CENCO Physics

Selective Experiments In Physics

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STATIC EQUILIBRIUM OF A RIGID BODY

OBJECT: To study the conditions of static equilibrium of a rigid body under the action of forces all of which lie in a common plane.

METHOD: A metal disk, supported on three steel spheres, is free to move in any direction in a horizontal plane. Known horizontal forces are applied at various points of the disk and their directions and points of application are recorded on a sheet of paper lying on the disk. These data are treated graphically to verify the conditions of static equilibrium.

THEORY: A body is said to be in equilibrium when (1) its linear acceleration and (2) its angular acceleration are zero. If in addition both its linear velocity and its angular velocity are zero, it is said to be in static equilibrium.

1. If several forces, in a plane, are applied at a *single point* in a body, and if the *vector sum of these forces* is zero, there is no linear acceleration and the body is in equilibrium. In other words, when the resultant of these forces is zero, the linear acceleration is zero and equilibrium obtains. By direct implication, if the sum of the components of the forces taken in two mutually perpendicular directions are each equal to zero, the body is in equilibrium.

2. If the coplanar forces are applied at *different points* on the body, the above criterion is a necessary but not a sufficient condition for equilibrium. Although linear acceleration of the body will not occur if the vector sum of the forces is zero, the body may, nevertheless, have angular acceleration in the plane of the forces.

The effectiveness in producing rotation about an axis depends upon two factors: the magnitude of the force and the perpendicular distance from the axis to the line of action of the force. This distance is called the *arm* of the force, or *moment arm*. The product of these two factors, *force* and *arm*, is called the torque or moment of the force about the axis.

When the sum of the applied moments of force about any axis or center is equal to zero, there can be no angular acceleration of the body. Consequently, there is rotational equilibrium. In this summation the direction in which each applied force tends to rotate the body about the chosen axis must be taken into account. For convenience consider those moments which tend to produce counter-clockwise rotation as positive and those which tend to produce clockwise rotation as negative. The point where the axis cuts the plane of the forces is often called the *center of moments*.

If the body is not accelerated about one axis perpendicular to the plane of the forces, it will not exhibit acceleration about any axis perpendicular to that plane. In the experimental procedure to follow, the tests for equilibrium will be made when linear and angular velocities of the body are initially zero. Consequently the test for equilibrium will consist of determining whether the applied forces and moments produce motion of the body. This is a test for static equilibrium.

Fig. 1. The Moments Apparatus attached to the Force Table.

APPARATUS: The apparatus (Fig. 1) consists of a force table, on the top of which two circular metal disks are placed. The two disks are separated by three steel spheres. A removable peg in the center of the lower disk protrudes upward through an enlarged hole in the upper disk. Thus the latter is free to move in any horizontal direction until constrained from further motion by the peg. Cords, attached to pegs at various points on the top disk, pass over the pulleys clamped at different points about the circular force table. Known masses suspended from the ends of the cords produce the forces required. Adapters for the pulleys bring the cords which pass over the pulleys into a horizontal plane above the disk. The table is provided with leveling screws.

PROCEDURE:

***Experimenta**l*: Center the plain disk on the top of the force table. Place the three steel balls on the disk at points widely separated. The balls may be kept from rolling by a drop of oil or a touch of vaseline. After carefully placing the disk containing the holes on the steel balls, level the table so that the disk will not tend to move in anyone direction in preference to another. Place a piece of plain paper upon the disk and insert the center pin. Attach cords to the disk at three different points chosen at random. Place the pulleys at convenient points and add masses until two of the forces have values of several hundred grams weight. Adjust the third force, both as to magnitude and direction, until no motion results on removing the peg. Be sure that the disk is free to move on the steel balls and that the cords all lie in a plane parallel to the top of the disk.

Draw lines on the paper to indicate the lines of action of the

forces and indicate with arrowheads their direction. Record with each line its corresponding force, which should include the weight of the hanger.
Place another sheet of paper on the disk and repeat the experiment using four forces, no two of which act along the same line.

Interpretation of Data: Smooth out the record sheet for the three-force problem and paste apiece of paper over the hole made by the centering peg. Construct a vector diagram of the forces, using as large a scale Unit as possible. Is the vector diagram a closed triangle? If not, measure the distance from the end of the line representing the third force to the beginning of the line representing the first force. With the aid of the scale unit, determine the force which this represents. This is the magnitude of the experimental error.
Construct a similar vector diagram for the four-force problem on the second sheet. In case the vector diagram does not form a closed figure, the length of line required to close the figure represents the magnitude of the experimental error.

Select any point not on the line of action of any of the forces and from it draw perpendiculars to the lines of action of the four forces. Measure these perpendiculars and calculate the moments of the forces about this point. Find the algebraic sum of the moments.
Repeat the calculations for two other widely separated points taken in turn as centers of moments,

QUESTIONS: 1. Show that if an extended body is in equilibrium under the action of three forces they must meet at a point.

2. If one of the four forces in the experiment were moved parallel to itself, would the vector sum still be zero? Would the sum of the moments about a given point be changed?

3. If with three forces the disk were held motionless while one of the forces is moved parallel to itself by moving peg and pulley, would this change the vector sum of she forces? What sort of motion would take place (a) when the disk is released, (b) the pin remaining in place?

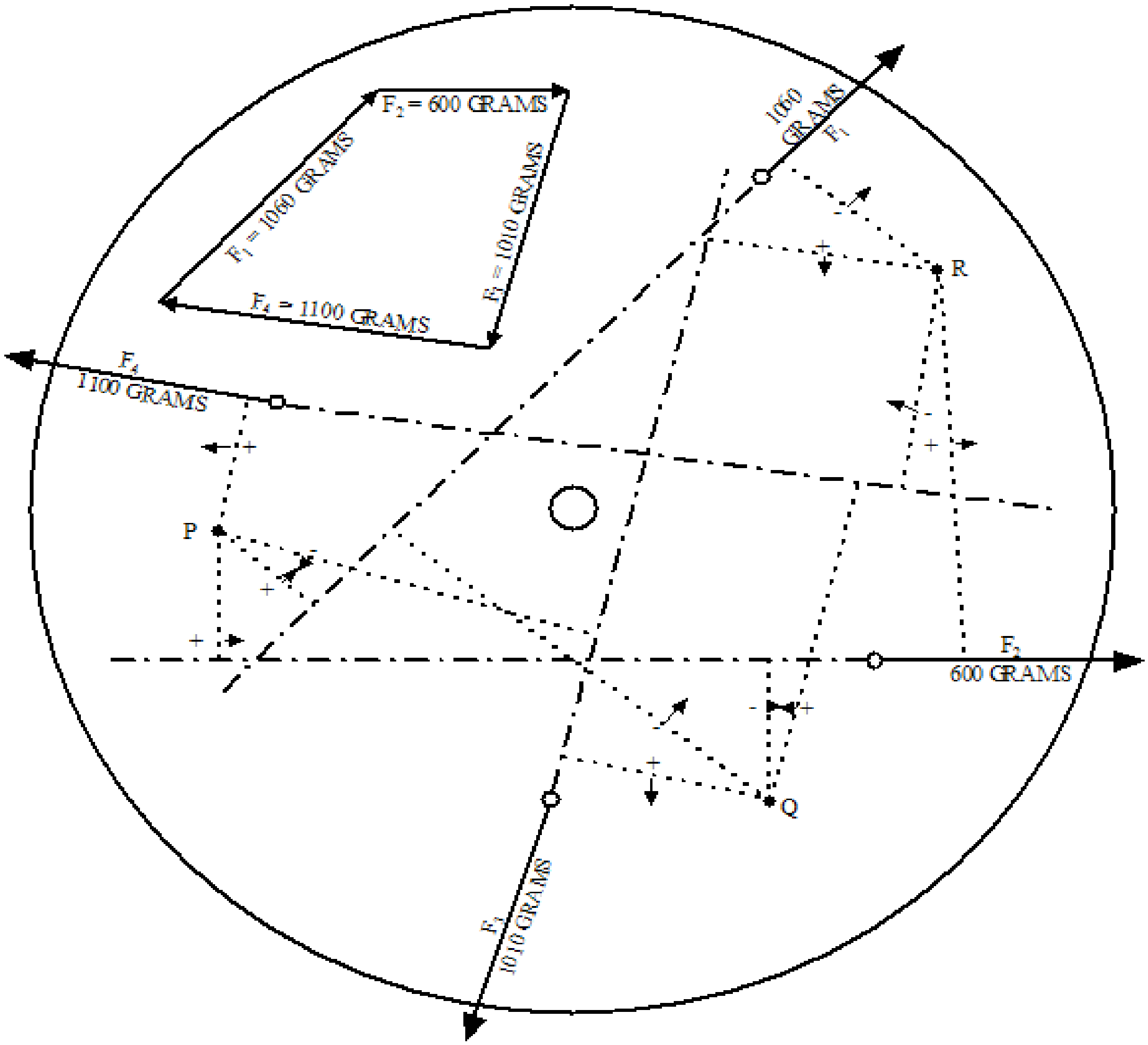

Fig. 2. Showing the method of finding the arms of the forces F_1, F_2, F_3, F_4, with reference to the points P, Q, R, taken in turn as centers of moments. Also the vector polygon of the forces.