Experiment 11: Torque

Up until now we have dealt with mostly translational motion in one dimension. Now we will focus on the dynamics of rotational motion about a fixed axis. When a force $\vec{F}$ is applied to body about its axis a rotation or pivot, a twisting or rotating force arises called torque. The magnitude of the torque, τ is given as the cross product between the applied force and the "lever arm", which is the length from the axis of rotation to the point where force is applied. Thus if $\vec{F}$ is exerted on a point described by the position vector $\vec{r}$, the magnitude of the torque is

$$\tau = \vec{r} \times \vec{F} = rFsin(\theta) \tag{1}$$

where θ is the angle between $\vec{r}$ and $\vec{F}$. For simplification, it is convenient to have and express $\vec{r}$ and $\vec{F}$ perpendicular to one another. In terms of Newton's second law, the net torque is given by

$$\tau = I\alpha \tag{2}$$

α is the angular acceleration about the axis due to the force, and I is moment of inertia. In the same way as the mass for translational dynamics, the moment of inertia is intimately related to how hard it is to make a system move with the application of a particular force (torque). The larger the moment of inertia, the harder it is to rotationally accelerate a system, the more energy is stored in a rotational motion and the larger the angular momentum.

For a single point particle of mass m at a distance r from the axis of rotation, the moment of inertia is found to be $I = mr^2$ from a simple analysis of kinetic energy. For a system of N particles, the moment of inertia is given by:

$$I = \sum_{i}^{N} m_i r_i^2 \tag{3}$$

where r_i, once again, is the shortest distance (perpendicular distance) to the axis of rotation. For a continuous distribution of mass, this definition my be generalized to an integral over the entire mass distribution

$$I = \int r_i^2 dm \tag{4}$$

The moment of inertia of common objects such as cylinders, spheres, etc. is usually given in tables (see your Textbook) with the axis of rotation passing through the center of mass. To calculate the moment of inertia of the body along another parallel axis, the parallel axis theorem may be applied: $I = I_{CM} + md^2$, where d is the shortest distance (perpendicular distance) from the center of mass to the actual axis of rotation.

Experimental Objectives

In this laboratory you have a rotating platform with an attachment in the shape of a rail, large masses which can be attached to the rotating rail, various masses, string, a pulley and a computer with the Scientific Workshop interface connected to the rotational measurement sensor that allows you to measure the rotational acceleration via Data Studio. The string can be wound around 3 different spool settings (bobbins), each with a different radii. Using this equipment:

- Devise an experiment to measure the moment of inertia of the rail by varying the length of lever arm, keeping the applied force constant. Convince yourself what the "lever arm" is in this set-up.
- Devise an experimental procedure to verify Newton's second law for rotational motion. First you will need to verify that torque τ is proportional to angular acceleration α for fixed moment of inertia. Then you will need to verify that for a constant torque, the moment of inertia is inversely proportional to angular acceleration. Make a graph for both of these cases and explain the slopes.

Questions

Answer these questions in your lab write-up. Show all your work.

1. Calculate the inertia of the rotational platform and of the masses which can be attached to the rotating rail at various distances from the axis of rotation and compare it the experimental measurements.
2. Can friction truly be ignored in this experiment? Explain using your data.