

Experiment 10

Moments of Inertia

Advanced Reading

(Halliday, Resnick & Walker) Chapter 10, Sections 10-5 through 10-9

Equipment

- Beck's Inertia Thing (rotational apparatus)
- vernier caliper
- masses
- meter stick
- stopwatch

Objective

The objective of this experiment is to dynamically measure the moment of inertia of a rotating system and to compare this to a predicted value.

Theory

The moment of inertia can be viewed as the rotational analog of *mass*. Torque and angular acceleration are the rotational analogs of *force* and *acceleration*, respectively. Thus, in rotational dynamics, Newton's second Law ($F=ma$) becomes $\tau=I\alpha$, where τ is the (net) applied torque, I is the moment of inertia of the body and α is the angular acceleration.

An object that experiences constant angular acceleration must have a constant torque applied to it. By applying a known torque to a rigid body, measuring the angular acceleration, and using the relationship $\tau=I\alpha$, the moment of inertia I can be found.

In this experiment, a torque is applied to the rotational apparatus by a string that is wrapped around the axle of the apparatus (Fig. 9-1). The tension T is supplied by a hanging weight mg . The tension is found by applying Newton's second law.

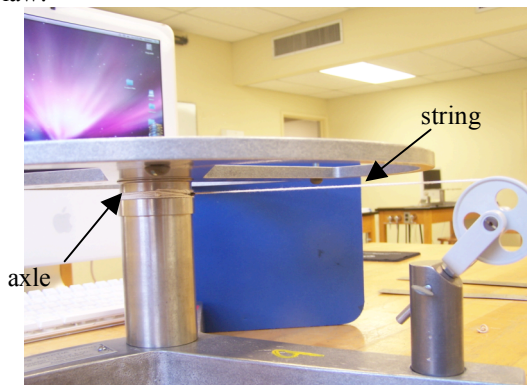


Figure 9-1 String wrapped around axle.

If we take upward direction as positive, and apply Newton's second law, we have

$$\Sigma F = T - mg = -ma ,$$

so the tension is

$$T = m(g - a)$$

The rotational apparatus has an original moment of inertia I_0 **with no additional masses added**. When additional masses are added, it has a new moment of inertia I_{new} . The relationship between I_0 and I_{new} is given by $I_{new} = I_0 + MR^2$ where M is the total added mass and R is the distance of this mass from the center of the wheel (i.e., from the axis of rotation). *Please note that it is assumed that the added masses are point masses. We will explore whether this is an appropriate assumption in the questions.*

Procedure

Part 1. Moment of Inertia of apparatus without additional weights

1. Using the vernier caliper, measure the diameter of the axle around which the string wraps. Calculate the radius. Make sure that no additional masses are added to the apparatus.
2. Wrap the string around the axle and attach enough weight on the string to cause the apparatus to rotate very slowly. The angular acceleration should be nearly zero. When this is the case, the sum of the torques on the body must be zero. The amount of mass needed is on the order of a few grams. From this data, calculate the frictional torque.
3. Place an additional 20 grams on the string. *The total mass is 20 grams plus the mass needed to compensate for friction.* Measure the distance from the bottom of the masses to the floor. Release the masses, being sure not to impart an initial angular velocity to the wheel of the rotational apparatus.
4. Use the stopwatch to time the fall. Perform a total of five trials and calculate an average distance and an average time. From this information, calculate the acceleration of the mass. Calculate the angular acceleration using $\alpha = a/r$.

approximation to assume that the masses are points in this particular case?

5. Next, calculate the tension of the string. (See the Theory section.) Be sure to use the *total* hanging mass.
6. The applied torque on the spinning wheel is provided by the tension of the string. Use the value of the tension to calculate this torque. Next, **calculate the net torque**, which is the **applied torque minus the frictional torque**.
7. Repeat steps 3-6 for **40 grams on the weight hanger** (40 grams plus friction mass).
8. **Plot the net torque vs. angular acceleration. Be sure to enter the origin as a data point.** Determine the moment of inertia I_0 , which is the slope of the best-fit line.

Part II Additional masses

9. Measure the distance from the center of the inertia wheel to the center of the outer set of tapped-holes.
10. Add the total mass of the three brass masses. The mass of each one is printed on the side and/or top. Attach the masses to the apparatus. Calculate the new moment of inertia, I_{new} , with these additional masses located at a distance R from the axis of rotation. *Measure the diameter of the masses. This information will be needed to answer one of the questions.*
11. Repeat the steps 2 through 8 for this new moment of inertia. Plot the data and determine moment of inertia I_{new} from the slope. Calculate the percent difference between the experimental value and the calculated value.

Questions/Conclusions

1. What are the units of torque? Prove your answer using dimensional analysis of the following equations: $\tau = Fr$ and $\tau = I\alpha$.
2. If the torque applied to a rigid body is doubled, what happens to the moment of inertia of the body? (Hint: read this carefully). Explain.
3. In the theoretical determination of the moment of inertia I_{new} with the additional masses, it was assumed that the masses are points. Using the parallel-axis theorem, calculate the moment of inertia such that the diameter of the masses is taken into account. Determine the percentage difference between this and the previous value. Is it a valid