Radial Force & Riding an Elevator
Fall 2017

Introduction

In the first part of this experiment, you will calculate – and then measure – the radial force needed to make a mass travel in a circular orbit. In the second part, you will measure the acceleration of an elevator using a bathroom scale.

The Equipment: Meet “Bob”

The apparatus allows you to spin a known mass around in a circle: you can measure the radius of the circle and the speed of the mass and then calculate the radial force from Newton’s second law.

1. Disconnect the spring from “Bob”. Your instructor will show you how to check the balance between Bob and the counterweight. Also be sure that the base is level. It is important to check the balance and level carefully.

2. Remove Bob from the supporting string, measure his mass, then reattach it to the string. Adjust the pointer until it is directly under Bob, and if necessary adjust the height of Bob (with the supporting string) to be no more than 1 mm above the pointer.

Calculating the Radial Force: Bob in Motion

You will first calculate the radial force exerted on Bob by rotating the apparatus. Keep linear measurements in cm until you are ready to calculate the force!

3. The radius of Bob’s orbit, $R_{orbit}$, is the distance from the center of the rotating shaft to the center of the pointer. Calculate the radius of the orbit from the radii of the rotating shaft and the pointer, and the closest distance between them – note that this is not simply the measurement of $d$ (Figure 1). Use vernier calipers to measure the diameters, but you’ll need to use a meter stick and calipers to measure $d$. Double check your measurement of the radius; each person in the group should take their own measurements. Check the value of your measured radius with your instructor.

4. Reconnect the spring and set the photogate to “pulse” mode, memory on. Spin Bob at a rate that stretches the spring until Bob is directly above the pointer. Measure the period of one rotation, $T$ - while doing your best to hold the speed at which the pointer and Bob are aligned (this will take some practice). Collect at least 10 trials, recording the data in a table in your report. Calculate the average period, $\langle T \rangle$ and write down the minimum and maximum periods. Keep Bob spinning during your measurements; don’t stop and restart the rotation!

5. Your analysis may be helped by considering the spread in the measured periods. Calculate the percent difference between the minimum and maximum period observed.

6. Draw an FBD for a rotating Bob. Call the force of the spring on Bob $\vec{F}_{rot}$, the force needed to move Bob in a circle at the fixed speed. Remember to specify the reference frame used in your FBD.

7. Calculate the velocity, $v$ and radial acceleration, $a$ of Bob (assuming a circular orbit), and record in your report:

$$v = \frac{2\pi R_{orbit}}{\langle T \rangle}$$

$$a = \frac{v^2}{R_{orbit}}$$
8. Use your FBD and Newton’s laws to calculate the force exerted on Bob by the spring during rotation, \( \vec{F}_{\text{rot}} \). Be careful with the units! Also, calculate the minimum and maximum values of the force (so that you have a range of values for \( \vec{F}_{\text{rot}} \)).

**Measuring the Radial Force: Bob at Rest**

9. Connect the mass hanger to Bob with the paper clip, and check that the string pulls straight over the pulley. Also check that the pulley rotates freely (if it doesn’t then you’re adding an additional force to the system!).

10. Add masses until the spring is stretched so that Bob is lined up above the pointer (Figure 2).

11. Draw a second FBD for this static system (Bob and the suspended mass), and use it with the data above and \( g = 9.80 \text{ m/s}^2 \) to find the force exerted on Bob by the spring (when the spring is stretched to the same length as when rotating). Call this force \( \vec{F}_{\text{static}} \).

**Discussion**

- Restate your values for \( \vec{F}_{\text{rot}} \) and \( \vec{F}_{\text{static}} \), and calculate the percent difference between them. You should also restate the minimum and maximum values of \( \vec{F}_{\text{rot}} \).
- Did \( \vec{F}_{\text{static}} \) fall within the range of possible values of \( \vec{F}_{\text{rot}} \)? If it didn’t, what contributed to the error? In your discussion of sources of error, be sure to consider what your result from step 5 tells you about your ability to rotate Bob at a uniform rate. You should also consider the assumptions that are made in this experiment.
- Which value of the period (minimum or maximum) corresponded to the larger value of \( \vec{F}_{\text{rot}} \)?

**Additional Exercise: Riding an Elevator**

In this experiment, you will measure the acceleration for the elevator in Bewkes Hall or Johnson Hall using a bathroom scale. This is similar to example N6.5 in Moore.

1. One person in your group will stand on an ordinary bathroom scale while still in the lab; record that person’s mass at rest (in kg). {You’ll note that the Physics department spared no expense in traveling to Canada to purchase a metric bathroom scale!}

2. Take your scale into one of the elevators and have the same lab partner stand on the scale. Ride up and down in the elevator, recording the maximum and minimum “weights” while the elevator is starting or stopping (you must take an average of several measurements of each trip.) Use long trips, going from the ground floor to the top, and vice versa. You’ll collect data for four excursions: starting and stopping for the trip up, starting and stopping for the trip down. Record your measurements on the worksheet; be sure to circle the name of the elevator used on the worksheet.

3. In your report, draw a large FBD for the static case (at rest in the lab, shown at right); try to draw the force vectors to the same scale relative to each other, as shown at right. Which of these two forces does the scale measure? Which force will change as you ride the elevator?
4. You will find four “bodies” on the worksheet, one for each trip. Add force vectors to these bodies, again scaling them relative to each other. Why do you think you would want to draw the force vectors like this?

5. From your FBDs and your measured weights, calculate $\sum \vec{F}$, and then your acceleration going up and down ($a_{up}$, $a_{down}$), for both starting and stopping. *Hint:* if your measured acceleration is close to or greater than $g$, then you’re doing something wrong! Draw an up or down arrow in the appropriate worksheet column to indicate the direction of the acceleration and velocity while stopping or starting in each case. In your report, be sure to include a sample calculation to show how your calculations were performed.

6. Discuss your results:
   - Did both forces change during the experiment, or just one? Which force changed during each trip? Why?
   - What was the state of the elevator’s motion (accelerating? Constant velocity? Which way?) in the middle of an up or down trip? How could you tell from the scale reading?
   - Think about a downward trip you took. Describe how you (your body) felt at the different parts of the trip, and why.

7. Answer and explain the following two questions:
   - When an elevator accelerates upward, the tension in the elevator cable is
     a. less than the weight of the elevator
     b. the same as the weight of the elevator
     c. more than the weight of the elevator
   - When an elevator accelerates downward, the tension in the elevator cable is
     a. less than the weight of the elevator.
     b. the same as the weight of the elevator.
     c. more than the weight of the elevator.