by distance equals to the pitch of the screw.

APPARATUS: Simple screw jack, thread, pan, weights etc

$$\text{Therefore velocity ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

$$= \frac{\text{Circumference of load drum}}{\text{Pitch of the screw}} = \frac{C_W}{P}$$

PROCEDURE:

1. Observe the machine – Screw Jack.‘ Identify the various components Such as screw, load drum and pulley.

2. Measure the pitch of the screw and circumference of load drum.

3. Find the velocity ratio.

4. Set up the machine and attach heavy load drum.

5. Find corresponding effort (P) by gradually increasing the value so that when effort

(P) moves down, load (W) just starts moving up. Label the motions in the diagram.

6. Repeat the procedure for different heavy load W.

7. Draw the graph by taking load values on x-axis and effort values on Y-axis with suitable scale. Note the co-linear relationship between efforts and load W.

8. Find slope (m) and intercept (C) on y-axis for the straight line, and write relation (in the form of P= (mW+C). Note this equation is called as Law of machine.

9. Calculate mechanical advantage & subsequently efficiency for each set of load (W) & corresponding effort (P) by relation MA= load (W) / Effort (P) & efficiency (%η) = MA/V.R. x 100. Tabulate the same in observation table.

10. Calculate ideal effort (Pi) for each of load (W) by a relation Pi = W / V.R. & tabulate it. Note that effort (P) in actual machine is greater than ideal effort (Pi) requiredinidealmachine.Plotthegraphofidealeffort-P_i(Ony-axis)&Load
– W (On x-axis).

11. Note linear relationship between them.

12. Calculate effort lost in friction (P_f) _for each of the load (W) by relation P_f = P – W / V.R. & tabulate the same.

13. Plot the graph of _Effort lost in friction _P_f(on y-axis) against Load (W) on X-axis. Note the linear relationship between Pf &W.

14. Draw an interference from the graph plotted.

15. Draw the graph taking load on x-axis and mechanical advantage & efficiency on y-axis.

16. Calculate load loss in friction by the formula W_f= P x V.R. –W.

17. Find the maximum mechanical advantage & maximum efficiency for the machine.

OBSERVATIONS:

1. Diameter of load table:D
2. Pitch of Screw:p
3. Circumference of load table:πD

4. Velocity Ratio: Sp/Sw =πD/p

5. Efficiency(%)= $\frac{\text{M.A.}}{\text{V.R.}} \times 100$

6. Law of machine =mW+C

Sr. No.	Load (W) Newton	Effort (Pa) Newton	M.A. = W/Pa	η%= M.A./V.R. * 100	Pi = W/V.R.	Pf = Pa-Pi
01						
02						
03						
04						
05						

RESULT:

i. V.R. of machine: =Sp/Sw
   Sp = Circumference of load table =πD= ______________________________Sw = Pitch of screw =p=___________________________
   Therefore V.R. = Sp/Sw =πD/p=______________
ii. Efficiency of machine = M.A./V.R.=___________
iii. Percentage of efficiency=(M.A./V.R.)*100=___________
iv. As the efficiency of machine is less than 50%, it is irreversible.
v. Law of machine, Pa = mW+C

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