Uniform Circular Motion

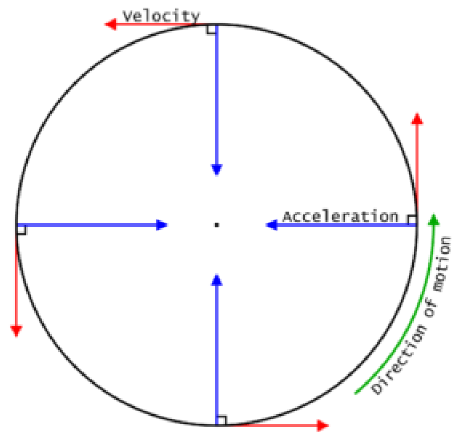

Figure 1: The diagram here shows the directions of the velocity and acceleration of an object in ccw uniform circular motion. At all times the velocity is tangent to the circle and the acceleration is directed radially inwards to the axis of rotation. Note also the magnitudes of the vectors are the same at each point it is only the direction which changes.

1 Introduction

In this lab you will be studying Newton's second law for an object in uniform circular motion. This object will be a metal bob attached by a spring to an apparatus which you will be able to rotate using a center shaft. Since velocity is a vector, it depends on both the speed and direction of an object. Therefore an object moving in uniform (constant speed) circular (constant radius) motion is still accelerating because it is constantly changing direction. Using Newton's 2nd law, $F = ma$, we can determine the mass of the object in uniform circular motion if we measure the acceleration and the force responsible. We will collect four data points, i.e. four different radii of rotation, in order to do a linear fit.

2 Equations

$$F = mg$$

$$a = r\omega^2 = \frac{4\pi^2 r}{T^2}$$

F is the force exerted by the spring on the bob to keep it in uniform circular motion; it is determined by hanging mass over a pulley until the bob is stretched to the radius of rotation. The acceleration, a, is determined by measuring the radius of rotation and period of rotation.

3 Procedure

1. Measure and record the mass of the bob (the object attached to end of spring that you will be rotating) using a triple beam balance scale. Then reattach the bob to the spring. [1]

2. I would recommend making a table to collect the data you will use to calculate the accelerations and forces for the bob at 4 different radii of rotation. You could make columns for radius, time, average period, mass hanging.

3. With the bob reattached spin the apparatus (by turning the center shaft), notice the faster it is spun the further the bob stretches the spring. The radius of rotation is measured from the axis of rotation (center of the post you are rotating) to the point that the central tip on the bottom of the bob is reaching during the rotation [2].

4. Choose a radius that the tip should pass over on each rotation and then adjust the rotation rate until you get it at the right speed. It will help if you place a piece of paper at the radius so you can see the tip hit on each rotation. Record this as the first radius in your table.

5. When you have found the right speed and the bob's tip is hitting the paper at the selected radius on each rotation, have your partner start the stopwatch and time how long it takes for fifteen rotations[3]. Record the time from the stopwatch in your table and repeat at least two more time measurements for this radius.

6. Use these times to determine the average period, the time it takes to complete one rotation and record this in the table.

7. Repeat this same procedure at three different radii so you have four radii total with three time measurements and an average period for each. Use this information to determine the acceleration of the bob for each radius.

[1] tuck/wrap the string on the bob which will later be used to hang mass over the pulley out of the way so it is not interfering with rotation

[2] on the apparatus the radii are labeled in centimeters

[3] You will get more accurate result for period by allowing it to complete fifteen rotations

8. To determine the force causing each acceleration move the apparatus to the edge of the table and hang mass on the string attached to the bob over the pulley until the tip of the bob is stretched to each radius. Record the mass hanging over the pulley in your table.

9. Use the mass hanging over the pulley to determine the force for each each radius.

4 Analysis

1. Include a table with all of the data you collected in the lab, the forces, and accelerations. Show sample calculations of how you used the measured data to determine the force and acceleration.

2. Using excel or another plotting software make a scatter plot of force (on y-axis) vs acceleration (on x-axis) and linear fit. Show the equation of the linear fit. What does the slope represent? (Spoiler) How close is it to your measured value at the beginning of the lab? Discuss success level of the lab and what you think was measured inaccurately if the agreement is not good.

3. Make a free body diagram for the bob while it is in uniform circular motion. Discuss the net force, and what if any forces cancel.

4. Make a free body diagram for the stationary bob, i.e. when the spring and weight hanger over the pulley are attached. Discuss the net force, and what if any forces cancel.

5 Questions

Newton's laws only apply in a non-accelerating reference frame; however they can be applied to the frame of an object which is accelerating by including inertial forces. The general rule is the inertial force is the force necessary to cause that object to have that acceleration but in the opposite direction of the acceleration. Inertial forces are sometimes referred to as fictitious forces since they aren't needed to describe motion of objects in a non-accelerating frame; however I think this is a bad label, they are actually felt by the accelerating object. [4]

1. To get a feeling for inertial forces discuss the familiar cases of accelerating in a car in a straight line while increasing or decreasing speed and turning the wheel to change direction. What direction do you feel a force in these scenarios and how does the strength of that force change if you either hit gas/brake harder or turn sharper?

2. From the bob's frame while it is in uniform circular motion what is the direction and magnitude of the inertial force it feels?

[4] Centrifugal force is the special name given to the inertial force for uniform circular motion