PCS 211 Lab 4 : Centripetal Acceleration

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1 Introduction

The main objective of this lab is to study the circular motion of a hanging mass around a pulley. This will be done by graphing the time the hanging mass took to make 20 revolutions vs the mass value required to bring the hanging mass in equilibrium.

The values measured in this lab will be the time it took for the mass to reach 20 revolutions (three trials for four different radii), the mass required to bring the hanging mass into equilibrium, and the force at equilibrium.

2 Theory

Before beginning this investigation we must know the methods and the theory behind the investigation and the due course of action.

2.1 Centripetal Force

Centripetal force refers to a force that acts on an object that keeps it moving along a circular path. It is described mathematically as,

$$F_c = m\frac{v^2}{r}$$

Centripetal force is always perpendicular to the direction of the object's displacement. Centripetal acceleration on the other hand refers to the motion of the object itself that is traveling in a circular path. It is described mathematically as,

$$a_c = \frac{v^2}{r}$$

Alternatively, we may mathematically represent the centripetal force as,

$$F_c = \frac{4\pi^2 mr}{T^2}$$

2.2 Acceleration

Acceleration is defined as a change in velocity, either in magnitude or direction . Because the direction of the velocity changes constantly in uniform circular motion, there is always an acceleration, even if the speed is constant.

3 Materials Required

- Vertical shaft
- Horizontal Crossbar
- Hanging Mass
- Spring
- Scale
- Timer
- Pulley
- Vernier Caliper1

4 Procedure

1. Using the scale, measure and record the mass of the hanging mass with uncertainty.
2. Attach the mass to the spring, loosen the screw that holds the cross arm and moves it to 14cm from the shaft.
3. Adjust the pin to be located on top of the hanger mass.
4. Using the vernier calipers, measure the distance between the center of the shaft and pin.
5. Reattach the mass, the string should be tight. If not, readjust it, so it is.
6. Practice Spinning the shaft at the right speed so it travels in a circular path
7. Once mastered, the rate of spinning spin starts the stopwatch and times how long 20 revolutions take.

8. Detach the spring and redo the experiment with three more radii.

5 Experimental Data

Experiment 1 (0.043 +- 0.005m)		
	T(20)	T(1)
Trial 1	18.81 +- 0.005	0.941 +- 0.0003
Trial 2	17.39 +-0.005	0.861 +- 0.0003
Trial 3	22 +-0.005	1.1 +- 0.0003

Experiment 2 (0.063 +- 0.005m)		
	T(20)	T(1)
Trial 1	17.83 +- 0.005	0.892 +- 0.0003
Trial 2	20.27 +-0.005	1.013 +- 0.0003
Trial 3	19.48 +-0.005	0.974 +- 0.0003

Experiment 1 (0.043 +- 0.005m)		
	T(20)	T(1)
Trial 1	14.84 +- 0.005	0.742 +- 0.0003
Trial 2	16.45 +-0.005	0.823 +- 0.0003
Trial 3	14.14 +-0.005	0.707 +- 0.0003

Experiment 1 (0.043 +- 0.005m)		
	T(20)	T(1)
Trial 1	14.98 +- 0.005	0.749 +- 0.0003
Trial 2	17.70 +-0.005	0.885 +- 0.0003
Trial 3	16.39 +-0.005	0.820 +- 0.0003

6 Analysis

In this particular lab experiment, the component of physics known as circular motion was introduced. This area of physics analyzes the fundamental behavior and laws that an object adhere's to when the object moves around a circular path. An important part of this is circular acceleration, or as it's known as centripetal acceleration. Therfore we have,

$$a_c = \frac{v^2}{r}$$

Where v is the velocity and r is the radius of the circular motion.

Combining Newton's 2nd law with the above experession, we have,

$$F = ma = \frac{mv^2}{r}$$

The circular motion also comprises circular velocity, which is the velocity of the object moving along the circumference of a circle. Through the circular velocity the relationship between velocity and period(T) is found to be,

$$v = \frac{\Delta x}{\Delta t}$$

The equation can be expressed in terms of a circle. For example, the distance(x) can be further denoted as the perimeter of the the circle's circumference which $2\pi r$. The time(t) can also be denoted as period(T) which is the time taken to complete one cycle specified by a given point. Therfore we have,

$$v = \frac{\Delta x}{\Delta t} = \frac{2\pi r}{T}$$

In this experiment to determine the spring force(F_s), the mass meter was used. The mass meter was attached to the mass(m), and the spring and the mass were pulled directly over the pin; the readings of the mass determined by the mass meter was denoted as M.

In order to calculate the force of the spring, the M value must be converted into F_s. To do this, it must be understood that the mass meter is no different than a hanging scale. A hanging scale measures the force of gravity of an object from the object's mass, the mass is hung on the scale and it is measured. Similarly, in this situation, the mass was hung on the scale, but instead a pulled force was applied, however the same instrument mechanics were applied. This implies that,

$$F_s = Mg$$

As it could be seen from the experiment, the results were calculated with fixed variables, to ensure accuracy. For example, for each time variable determined, there were 20 revolutions made. So although time is given, it is based on time required for 20 revolutions. However, period(T) is defined by the time required for a single revolution.

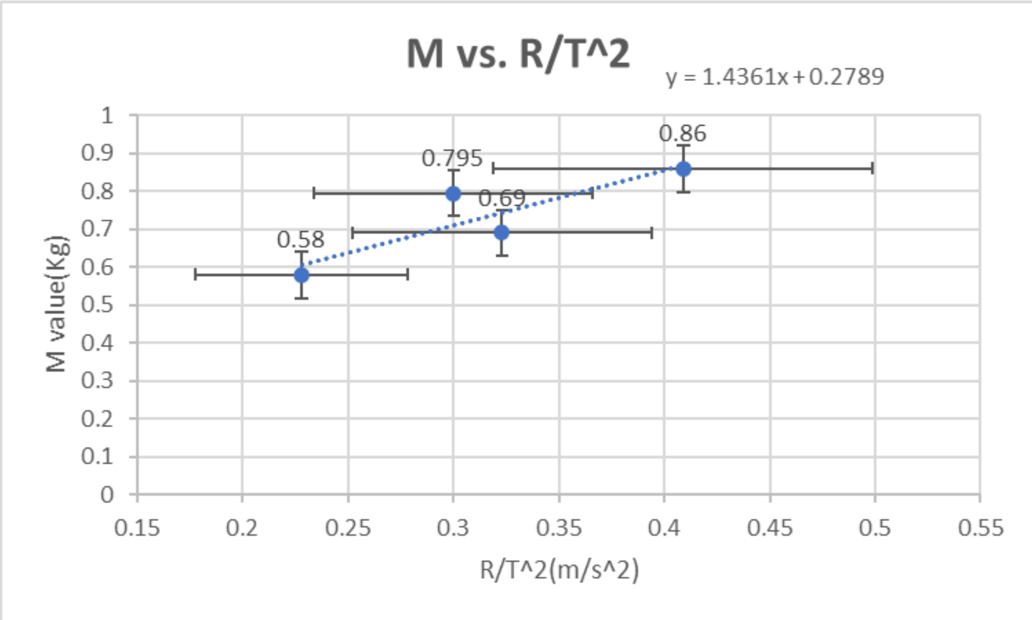
Using the given data, for the three main variables, T(period), R(radius), and M(mass of object stretched to equilibrium with applied force), we can establish the relationship between them, and express it through a graph. The following relationship requires a equation that combines all of these elements into a single equation. Therefore we have,

$$Mg = \frac{mv^2}{r} = \frac{\frac{4m\pi^2 r^2}{T^2}}{r} = \frac{4m\pi^2 r}{T^2}$$

$$\implies M = \frac{4m\pi^2 r}{gT^2}$$

Thus, the relation between the three variables is solved with M on one side, and the other two variables on the other side. However to demonstrate the relationship using a graph we must separate the equation to the graph form of $y = mx + b$. Where the M is proportional to the variables T and r by some factor, that is the slope m.

$\frac{r}{T^2}$(m/sˆ2)	Error propagation($\frac{r}{T^2}$)	M value(Kg)	Error propagation(M)
0.228	0.123	0.58	0.05
0.323	0.162	0.69	0.05
0.30	0.135	0.795	0.05
0.4090	0.221	0.86	0.05



To be able to find the predicted slope of the graph, for the constant 'm' value, the previous combined equation must be examined. Through the formula for the relationship between M, T and R, in the slope-intercept form for a straight line, the slope value can be determined as,

$$M = \frac{4m\pi^2 r}{gT^2}$$

Therefore we have,

$$m = 1.8531\frac{kgs^2}{m}$$

As it could be seen from the results, the measured slope based on our graph is 1.4361, while the predicted slope which is derived from various physics concepts and laws is 1.8531.

Although the results have a small difference, there were multiple factors that accounted for this. Such as inaccurate readings, instrumental inaccuracies, and unintended interference in the lab. The percentage error is figured out to be,

$$\Delta M = 17\%$$

However, as evidently proved the slope determined from the lab experiment with the practical results well complemented the theoretical and mathematical approach to calculate the slope.

Both methods relied on fundamental concepts, and abided by the physics laws, thus both methods are valid and play a key role in determining the results.

7 Conclusion

Without a doubt these crucial physical quantities are an important aspect of physics, and these variables set the principles for circular motion. The relationship between the three main quantitative variables, T(period), M(mass of object stretched to equilibrium with applied force), and R(radius) is the core concept that outlines circular motion. In order to successfully build, test and create a structure, the principles of circular motion must be understood thoroughly.

As a matter of fact, to design the centrifuge that helps astronauts prepare in proper training, the circular motions must be placed into great consideration. The goal of an effective centrifuge is to have the right rotation period, one that is not excessive to the spring, but also with high-speed capabilities for training. From the results, it could be very well concluded that as rotational periods get smaller, the less time it takes to do a single revolution, which implies that the object gets quicker and both velocity and acceleration increase dramatically. This also means that more force is present, and force is needed to get the rotation to spin appropriately.

As a result, based on this experimental situation, the rotation period that will give the astronauts the appropriate adequate training and will not overstress the spring is a period no less than 0.717 (seconds/Revolutions). Any rotation period below that can be considered excessive, as it not only requires a lot more force that is hard to achieve, but it also requires very high speeds to maintain a constant circular movement over the designated pin. Using the circular motion principles of physics, the very behavior of an object moving around a circumference can be understood and can be well applied to the real world.

Bibliography

[1] Serway, R. A., Jewett, J. W. (2018). Physics for Scientists and Engineers. Cengage Learning.