# TORQUE

<u>Objective</u>: To measure the angular motion of a disk, which rotates due to the application of a force.

<u>Apparatus</u>: Computer, 750 interface, rotational motion apparatus, smart pulley, pulley, 25 gm weight, string, meter stick, vernier caliper, bull's eye level, 2kg electronic scale, weights.

<u>Theory</u>:   (Giancoli Chapter 10) for linear dynamics (objects moving in a straight line), Newton's second law states that F = ma, where F is the force, m is the mass, and a is the acceleration. Here, we will find a similar equation for rotational dynamics.

Consider a force F acting on a wheel.
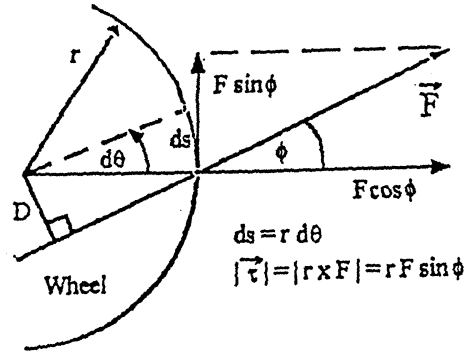
The force makes an angle φ with the radial line from the axis of rotation to the force's point of application. The tangential component of this force, which is the component that causes the wheel to spin, is Fsinφ. In a small time interval dt, the wheel rotates through an-angle dθ = ωdt, where ω is the angular velocity, measured in radians/sec. The point of application of the force moves a distance ds = rdθ = rωdt. The work done by the force is, then

$$dW = \vec{F} \bullet d\vec{s} = F\sin\varphi rd\theta = Fr\sin\varphi\omega dt$$

The rate at which the force does work is the power, which equals the rate of change of kinetic energy in time:

$$P = \frac{dW}{dt} = F\sin\phi\, r\omega = \frac{d}{dt}\left(\frac{1}{2}I\omega^2\right) = I\omega\frac{d\omega}{dt}.$$

Canceling out ω, we obtain:

$$F\sin\phi\, r = I\frac{d\omega}{dt} = I\alpha,$$

Where α is the angular acceleration.

TORQUE

The left-hand-side of this equation, Frsinφ, is the magnitude of the torque of the force F about the axis. If the line of action of the force was to pass through the origin, rsinφ would equal zero, there would be no torque, and the wheel would not accelerate. The distance rsinφ = D is called the lever arm of the force. In the experiment, the angle φ is 90 deg., since the string extends tangentially from the pulley. The distance D then, is just the radius of the pulley.

Gathering all of our equations for torque:

$$\tau = FD = I\alpha .$$

The force, F, in the above equation is not equal to the mass times the acceleration of gravity. It is, instead, equal to the tension on the string, which is given by: (verify using a free body diagram and Newton's second law.)

$$F = \text{tension} = mg - ma$$

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

The linear acceleration, a, is related to angular acceleration by the equation

$$a = D\alpha$$

So that the force can be expressed as,

$$F = m (g-D\alpha).$$

Procedure

1. Use a bull's eye level to level the rotational motion apparatus

2. Get a string about 90 cm long.

3. Tie one end to the small hole in the bottom/largest spool attached to the spindle. Tie the other end of the string to the mass holder.

4. Use calipers to find the radius (D) of the largest/lowest spool, record the value on the data page.

5. Use calipers to find the radius (p) of the smart pulley.

6. Clamp the individual pulley to the leading edge of the rotation motion apparatus.

7. Suspend the string over the individual pulley, attached to the leading edge of the rotational apparatus. Make sure the mass holder will not hit the floor at the lowest point of its fall.

8. Attach the smart pulley to the rotational motion apparatus so that it is in contact with the platen and is free to spin when the platen spins.

9. Add about 20 grams to the mass holder. Weight the mass and mass holder (m) and record its value in the data table.

10. Plug the smart pulley into channel 1 of the 750 interface.

11. Open data studio

12. Click create experiment.

13. Click channel 1 and select the smart pulley

14. Click the constants tab and make sure the smart pulley constants are set as follows: Spoke arc length 0.015, spoke angle separation 36°

15. Click on the 2nd measurement tab and check the angular velocity box. Make sure the units are in rad/sec.

16. Under display, tabs select graph and choose angular velocity.

17. Run experiment: rotate the platen to windup the string on the largest spool. Windup the string until the mass holder is just below the pulley.

18. Press start and release the platen. Allow the apparatus to run through a few (three) oscillations and click stop.

19. Using the mouse to place the cursor on the graph of angular velocity. Click and highlight the linear portion of the angular velocity graph.

20. Under the fit option, select linear fit. The slope of the linear fit is the angular acceleration of the smart pulley (α_p). Record this value on your data sheet.

21. Repeat this experiment for three different masses of about 50gm, 70gm and 170 gm.

22. Use meter stick to measure radius (r) of platen, record the value on the data page

23. Use the electronic scale to find the mass (M) of the platen, record the value on the data page.

24. Find the formula for the moment of inertia of disk. Using the necessary measurements of the disk, calculate the moment of inertia of the disk (I).

25. Using the values for the angular acceleration (α_p) of the smart pulley, as determined from the graph of angular velocity. Calculate the angular acceleration (α) of the rotating platen, using the formula, $\alpha = \alpha_p \, (p/r)$. Record these values in the data table. Calculate the applied torque (Γ_2) using your value of the moment of inertia I and angular acceleration α.

26. Calculate the applied torque (Γ_1) from the equation, m (g-Dα) D, as derived from the free body diagram.

26. Calculate the percent discrepancy between Γ_2 and Γ_1.

Questions:

1. What effect did the increased mass have in the angular acceleration?

2. What effect did it have on the percent discrepancy between the two torque calculations, why?

Suspended mass (m)	α_p (rad/sec^2)	Γ_1 m(g-Dα)D	I $\dfrac{Mr^2}{2}$	$\Gamma 2 = I\alpha$	% Discrepancy

D= _____m   Slope $= \alpha_p = \Delta\omega/\Delta t$
r= _____m
M= _____Kg
m=_____Kg
p=_____m