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**Report Sheet for Experiment 5: Rotational Inertia**

Abstract

In this experiment, the moment of inertia for disk and ring shaped, the conservation of angular momentum, and the positions of added mass effect on the moment of inertia are investigated. The inertia explains how hard the object can rotate which is determined practically by letting gravity force act on the pulley attached with object of interest. The proportion of that gravitational force over the angular acceleration of the object is moment of inertia. The conservation of angular momentum is also confirmed when there is no external torque with some error coming from the assumption that there is no frictional force and the moment of inertia of the pulley is negligible. Finally, if point masses are to be added to the system at a distance, the moment of inertia increase by the multiplication additional mass and the distance from the mass to the rotation axis(squared).

Introduction and Theory

When an object starts to rotate by an external force, for example, its angle referenced to a frame will change – its change is called angular velocity which is the speed over its rotational radius. The derivative of that naming the acceleration will be the product of radius and angular acceleration as well.

When there is an external force (F) acting on the object at some distance (r), there will be torque which is the cross product of radius and force. The following equation of torque and angular acceleration will be achieved if the rotational inertia, as mass in rotations, is defined below. The moment of inertia of objects of different shapes are listed below as well.

Rod =

Furthermore, the derivative of angular momentum over time is torque, meaning that when there is absent of external torque, the system’s angular momentum will be conserved as following:

Chart, diagram

Description automatically generatedThe potential energy from a falling object will be converted into kinetic energy including that of the directional and rotational motions.

Figure 1 shows the experimental setup

In this experiment, the only force acting at a radius from a disk, rod, or ring is the gravitational force from the falling object mass m. The object of interest has mass M, radius R, and angular acceleration . The theoretical moment of inertia can be derived as:

…..(10)

This value can be calculated from the experiment results when observing the angle change (rotational velocity) of the spinning object versus time. The fitted slope will be angular acceleration to substitute in the equation above.

…..(11)

Method

Part 1 – Rotational Inertia of Ring and Disk

1. Install a rotational inertia device, tie thread with the pulley, rotational motion sensor, and wrap around the other pulley to the mass.
2. Measure mass of objects and their radii.
3. Put the ring on the sensor, additional mass hanger to fall
4. Record the angle over time then let the mass fall
5. Remove the ring and repeat method 3 and 4.

Part 2 – Conservation of Angular Momentum

1. Use the same set up as part 1
2. Record the angle over time then gently drop the ring onto the already rotating disk.
3. Measure the distance between the center of the disk and the ring when they all stop.

Part 3 – Changes in the Rotational Inertia of Rod on Different Mass Positions

1. Mount the rotating arm to the sensor with masses at distance 9 and 18 cm from the center of the arm
2. Wind the thread through a pulley and to the mass.
3. Let the hanging mass fall and collect the data of angle over time.

Chart

Description automatically generatedChart, line chart

Description automatically generatedResults

Chart, line chart

Description automatically generatedFigure 2 shows the a) angle b) angular velocity and c) angular acceleration of rotating disk with support and with the ring included.

Figure 3 shows the angle (on the left) and angular velocity (on the right) of experiment part 2

Chart

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Figure 4 shows the angle versus time of rod and rod with mass loading at distance 9 and 18 cm from the center

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Experiment | Angular Acceleration (rad/s2) | Torque (Nm) | Moment of inertia (kgm2) | | |
| Theoretical | Experimental | %Error |
| disk | 31.394 | 0.00370 | 0.000103 | 0.000118 | 14.495 |
| disk+ring | 12.482 | 0.00381 | 0.000287 | 0.000305 | 6.453 |

Table1 summarizes the angular acceleration, torque, and moments of inertia for disk and disk with ring in the first experiment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Experiment | Angular Velocity (rad/s) | Moment of Inertia from Table1 (kgm2) | Angular Momentum (kgm2/s) | %Change |
| Before collision | 46.0 | 0.000118 | 0.00542696 | 12.428 |
| After collision | 20.0 | 0.000305 | 0.00610141 |

Table2 summarized the angular velocity, angular momentum, and their conservation in the second experiment

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Experiment | Angular Acceleration (rad/s2) | Torque (Nm) | Moment of inertia (kgm2) | | |
| Theoretical | Experiment | %Error |
| rod | 6.178 | 0.00384 | 0.000325 | 0.000622 | 91.437 |
| rod-9cm | 2.178 | 0.00386 | 0.001558 | 0.001774 | 13.909 |
| rod-18cm | 0.718 | 0.00387 | 0.005256 | 0.005394 | 2.616 |

Table3 summarizes the angular acceleration, torque, and moments of inertia for rod and rod with masses at 9 and 18 cm from the center with ring in the third experiment

Discussion

The moments of inertia in Table1 and Table3 are calculated from the equations in the introductions as follows:

* Idisk = MR2/2 = (0.1078\*0.04382)/2 = 0.000103 kgm2
* Idisk+ring = Idisk + M(R2+r2)/2 = Idisk + (0.103\*(0.03992+0.04452))/2 = 0.000287 kgm2
* Irod = MR2/12 = (0.027\*0.382)/12 = 0.000325 kgm2
* Irod9cm = Irod + 2md2 = Irod + 2\*0.076\*0.092 = 0.001558 kgm2
* Irod18cm = Irod  + 2md2 = Irod + 2\*0.076\*0.182 = 0.005256 kgm2

First of all, in the experiments where there is an external force creating torque at a distance r from the sensor, they all agree that the angle in which the sensor rotates have a quadratic dependence on time as predicted by equation11. Subsequently, the angle’s derivative, angular velocity, has a linear relationship over time and by fitting this graph, the angular acceleration can be found as the value of the slope.

In the first experiments of disk and disk with ring, the obtained moments of inertia are higher than the theoretical values, meaning that the error should not be coming from the air friction which energy lost will occur and less should be given. The error then would possibly come from the inertia of two pulleys themselves and/or the friction between the threads and pulley that being negligible in this case, leaving a flaw in the model used to evaluate the experiment. Other possibility might be the movement of the rotation axis which can reverse-calculate to find the D distance that the center moves as:

* Ddisk =sqrt[(Iexp - Itheo)/Mdisk]= 0.0118 m = 1.18 cm
* Ddiska+ring =sqrt[(Iexp - Itheo)/Mdisk+ring]= 0.0093 = 0.93 cm

which these values are quite large compared to the rotary sensor radius of 0.0284/2 m = 1.42 cm, confirming external factors like the negligence of the moment inertia of the pulley as mentioned above.

Furthermore, in the second experiment, the conservation of angular momentum is confirmed with considerable amount of error in between the initial(before collision) and final(after collision) states. The error is 12.428%. As depicted in Figure3, even the system is absent of a hanging mass creating continuous amount of force and therefore torque, solely rotating by hand has a deceleration in the pulley even long before the collision. This is confirmed by a linearly decreasing trend of the angular velocity. Moreover, the trend still holds even after the collision, indicating friction between in the pulley, the moment of inertia of the pulley itself that has been negligible, and air friction are some of all possibilities of the cause of an error.

In the last experiment, the goal should be investigating how the additional mass in the system at various distances affects the moment of inertia and consequently, their angular acceleration. Rotating solely the rod creates a severe error of above 90% from the theoretical value. Nevertheless, the objective can be examined as the error in the rod-9cm and rod-18cm is reduced to an appropriate range. There errors are calculated from the deviation of the experimental value from the theoretical one. It means that masses can be added to the system and the moment of inertia increase by the multiplication additional mass and the distance from the mass to the rotation axis(squared). The slight remaining error might contribute from the size of the mass bar which is assumed to be point mass but in practical, it is not.

Conclusion

In a nutshell, the moment of inertia of objects can be determined theoretically by integrating all infinitesimal mass points at distance r for the whole object, or experimentally by letting it spin with consistent external force acting at a distance r, naming torque – the proportion of that torque over the observed angular acceleration will result in the moment of inertia. Experiments show that angular acceleration can be calculated by fitting quadratic equation of angle of rotation over time. The conservation of angular momentum, a production of such moment of inertia and angular velocity, just like in translational motion, is shown to be conserved. Notwithstanding, the error occurring in this experiment is expected to come mainly from the moment of inertia of the pulley itself that being negligible and the movement of the axis of rotation form the center of the sensor in which the latter one is less likely to happen.

Reference

1. https://genphylab.kaist.ac.kr/labs/general-physics-lab-1/rotational-inertia/manual