Lab Report 11: Center of Mass and Torque

PHY121

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Purpose

To use static equilibrium situations to solve for the center of mass of rigid rods.

Theory

Torque is the measure of force needed to cause an object to rotate. Torque can be calculated by multiplying the force applied to an object, the radius of that force from the object's pivot point, and the angle between the component of the force that is perpendicular to the pivot axis. This relationship between the angle of the force applied, and an object's pivot point can be represented using the following equation:

$$T = |r|\,|F|\sin\theta$$

Since gravity is a force that acts on all parts of an object, it applies torque at multiple points at the same time. Instead of calculating the torque caused by gravity at multiple positions on an object, a single position, the object's *center of mass*, is used. Objects with a uniform distribution of mass, typically symmetrical with no varying mass, usually have their center of mass right at the center as shown below:

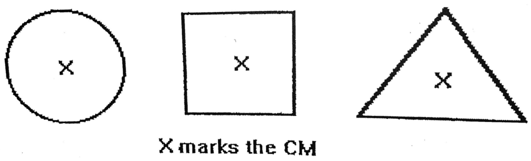

Figure 1: Symmetrical objects usually have their center of mass...at the center.

An object's center of mass can be calculated using the following equation:

$$x_{\text{com}} = \frac{m_1 x_1 + m_2 x_2 + ...}{M_T}$$

x_{com} : center of mass
m_1 : mass of object 1
m_2 : mass of object 2
x_1 : position of object 1
x_2 : position of object 2
M_T : total mass of system

Procedure

1. Found the center of the **meter stick** by going to the halfway point (0.5 m).
2. Placed **knife edge clamp** on the **meter stick.**
3. Slid **knife edge clamp** on **meter stick** until **meter stick** was balanced on the **knife edge** support.
4. Recorded center of mass of the **meter stick**.
5. Attached 60 g of mass to the **meter stick** at 20 cm from one end.
6. Recorded distance of the 60 g to the pivot point.
7. Placed 100 g on the **meter stick** such that it remained balanced.
8. Solved for the actual placement position of the 100 g using center of mass equation.
9. Attached 20 g of mass to the **meter stick** at 10 cm from the end on the same side as the 60 g.
10. Adjusted placement of the 100 g so that the **meter stick** remained balanced.
11. Repeated step 8.
12. Removed all attached masses.
13. Placed 50 g of mass on the meter stick at 20 cm from one end.
14. Moved **knife edge** placement such that the **meter stick's** center of mass changed.
15. Solved for **meter stick's** center of mass using center of mass equation.

Calculations & Graphs

Tangential Velocity

$$v = \frac{2\pi r}{t} \tag{1}$$

v : velocity
r : radius of circle
t : time for 1 revolution

Sample Calculation

using part 1 data with 50 g of weight

$$v = \frac{2\pi r}{t}$$

$$= \frac{2\pi(0.2 \text{ m})}{0.3426 \text{ s}}$$

$$v = \boxed{3.666 \text{ m/s}}$$

Centripetal Force

$$\mathrm{F_c} = \frac{mv^2}{r} \tag{2}$$

$\mathbf{F_c}$: centripetal force
m : mass of object
v : tangential velocity of object
r : radius of circle

Sample Calculation

using expected velocity in part 2 with 50 g

$$\begin{aligned}\mathrm{F_c} &= \frac{mv^2}{r} \\ &= \frac{(0.012 \text{ kg})(2.858 \text{ m/s})^2}{0.2 \text{ m}} \\ \mathrm{F_c} &= \boxed{0.49\,\mathrm{N}}\end{aligned}$$

Average Value Formula

$$\overline{a} = \frac{\text{sum of values}}{\text{total \# of values}}$$

Sample Calculation
average period using Part 1 at 50 g

$$\overline{a} = \frac{\text{sum of values}}{\text{total \# of values}}$$

$$= \frac{0.334 \text{ s} + 0.3515 \text{ s}}{2}$$

$$\overline{a} = \boxed{0.3426\,\text{s}}$$

Percent Error

$$\text{PD} = \left| \frac{\text{measured - actual}}{\text{actual}} \right| \text{ x}\,100\% \tag{3}$$

Sample Calculation
percent error between theoretical period and measured period using values from part 3

$$\text{PD} = \left| \frac{\text{measured - actual}}{\text{actual}} \right| \text{ x}\,100\%$$

$$\text{PD} = \left| \frac{0.3426 \text{ s - } 0.5071 \text{ s}}{0.5071 \text{ s}} \right| \text{ x}\,100\%$$

$$PD = \boxed{32.41\%}$$

Tables

Table 1: Part 1

Mass (kg)	0.05	0.06	0.07	0.08
Trial 1 Period (s)	0.334	0.329	0.332	0.359
Trial 2 Period (s)	0.3515	0.353	0.354	0.3295
Average Period (s)	0.3427	0.341	0.343	0.3442
Average Velocity (m/s)	3.666	3.685	3.663	3.65
Expected F_c (N)	0.49	0.588	0.686	0.784
Actual F_c (N)	1.072	1.083	1.07	1.062

Table 2: Part 2

Mass (kg)	0.05	0.06	0.07	0.08
Theoretical Velocity (m/s)	2.478	2.715	2.932	3.135
Theoretical Period (s)	0.5069	0.4627	0.4284	0.4007
Actual Period (from part 1) (s)	0.3427	0.341	0.343	0.3442
Percent Error	32.39	26.31	19.94	14.1

Table 3: Part 3

Radius (m)	0.1	0.15	0.2	0.3
Trial 1 Period (s)	0.273	0.7	0.5015	0.5625
Trial 2 Period (s)	0.252	0.4575	0.5015	0.568
Average Period (s)	0.2625	0.5787	0.5015	0.5652
Expected Velocity (m/s)	2.146	2.629	3.035	3.718
Average Velocity (m/s)	2.393	1.628	2.505	3.335
Percent Error Velocity (%)	11.50	38.07	17.46	10.30
Expected F_c (N)	0.735	0.735	0.735	0.735
Actual F_c (N)	0.9133	0.2818	0.5004	0.5913
Percent Error F_c (%)	24.25	61.65	31.91	19.55

Graphs

Figure 2: Part 1: Actual F_c vs Actual Average Velocity

Figure 3: Part 1: Expected F_c vs Expected Velocity

Figure 4: Part 3: Radius vs Actual Average Velocity

Figure 5: Part 3: Radius vs Expected Velocity

Questions

1. **Should the 100 grams be placed closer or further away from the pivot point when compared to the 60 grams?**

   We had more trouble with the lighter masses.

2. **How does the calculated value compare to the experimental value you found? (Percent error)**

   The biggest source of error in the lab was not following directions properly. Instead of swinging the rubber stopper such that the alligator clip remained 1 cm below the tubing, we attached MORE alligator clips and swung the stopper such that the centripetal force exceeded the weight of the stopper below. Our measured velocity ended up being way higher and consistent than it should have been.

3. **How does the calculated value compare to the experimental value you found? (Percent error)**

   Since we didn't follow directions properly in part 1, part 3 ended up being the most difficult. I think this was the case because as the radius increased, we needed to find the right speed to balance the weight of the hanging mass at the bottom. We got close but the results would have aligned with our expectations more if we practiced doing the experiment properly the first time.

4. **Where do you need to place the knife edge such that the meter stick would be balanced?**

   Our own data shows no correlation, but using algebra, we'd expect the centripetal force to increase as the velocity increased.

5. **Explain in your own words why the meter stick needed to be shifted to find the new balance point. How can the system balance with one mass placed on it?**

6. **Describe the procedure that you used to find the center of mass.**

7. **What can you deduce about the distribution of mass inside the non uniform rod? (Is one side heavier than the other? How does that affect finding the center of mass?)**

Conclusion

The purpose of this lab was to test the conservation of mechanical energy. In a system where no non-conservative forces, such as friction, exist, the change in potential energy of an object should equal its change in kinetic energy. To remove the force of friction as much as possible, a glider was placed on an air track. Under these conditions, we attempted to measure the kinetic energy of the glider between two photogates on the track, and compared it with its calculated gravitational potential energy. We also attempted the measure the impact of mass on the conservation of mechanical energy, and increased add 100 grams of mass to the glider with each trial. Our results were interesting.

The time elapsed between the photogates had a low standard deviation across all our trials, meaning our measurements were precise (see Table ??). Using equation's ??, ?? and ?? we measured how much energy was conserved in the system along the track. We found that across all our trials, the percent difference between the gravitational potential energy and the change in kinetic energy was at least 27% (see Table ??). The consistency of these percent differences suggests two things: firstly, changing the mass did not significantly influence the amount of energy conserved, and secondly, there was some external force, factor, or systemic error that contributed to the difference in energy.

If we look at the equations for change in kinetic and potential energy and set them equal to each other, it makes sense that mass has no influence on the conservation of energy since it gets cancelled out (see equation's ?? and ??). Velocity and height are the remaining variables in the equations that could impact the conservation of energy. If we assume our measurements for the gravitational potential energy are correct, then it's highly possible the source of the energy differences lies within the measured kinetic energy. The kinetic energy of the glider that was measured and calculated, consistently had an absolute value that was higher than the calculated gravitational potential energy (see Table ??). Based off our analysis of equations ?? and ??, we can rule out mass and focus on velocity. A greater velocity results in a greater kinetic energy.Giving the glider a head start on the air track, or incorrectly measuring he distance between the photogates for equation ?? could have resulted in greater velocity and influenced our calculations for kinetic energy.

If assume that our measurements for kinetic energy are correct, that the distances between the photogates were accurately measured, and that the glider was not given a head start on the air track, then, ruling out mass, the source of the energy differences would lie in the height measured for the gravitational potential energy calculation. Gravitational potential energy is directly correlated with the height of an object, so a lower height would result in a lower potential energy. Under the assumption that the kinetic energy measurements are correct, it's possible the heights measured for photogate 1 and 2 are lower than they should be, resulting in a lower gravitational potential energy.

Were I to conduct this experiment again, there are a few things I would change to minimize the difference in energies. In order to prevent the possibility of giving the glider a head start, some sort of locking mechanism would need to be added to the air track such that the glider does not need to be let go by human hands. Thereby the initial velocity of the glider is set almost exactly to zero, and the air track is given enough time to negate friction. Regarding measurements, a locking mechanism could also be applied to the photogates, not only to make the time between gates even more consistent, but also to make the starting points for our measurements easier. There was difficulty determining exactly where to start and stop the measurements for the heights of the photogates because of the slanted angle of the air track, so having a locking mechanism would reduce the ambiguity of the measurements.