NORTHERN ILLINOIS UNIVERSITY

PHYSICS DEPARTMENT

Physics 210 – Mechanics & Heat Spring 2022

Lab #7

Lab Writeup Due: Tue/Wed/Fri, March 22/23/25, 2022
Read OpenStax: Chapter 6.1,6.2,6.3, Lecture Notes #5

Centripetal Force

Apparatus

This experiment uses a vertical shaft that can freely rotate to spin a massive bob of mass m. The bob hangs by two strings from a horizontal bar with a counterweight on the other side. The counterweight helps the shaft rotate evenly. A spring connects the bob to the shaft and provides a force to pull the hanging mass toward the shaft.

A vertical indicator is used to line up the bob. When the spring is not connected to the bob, the bob should hang directly over the indicator. A string can be connected from the bob over a pulley at the end of the apparatus to a hanging weight. The weight is used to measure the spring force when the shaft is not rotating.

When the weight is disconnected from the bob, the shaft can be spun by hand. As the shaft spins, the mass will swing away from the shaft held back by the spring. With enough rotational speed, the mass will line up directly over a vertical post. A clock is used to measure the number of revolutions, n, in a time, T, for the spinning bob.

Theory

Force, acceleration and velocity are all vectors. This means that they have both a magnitude and a direction. Acceleration occurs when velocity changes in magnitude or direction over time. Because velocity is a vector, even if the speed is constant the velocity can still change due to a change in direction. A car accelerates as it goes around a curve even though its speed is not changing.

Uniform circular motion occurs when an object moves in a circular path at a constant speed v_t. The speed of the object moving in a circle can be determined by the angular speed ω times the radius, r, of the circle. The angular speed is the number of rotations n an object makes times 2π radians divided by the time T it takes to make the n revolutions. Thus,

$$v_t = \omega r = \frac{2\pi n r}{T} \tag{1}$$

For uniform circular motion the acceleration is always pointed towards the center of the circle. This acceleration is called centripetal acceleration. The magnitude of the centripetal acceleration a_c is v_t^2 / r or using Eq. (1) for the speed v_t:

$$a_c = \frac{v_t^2}{r} = \frac{4\pi^2 n^2 r}{T^2} \qquad (2)$$

A net force on an object gives rise to an acceleration of that object. The acceleration is in the same direction as the force and has a magnitude equal to the net force divided by the mass of the object. Since an object in uniform circular motion has an inward pointing acceleration, it must also have an inward pointing force (called a centripetal force). That inward pointing force comes from the stretched spring exerting a spring force tending to pull the spring back together:

$$F_s = ma_c = \frac{4\pi^2 m n^2 r}{T^2} \qquad (3)$$

The force exerted by the spring is balanced by an equal and opposite gravitational force from the mass M hanging from the pulley. The inward-directed force of the spring is then

$$F_s = W = Mg \qquad (4)$$

Data Collection

(1) Measure the mass, m, of the bob, and the diameter, d, of the vertical shaft and write down these values in your lab notebook.

(2) Slide the indicator bar to the closest position and measure the distance from the shaft to the indicator and add half the diameter $d/2$. This total is the radius, r, of its circular path.

(3) With the spring disconnected from the weight, adjust the knob on the top of the horizontal bar so that the bob hangs directly over the indicator. Reattach the spring and tighten all screws.

(4) Attach the string to the pulley and hanging mass.

(5) Add weight to the hanging mass until the bob is directly over the indicator. Record the total hanging mass M in your lab notebook.

(6) Practice rotating the vertical shaft pulling so that the bob moves to consistently pass over the indicator. Hold a white sheet of paper behind the indicator to see the bob and indicator tips more easily.

(7) When you feel that you can do this, measure the time T it takes for the bob to make 50 revolutions ($n = 50$) using the photogate detector (fix the position of the photogate so that it is over the knob at the top of the horizontal revolving bar). Notice that the photogate detector *double counts*. That is, it measures both when the bob enters the photogate detector and (a very short time later) when the bob leaves the detector. Thus, to get the proper number of revolutions, divide the number of measurements the computer makes by a factor of 2 to get n .

Repeat this 5 more times and record the results. Find the average value of the 6 values for T and record this calculation in your lab notebook.

(8) Slide the indicator bar to the middle position. Measure the radius r as in step 2.

(9) Repeat steps 3 through 7 for the new position finding M and T .

Data Analysis

(1) Use Eq. (3) to find the spring force (which is equal to the centripetal force) F_s in Newtons.

(2) Use Eq. (4) and M from step 5 to find the gravitational force W in Newtons.

(3) Compare your calculated and measured spring forces by computing the *percent error*:

$$\%Error = \left| \frac{Measured - Calculated}{Calculated} \right| \times 100$$

where $Calculated = F_s$ and $Measured = W$. Discuss your results using your knowledge of what a good or poor *percent error* values is).

(4) Repeat these comparisons for the other value of r . Does the calculated centripetal force agree with the measured spring force (which is the weight W)? Where do the discrepancies come from (that is, what are the possible sources of error)?