Forces and Centripetal Acceleration

Physics Topics

If necessary, review the following topics and relevant textbook sections from Serway / Jewett "Physics for Scientists and Engineers", 10th Ed.

- Circular motion (Serway/Jewett, Sec 4.4)
- Dynamics of uniform circular motion (Serway/Jewett, Sec 6.1)

Introduction

Your engineering firm has been hired by NASA to design a centrifuge to help prepare astronauts in-training for the high acceleration of a shuttle launch. The centrifuge consists of a rotating "pod" (of mass m), which is joined to a central axis by stiff spring. You have been tasked with determining what rotation period will give the astronauts adequate training, but is also safe so that the spring does not over-extend and break.

To get started, you want to investigate the basic physics relating the rotation period to the force exerted by the spring; this relationship is predicted by Newton's Laws of motion. You build a simple model of the setup shown below to begin your investigations.

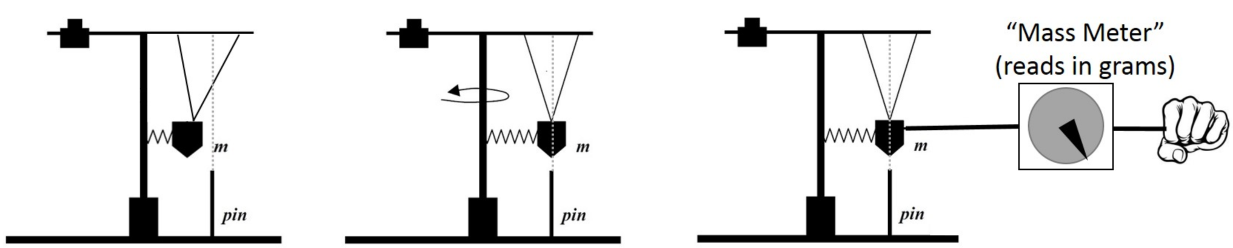

Fig 1: Static equilibrium Fig 2: Circular motion Fig 3: Static Equilibrium (with pulling force)

Apparatus

- Vertical shaft (fit into a bearing)
- Horizontal crossbar with counterweight
- Hanging mass m
- Spring
- Timer
- Pulley
- Hanging mass scale
- Vernier caliper

Pre-Lab Questions

Please complete the following questions prior to coming to lab. They will help you prepare for both the lab and the pre-lab quiz (Found on D2L).

1.) Read through the entire lab writeup before beginning

2.) What is the **specific** goal of this lab? Exactly what question(s) are you trying to answer? Be as specific as possible. ("To learn about topic X..." is **not** specific!)

3.) What **specific** measurements or observations will you make in order to answer this question?

4.) Consider the apparatus in Fig 2, where the mass m is rotating at a constant speed v, constant radius R, with a rotational period T.

(a) Draw a free body diagram for the mass m and choose a coordinate system.

(b) Use your free body diagram and coordinate system to write Newton's Second Law for the mass m. We will focus on the horizontal component of Newton's Second Law in what remains.

(c) What kind of motion is the mass undergoing? With this in mind, relate the spring force to the velocity v of the rotating mass (and other measurable variables such as M, T, and R.)

(d) The velocity v is not directly measurable. What measurements could you take with a ruler and stopwatch to determine v? Write an equation relating v to quantities you can directly measure: the period T and the radius of the path R.

(e) Combine your previous steps to write an equation relating the force exerted by the spring to the directly measurable quantities R, T, and m.

5.) Since your goal is to test the *relationship* between force and rotational period, you also need to determine the spring force F_s by an independent method. To do this, see Fig 3, where the mass m is attached to a "mass meter" by a string. An external force is pulling the mass outward from its equilibrium position.

(a) For the setup in Figure 3, draw a free body diagram for *both* the mass m, and the mass meter. Choose a coordinate system.

(b) Write Newton's Second Law for the mass m, assuming equilibrium. Do the same thing for the mass meter.

(c) The mass meter is designed to be a hanging scale, hence its reading will be one of *mass*. Let us call the reading registered by the meter M. How can you convert this mass M to the quantity in which you are interested: the force being applied to the meter?

6.) Combine the results of the previous steps together to write a predicted relationship between directly measurable quantities m, M, T and R.

Procedure

1.) Detach the mass m from the spring and string. Measure and record its mass including an estimate of uncertainty.

2.) Place the mass back on the string (leave the spring detached). Loosen the screw that holds the cross arm in place and adjust its position so that the point at the bottom of the mass is about 14cm from the shaft. Fix the screw back in place.

3.) Move the pin so that the top of the pin is located just below the point at the bottom of the hanging mass.

4.) Measure and record the distance from *the center* of the shaft to the pin. You will need to use Vernier calipers to determine the radius of the rod. Include an estimate of the uncertainty in this measurement.

5.) Re-attach the mass to the spring. The connecting string should be taut; if it is not, shorten the string or go back and increase the distance between the mass and the shaft.

6.) Practice spinning the shaft. You should be able to spin the shaft at the right speed so that the mass travels in a circular path directly above the pin. Note that when this occurs, string attaching the mass to the rod above it should be exactly vertical. A sheet of white paper held behind the pin might be useful in seeing when the mass passes exactly over it.

7.) Once you are comfortable that you can maintain a stable speed at the correct radius, have your partner time how long it takes to make 20 full revolutions. Do this three times and average the result. Record all data. Include your estimated uncertainty.

8.) Stop the rotation and configure the setup as shown in Fig. 3 by attaching the "mass meter".

9.) Pull on your hanging mass scale until the mass m is in static equilibrium directly over the pin. Record the value of M that was needed to bring the mass to this position, including uncertainty.

10.) Detach the spring, and loosen the screw on the shaft. Move the mass to a larger radius. Go back to step 3 and repeat the procedure for this larger radius. Remember that when the mass is detached from the spring, it needs to hang directly above the pin. Continue to repeat the whole procedure at least 3 times so that you have measurements of T and M for four different radii. Record all your results with uncertainty.

Analysis

1.) Use your prediction equation (from the pre-lab) to plot your data in such a way that it becomes a straight line. You have three quantities which changed in this experiment M,

T and R, but only two axes on your plot. Thus, you will need to take an appropriate combination of these quantities to put on one axis of your plot. Your prediction equation can help you determine which ones.

2.) Add error bars to your plot, propagating uncertainty through the calculation if necessary. (If you need to, go back and review lab 1, and the "Introduction to Uncertainty and Measurement Analysis" document posted on the Ryerson Physics Lab homepage).

3.) For the quantities you chose to plot, what do you predict for the slope of your line?

4.) Determine the slope of the line and compare to your prediction. Calculate a % error. .

Wrap Up

The following questions are designed to make sure that you understand the physics implications of the experiment and also to extend your knowledge of the physical concepts covered. Your report should answer questions should be answered in particular sections in a seamless manner.

1.) [Theory] - Why does the mass experience an acceleration if its speed is constant?

2.) [Theory] - When you spin the apparatus faster, why does the hanging mass appears to move "outward" away from the center of rotation.

3.) [Procedure] - When measuring the period, we asked you to measure 20 revolutions instead of just one. Why is it better to measure 20 revolutions (and then divide by 20) than to just measure 1 revolution directly?

4.) [Procedure] - Without using the "mass meter", could you use this apparatus to measure the spring constant of the spring? Describe in words the measurements and/or analysis steps which could help you determine k. You do not actually have to determine it, but give an experimental plan for doing so.

Report

Here is a brief guide for writing the report for the lab. The report should include the following sections:

- **Title Page**
  - Include: Report Title, Your Name, Course, Section Number, Instructor, TA Name, and Date of Submission.
- **Introduction**
  - What is the experiment's objective?

- **Theory**
  - Derivations of the physics being investigated, or reference to a source that provides a description/equation representing the physics being investigated.
  - Providing graphs that illustrate or predict how the system under study is expected to behave.
- **Procedure**
  - Briefly explain the systematic steps taken for the experiment.
- **Results and Calculation**
  - Tabulate the measurements in an organized manner.
  - Based on the procedure, one should have a sense of how the tables will look like prior to taking measurements.
  - Graph the main results.
  - Provide examples of any calculations.
- **Discussion and Conclusion**
  - Discuss the main observations and outcomes of the experiment.
  - Summarize any significant conclusions.
- **References**
  - Very important to include to avoid plagiarism claims.
- **Appendices**
  - If large quantities of data are obtained, or lengthy details are needed, but break the overall flow of the report, they should be referenced and placed in the appendix.