Experiment

Uniform Circular Motion

A body is suspended by a string from a horizontal crossbar which is spun around a vertical axis. The body is prevented from swinging outward by a horizontal spring attached to the axis of rotation. The centripetal force exerted by the spring on the body is determined. The system is then brought to rest and a static force pulls the body to the position the body occupied in the dynamic case. This force is compared with the centripetal force.

Theory

For circular motion, the centripetal force is given by

\[ F = \frac{m v^2}{R}. \]  
(1)

Where the speed is tangential around the circular path. If the speed is constant, then its value may be determined by using the number of revolutions, \( N \), that occur during a time interval \( T \) ("T" here represents the time for \( N \) revolutions), that is,

\[ v = \frac{2 \pi R N}{T}. \]  
(2)

Substituting (2) into (1), the centripetal force is then

\[ F = 4 \pi^2 m \frac{R N^2}{T^2}. \]  
(3)

Apparatus

- Centripetal force apparatus
- 50 gram weight hanger
- Stop watch, ± 0.02 sec
- Assortment of slotted weights
- Metric ruler, ± 0.05 cm
- String
- Bubble level
- Double pan balance

The apparatus consists of a heavy mass supported by a string tied to a crossbar which is attached to a vertical shaft. The shaft is supported in a metal housing on a wooden base and has bearings that allow the shaft to be rotated easily. The crossbar is counterbalanced. An adjustable vertical rod mounted on the base serves as a radius indicator. A pulley mounted on a rod near one end of the base is used when measuring the static force exerted on the spring by a hanging mass.
In the dynamic situation, the vertical shaft is turned by hand until the pointer on the hanging body passes directly over the radius indicator. (Refer to Figure 2.)

![Centripetal force apparatus in the configuration it has when operated dynamically.](image)

In the static situation, the hanging body is pulled outward by a mass, $M$, attached to the body by a string passing over the pulley. The amount of mass, $M$, is adjusted until the pointer on the hanging body is directly over the radius indicator. (Refer to Figure 3.)
Procedure

1) Position the apparatus so that the pulley overhangs the edge of the table as shown in Figures 2 and 3. Level the apparatus. Record the mass of the hanging body, $m$.

2) Allow the hanging body to hang freely. (If the spring is attached to the body, then remove it.) Adjust the position of the crossbar to some convenient position on the vertical shaft. Make sure that the crossbar is tightened securely to the shaft and that the counterweight is also tightened securely to the crossbar.

3) Adjust the position of the radius indicator until the pointer on the hanging body is directly over the tip of the radius indicator. This position then represents the radius that the hanging body must be at in both the dynamic and the static determination of the forces. Measure the distance and its uncertainty from the tip of the radius indicator horizontally to the center of the vertical shaft. This distance is the radius, $R$.

4) Attach the spring to the vertical shaft and to the hanging body. Begin to rotate the system by turning the vertical shaft with your fingers. Slowly increase the rate of rotation until the pointer on the hanging body passes directly over the tip of the radius indicator. (You should practice this procedure.) Maintain this speed of rotation. A piece of white paper used as a background may make it easier to see the tip of the hanging mass as it passes over the radius indicator.

5) While one student maintains the speed of rotation, a second student determines the time, $T$, for $N$ rotations. A convenient value of $N$ is 50. Repeat this determination a total of at least three times and take an average. Partners should perform different functions from one trial to the next to help eliminate systematic error due to personal bias. Use the maximum and minimum time values to determine $T \pm \delta T$.

This lab for Physics 14 is slightly modified version of Professor Morris' Lab Book for Physics 21: http://homepage.smc.edu/rodriguez_nuria/P21Labs/CircularF02.doc
6) Stop the rotation of the system. Hook one end of a piece of string to the hanging body, pass the string over the pulley, and attach the other end to a weight hanger. (Refer to Figure 3.) Add weight to the weight hanger until the pointer on the hanging body is directly over the tip of the radius indicator. Estimate the range over which the mass can vary while still maintaining the hanging body over the radius indicator. Record the total mass attached to the string, \( M \).

7) Add 100 g to the rotating bob and repeat the experiment. If time allows, repeat with an additional 100g on the rotating bob.

**Analysis**

Calculate the centripetal force in the dynamic case from (3) for each mass trial. Use the average value of \( T \) in the calculations. Use the SI system of units.

Calculate the weight needed to stretch the spring in the static case. This value is

\[
W = Mg,
\]

where \( M \) is the mass stretching the spring. Use the SI system of units.

**Conclusions and Questions**

1) Do the forces derived from the static and dynamic cases agree to the degree of uncertainty predicted by the fractional uncertainty formula? Is there evidence of systematic errors? Can you think of some possible systematic errors that could account for the differences?

2) The ideal equality of \( F \) and \( W \) assumes the mass of the spring to be negligible compared to the mass \( m \). The presence of a *non-negligible* but otherwise unknown spring mass lowers the value of \( F \) in (3). Explain why this is true.

3) Explain why air resistance can be neglected is this experiment.

4) Explain why the additional mass on the bob does not change the value of \( F \) or \( W \).

5) Why is it important that the spring be horizontal? If not, how would it affect the results?

6) How could you determine the spring constant of the spring? Be specific.