PHYS221

Experiment 7 - Centripetal Force

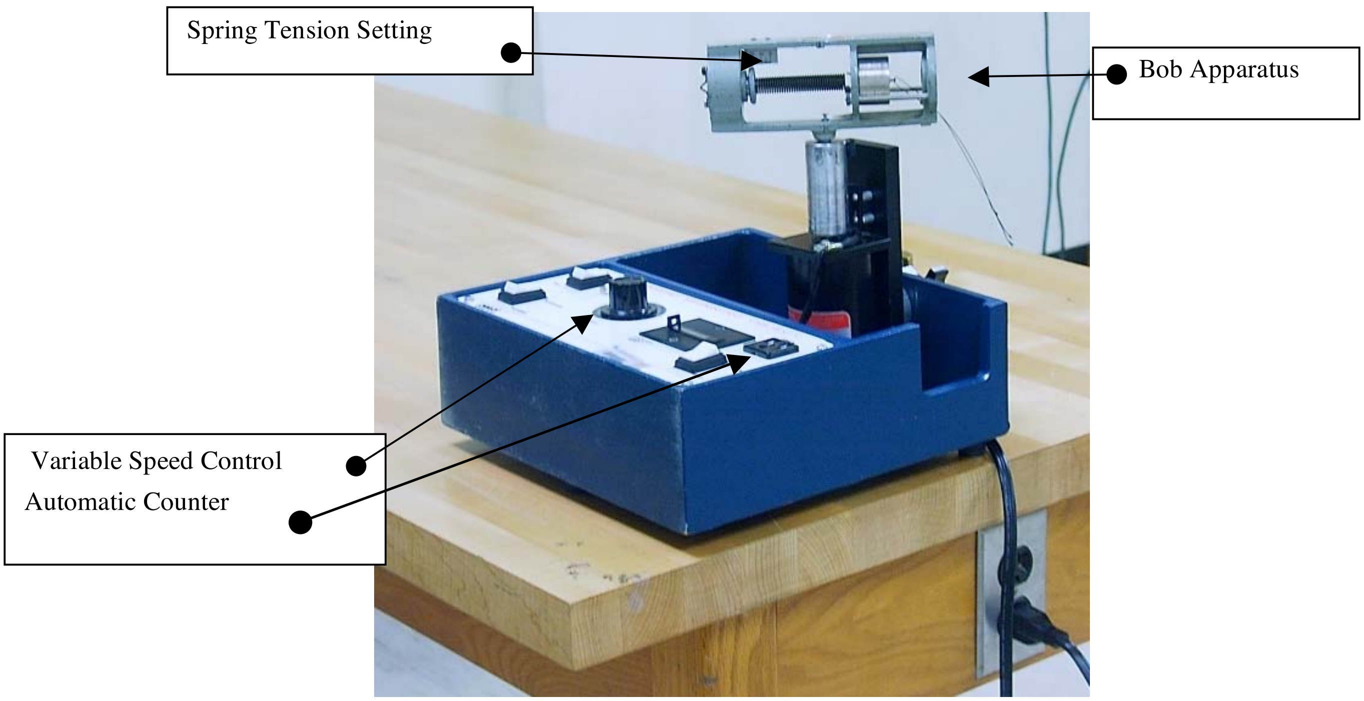

Fig. 7-1 Centripetal Force Apparatus. Note: NO HANGER when upright!

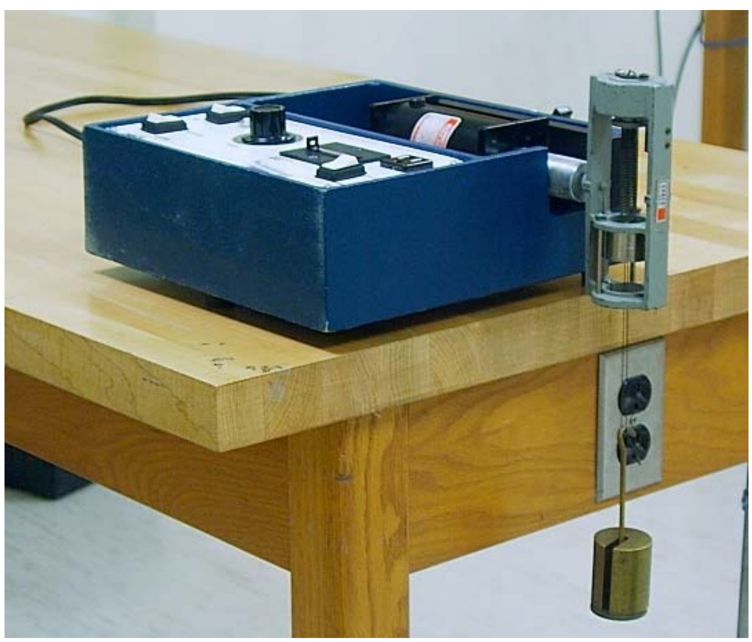

Fig. 7-2 Centripetal Force Apparatus. Note: UNPLUGGED when horizontal!

Equipment

Centripetal Force Apparatus
Hanger & masses

Stopwatch
Vernier Caliper
Goggles

PHYS221

Experiment 7-Centripetal Force

Advanced Reading

Halliday, Resnick and Walker
Chapter 6, Section 6-5

Objective:
The objective of this experiment is to measure the centripetal acceleration of a rotating body and thus determine the centripetal force on the body. This force will then be compared to a statically determined value.

Theory

When an object moves in a circle, it undergoes centripetal ("center seeking") acceleration with magnitude $a_c = v^2/r$, where v is the speed and r is the radius of the circle. Newton's First law states that: *An object at rest will remain at rest and an object in motion will continue in motion with a constant <u>velocity</u> unless it experiences a net external force*. Velocity is a vector quantity which has both magnitude and direction. In this experiment, a mass undergoes *uniform circular motion*. The speed is constant, but the direction is continually changing. Thus, the mass does not have a constant velocity; it is being accelerated as it rotates.

According to Newton's Second Law, F = ma, in order to accelerate an object with mass m a non-zero net force must act upon the mass. For an object moving in a circle, the magnitude of the centripetal force is $F_c = mv^2/r$.

In this experiment the centripetal force required to stretch a spring a certain amount will be dynamically determined and compared to the static force (provided by hanging weights) required to stretch the spring by the same amount (Figs. 7-1 & 7-2).

Procedure

1. The mass undergoing circular motion is referred to as a "bob." Turn the spring setting on the bob cage until it is near the zero position (weakest setting). Zero the counter on the centripetal force apparatus. Switch on the machine and adjust the speed of the

apparatus so that the needle position points to the middle of the indicator located at the axis of rotation (Fig. 7-2).

If the speed of the bob is too great, the bob will rest against the cage, the needle will point above the indicator and the spring will no longer be the sole source of the centripetal force. If the bob is rotating too slowly, the needle will point *below* the middle of the indicator. One method of obtaining an uncertainty in the number of revolutions (i.e., δn) is to run multiple trials and to use the *difference* (between the high value and the low value) *divided by two* in the results as the uncertainty.

2. When the bob is rotating at the critical speed, turn on the counter and count the number of revolutions during a two minute period. Repeat. Estimate both the uncertainty δn in the reading of the number of revolutions and the uncertainty δt of the time.

3. **Unplug the apparatus**. Turn the rotational apparatus so that it hangs off the table (Fig. 7-3). Ask your lab instructor for help if necessary. Attach a weight hanger to the string tied to the bob, and carefully place enough slotted weights on it to cause the needle to point to the middle of the indicator. Calculate the weight Mg hanging from the spring. Use the *total* mass M hanging from the spring (weight hanger, slotted weights and the mass of the bob, which is stamped on the bottom of the bob).

4. By adding or subtracting a small amount of mass from the weight hanger, and observing the deflection of the needle, estimate the uncertainty δM of the total hanging mass. The true value should lie in the interval $M \pm \delta M$.

5. While the hanging mass has displaced the bob to its rotating position, measure the distance from the axis of rotation to the center of mass of the bob (the line scribed into the bob marks its center of mass). *This*

distance is the same as the radius r of the circle made by the bob when it was rotating. Estimate the uncertainty δr of the radius.

6. Using the information in steps 2 and 5, calculate the speed v of the bob. This is given by v = distance/time = $2\pi rn/t$, where r is the radius of the circle and n the number of revolutions, and t is the elapsed time.

7. Calculate the centripetal acceleration $a_c = v^2/r$. Calculate the centripetal force ma_c acting on the bob and compare this value to the weight Mg hanging from the bob in step 3. Calculate the percent difference between the centripetal force and the hanging weight.

8. Repeat steps 1-7 for the spring setting 10 (intermediate setting), and then at 20 (strongest setting). These settings should only be approximate.

Questions/Conclusions

1. How did the two values of force in parts 3 and 7 compare? If these values are not approximately the same, check your calculations. (Did you include all the mass hanging on the bob? Did you mismeasure or misread the vernier caliper when measuring the radius?)

2. In what direction is the bob accelerating when it is rotating at a constant speed? Draw a force diagram for this situation.

3. What are the major sources of uncertainty in this experiment?

4. Show that, in terms of measurable quantities in this experiment, the centripetal force is

$$F = \frac{4\pi^2 mrn^2}{t^2}.$$

The fractional uncertainty of this value is then

$$\frac{\delta F}{F} = \left[4\frac{(\delta n)^2}{n^2} + 4\frac{(\delta t)^2}{t^2} + \frac{(\delta r)^2}{r^2}\right]^{1/2},$$

where it is assumed that the uncertainty of mass is negligible. The fractional uncertainty of the hanging weight is

$$\frac{\delta W}{W} = \frac{\delta M}{M},$$

where M is the total mass. From these expressions, compute δF and δW for each set of values in the experiment. On a single horizontal number line, plot the intervals $F \pm \delta F$ and $W \pm \delta W$ for each set of data. Displace the intervals vertically so that they can be clearly visible. Does F=W within experimental error? That is, do the intervals overlap as the theory predicts?