General Physics I Lab

M3 Centripetal Force

Purpose

In this experiment, you will study the uniform circular motion of a mass and measure the centripetal force resulting from the circular motion.

Equipment and components

PASCO 550 Universal Interface, force sensor, Centripetal Force apparatus (a frame with a mounted electric motor and rotating arm), power supply, electronic balance, a connecting cable with ball bearing swivel, photogate, mass, stand and clamp.

Background

When an object undergoes a uniform motion in a circle of radius R, the speed of the object remains constant but the direction of the velocity vector changes with time. This means that the object is undergoing acceleration and, in accordance with Newton's first law, is being subjected to a non-zero net force. This force is called the *centripetal force* (denoted by $\mathbf{F}_c$) and is directed radially inward toward the center of the circular motion (see Figure 1).

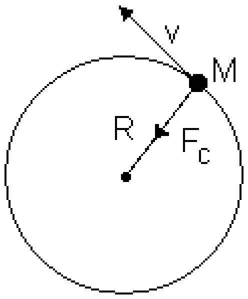

Figure 1 Uniform circular motion of mass M

The amplitude of the centripetal force is given by

$$F_c = M\omega^2 R\,, \tag{1}$$

where M is the mass of the circulating object and ω is its angular velocity. It should be noted that the centripetal force results in an object undergoing circular motion; however, the force itself is not $M\omega^2R$. This term corresponds to the *Ma* side of Newton's second law, $F = Ma$. For example, the centripetal force of an object attached to a rope and undergoing uniform circular motion in a horizontal plane is the tension in the rope.

Procedure

Initial setup

1. Mount the Centripetal Force apparatus to the rod of the stand, as shown in Fig. 2.
2. Connect a power supply to the electric motor on the Centripetal Force apparatus.
3. Use a thumbscrew to mount a photogate to the bottom base of the Centripetal Force apparatus. The photogate is used to measure the angular velocity, ω, of the mass on the rotating arm ($\omega = 2\pi/T$ (in rad./s), where T is the time between the blockings of the photogate].
4. Slide the Force Sensor through the stainless steel rod and position it right above the center of the rotating arm. Adjust the top screw to anchor the Force Sensor to the rod. The Force Sensor is used to measure the tension in the cable, which is attached to the rotating mass.

5. Attach the ball bearing swivel to the bottom of the Force Sensor.
6. Connect the *PASCO 550 Universal Interface* to the computer. Turn on the interface and the computer.
7. Connect the stereo phone plug of the photogate to Digital Channel 1 and the DIN-5 plug of the Force Sensor to Analog Channel A of the interface.

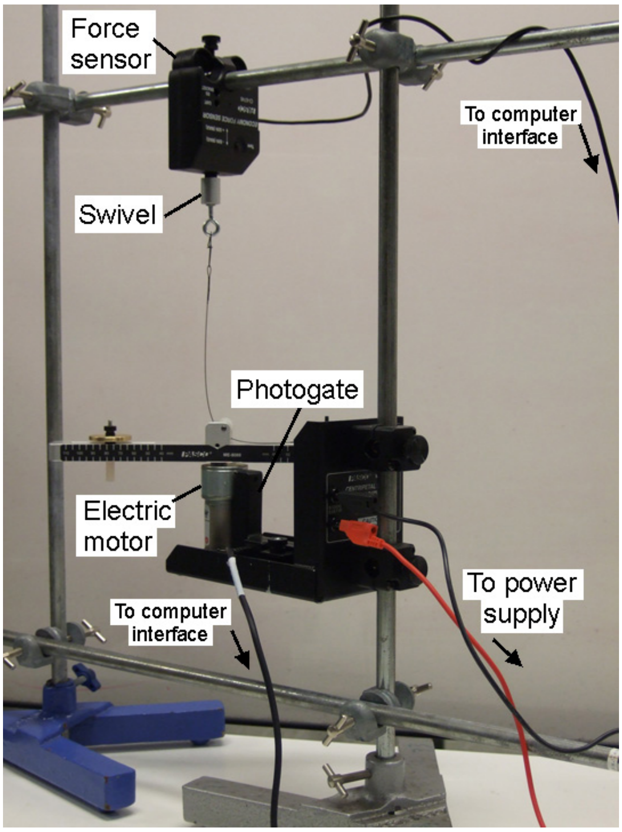

Figure 2 Initial experimental setup

Part I. Centripetal force vs. Angular velocity at fixed values of *M and R*

1. Remove the free mass holder (see Fig. 3) and measure its mass. Record the value in the lab report. To remove the free mass holder, loosen the thumbscrew and nut above the rotating arm. **NOTE:** The free mass holder includes the thumbscrew, nut, two plastic washers (one above the rotating arm and another below) and an attachment screw.
2. Install the free mass holder back to the rotating arm. *Do not over-tighten the nut.* The free mass holder should be free to slide along the groove. Otherwise, significant frictional losses may occur.
3. Thread the cable through the pulley to the swivel hook on the Force Sensor.
4. Add 30g mass to the free mass holder. To add the free mass, lay the components over the attachment screw in the following order: i) cable, ii) mass and iii) thumbscrew to tighten. **NOTE:** Place the cable above the washer and nut on the screw.
5. Place an equal amount of mass (30g mass) on the fixed mass holder, as shown in Fig. 3.
6. Place the free mass to a position with radius R = 8 cm. The position of the free mass can be adjusted by positioning the Centripetal Force apparatus while the cable attached to the Force Sensor and the free mass is stretched. When positioning the Centripetal Force apparatus, make sure that the cable (from the swivel hook to the pulley) is aligned vertically.
7. Place the fixed mass at the same radius to ensure the balance of the entire unit as it rotates.

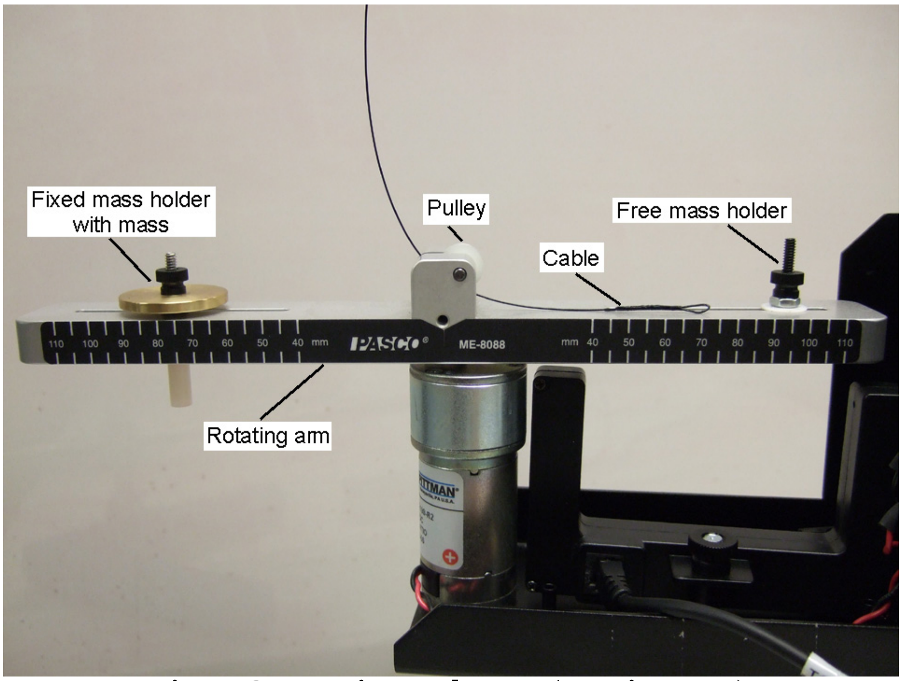

Figure 3 Experimental setup (rotating part)

Data recording and analysis

8. Open the "M3" program in the course folder. It contains two measurement pages. Choose the "Part I Centripetal force versus Angular velocity" page with a graph display of Force (N) versus Angular velocity (rad/sec) and a table display of Force versus Angular velocity.
9. Before turning on the electric motor, make sure that all cords and parts are away from the motor and rotating arm. Keep your body at least one foot away from the motor and rotating arm when the motor is running.
10. Loosen the cable attached to the Force Sensor and the free mass, press the "Tare" button on the Force Sensor to "zero" the sensor. When the tare button is pressed, the voltage from the sensor will be set to zero.
11. Turn on the power supply and slowly increase the applied voltage until the rotating arm starts to rotate and the cable become stretched. (The applied voltage needed should be around 3V).
12. Fine adjust the position of the Centripetal Force apparatus such that the cable keeps vertical when the rotating arm is running.
13. Click the "Record" button in the Controls palette.
14. Slowly increase the applied voltage up to about 8V. **NOTE:** *NEVER apply voltage larger than 12V to the motor.*
15. Click the "Stop" button to end the data recording. "Run #1" will appear in the Data Summary.
16. Decrease the applied voltage to zero and turn off the power supply.
17. Export the data of Force versus Angular velocity to Microsoft Excel by:
    a. Select all the data on the table by clicking anywhere in the table and press Ctrl+A;
    b. Press Ctrl+C to copy data to clipboard;
    c. Open Microsoft Excel;
    d. Click in a cell where you would like the data to appear;
    e. Press Ctrl+V to paste data.

18. In Excel, create two columns with values of the logarithm of the angular velocity and the logarithm of the centripetal force respectively. Plot a graph of the logarithm of the centripetal force versus the logarithm of the angular velocity in linear scales.
19. Fit the data with a linear function and record the fitting results in the lab report. Verify that the force is proportional to the square of the angular velocity. Paste the graph with appropriate fitting in the lab report.

Part II. Centripetal force vs. Radius at fixed values of *M and ω*

1. In "M3" program, choose the "Part II Centripetal force versus Radius" page with a graph display of Force (N) versus Time (sec) and digits displays of Force (N) and Angular velocity (rad/sec).
2. Put 30g mass each to the free mass holder and fixed mass holder as in Part I.
3. Place the free mass to a position with radius R = 6 cm. The position of the free mass can be adjusted by positioning the Centripetal Force apparatus while the cable attached to the Force Sensor and the free mass is stretched. Be sure to place the fixed mass at the same radius to ensure the balance of the entire unit as it rotates. Record the value of radius in Table 1.

<u>Data recording and analysis</u>

4. Before turning on the electric motor, make sure that all cords and parts are away from the motor and rotating arm. Keep your body at least one foot away from the motor and rotating arm when the motor is running.
5. Loosen the cable attached to the Force Sensor and the free mass, press the "Tare" button on the Force Sensor to "zero" the sensor.
6. Turn on the power supply and slowly increase the applied voltage until the rotating arm starts to rotate and the cable become stretched. (The applied voltage needed should be around 3V).
7. Fine adjust the position of the Centripetal Force apparatus such that the cable keeps vertical when the rotating arm is running.
8. Click the "Record" button.
9. Slowly increase the applied voltage until the angular velocity reaches and is stabilized at 35.0 rad/s. **NOTE:** *NEVER apply voltage larger than 12V to the motor.*
10. Keep the angular velocity constant for about 5 seconds and click the "Stop" button to end the data recording.
11. Decrease the applied voltage to zero and turn off the power supply.
12. Select the last 5 second data (that is, the part with constant angular velocity) by using the **Data Highlighter** in the Graph display.
13. Use the **Statistics** tool of the Graph display to determine the mean and the standard deviation of the centripetal force and record these values in Table 1 by:
    i. Click to depress **Statistics** icon in the toolbar ;
    ii. Click the pull-down arrow next to **Statistics** to select the values.
14. Repeat steps 3-13 with the radius R changed to 7, 8, 9 and 10 cm, respectively.
15. Plot the measured centripetal force as a function of radius (R) for fixed values of mass (M) and angular velocity (ω) in linear scales.
16. Fit the data with a linear function and record the fitting results in the lab report. Verify that the force is proportional to the radius. Paste the graph with appropriate fitting in the lab report.