Rotational Motion with a Photogate Using Physlogger Technology

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1. Conceptual Objectives:

- We will observe that torque produces rotational acceleration.
- We can derive acceleration and angular displacement from angular velocity.
- We will understand and use the relationship v = r ω which connects rotational with linear motions.
- We will understand that there are frictional losses in rotational motion.

2. Experimental Objectives:

- The experiment employs a photogate (Qosain Scientific) the obstruction in the path of light between two arms.
- The rate of obstruction is measured and from it rotational speed, called the angular velocity of the object is deduced.
- The angular displacement and acceleration can be achieved by differentiation and integration of the data which can be achieved by a computer program.

3. Experimental Setup:

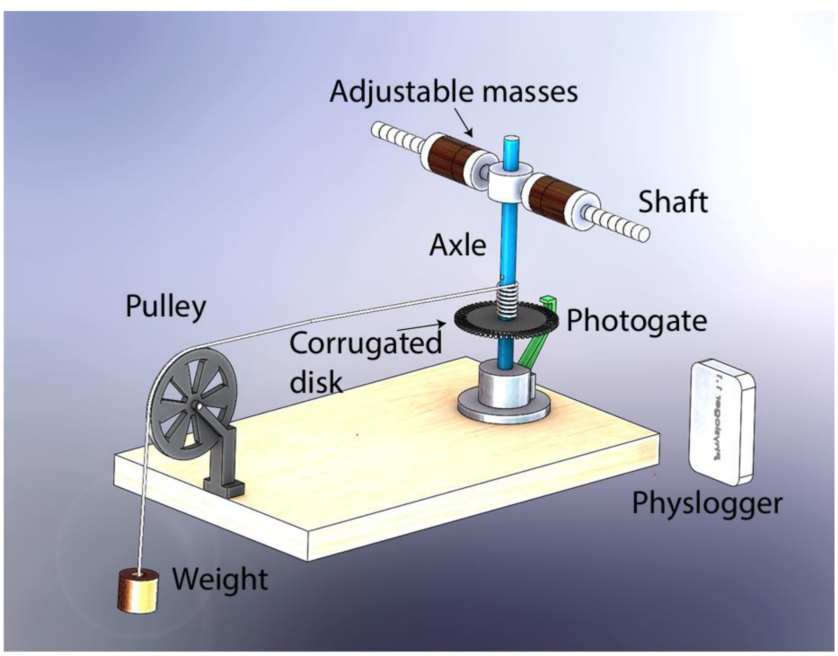

Figure 1: The setup consists of a disc having equally spaced spokes and a photogate mounted to detect the light obstruction and clear path through spokes during the rotation. A string passed through pulley and mass of approximately 500 g is attached.

4. Phase 1: Measuring angular velocity and observing how it decays

The shaft is allowed to rotate and the string wrap around the axle till mass reaches certain height. The angular velocity after releasing the mass from the height has been measured through PhysGate.

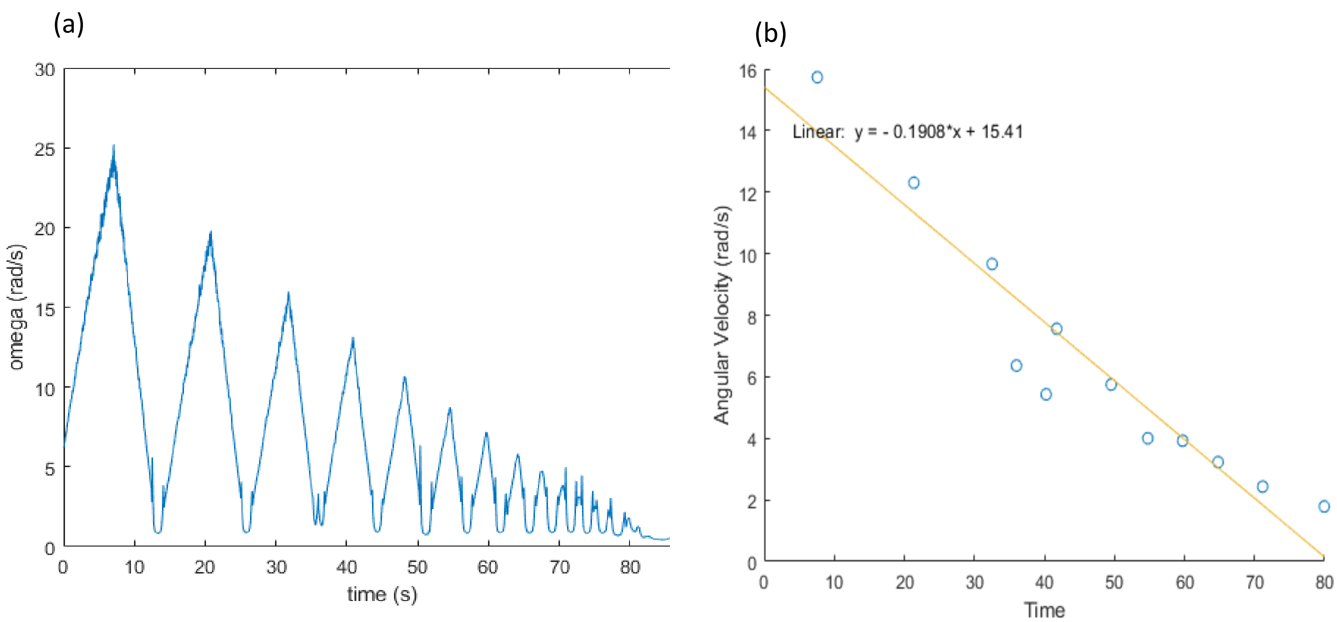

Figure 2: (a) Angular velocity-time curves for the rotational motion of the disc. (b) Linear decline of peak values of angular velocity with time. The uncertainty in angular velocity is so small that it would not appear in error bars that are not taken.

- The above figure shows that the motion is periodic.
- In each cycle, the angular velocity increases with time and starts to decline after reaching the peak values.
- The peak values of angular velocities decreases in each cycle which depicts energy loss.
- The peak values of angular velocity at each cycle decreases as a result of frictional loses and the motion eventually ceases.

4.1. The Effect of Varying Moment of Inertia on Angular Velocity of the disc

The angular velocities have been calculated and plotted for changing the moment of inertia by moving the masses close to axle on both sides of the shaft.

- The plots show that a decrease in moment of inertia speeds up the motion and the angular velocity increases.
- The law of conservation of angular momentum suggests that the angular velocity increases as the moment of inertia decreases. ($L = I\omega\ constant$).
- It is also noticed that time period decreases as the moment of inertia decreases in the figure 3.

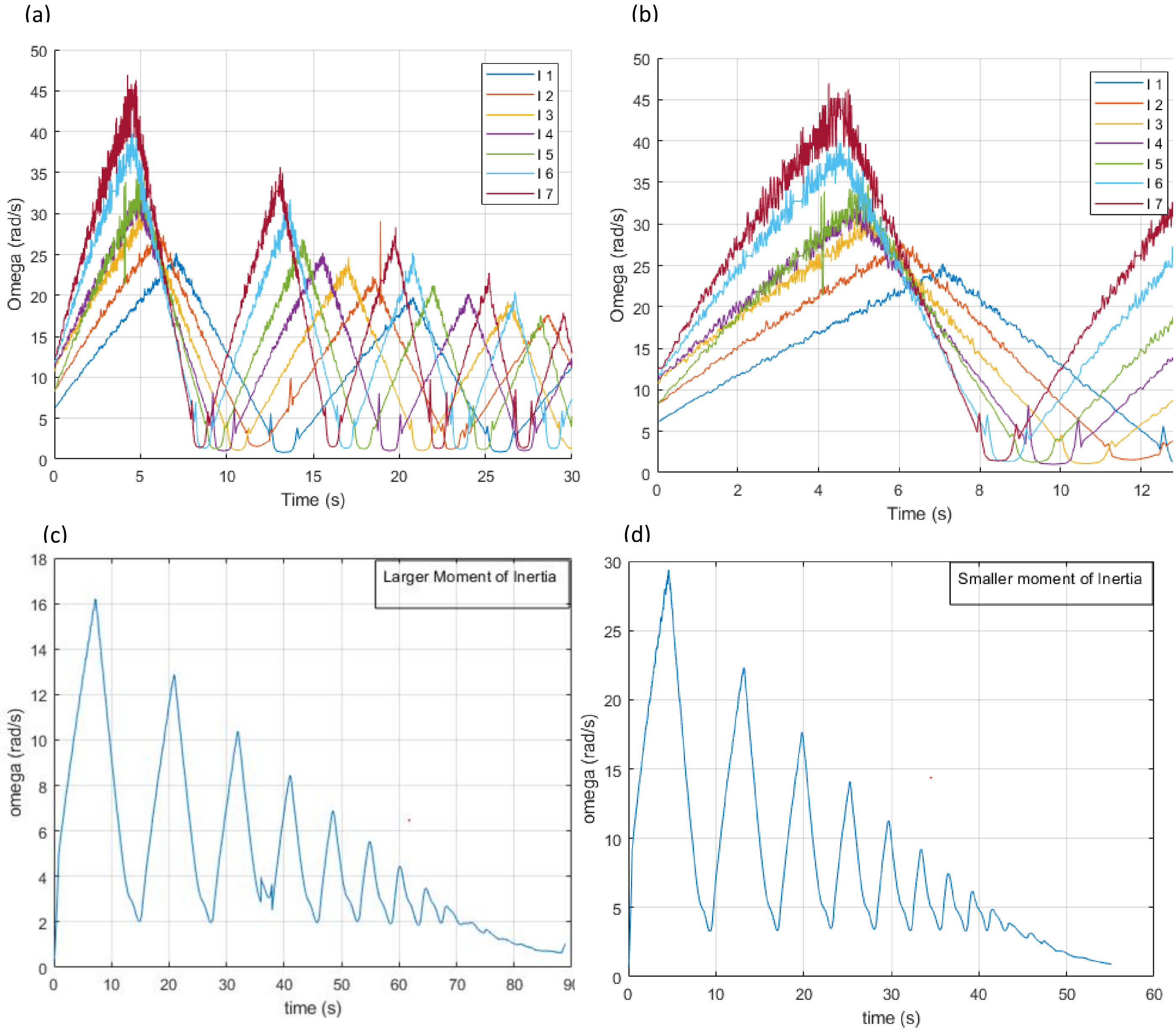

Figure 3: (a) The Angular velocity of a disc with varying the position of masses on the shaft i.e., to observe the speed at different moment of inertia. So (b) clearly shows the effect of decreasing moment of inertia. The I 1 = 5.0 × 10^{-3} Kgm^2, I 2 = 4.2 × 10^{-3} Kgm^2, I 3 = 3.3 × 10^{-3}, I 4 = 2.6 × 10^{-3} Kgm^2, I 5 = 1.9 × 10^{-3} Kgm^2, I 6 = 1.3 × 10^{-3} Kgm^2 and I 7 = 8.9 × 10^{-4} Kgm^2. (c) Filtered angular velocity verses time for larger moment of inertia. (d) Filtered angular velocity verses time for smaller moment of inertia.

4.2. Angular acceleration, revolutions and height of hanging mass

The angular acceleration can be calculated from the angular velocity using Matlab program which differentiates the angular speed in figure 4.

- Figure 4 contains the complete picture of rotational motion. The plots show that angular velocity has peaks value at specific time where the height has the lowest value so; the time where the hanging mass reaches its minimum height has maximum speed.

- In a similar way, the angular acceleration verses time plot highlights the higher angular acceleration at smaller values of angular velocities.
- The decline of peak values of height in each cycle reflects the loss of energy in each bounce of hanging mass.

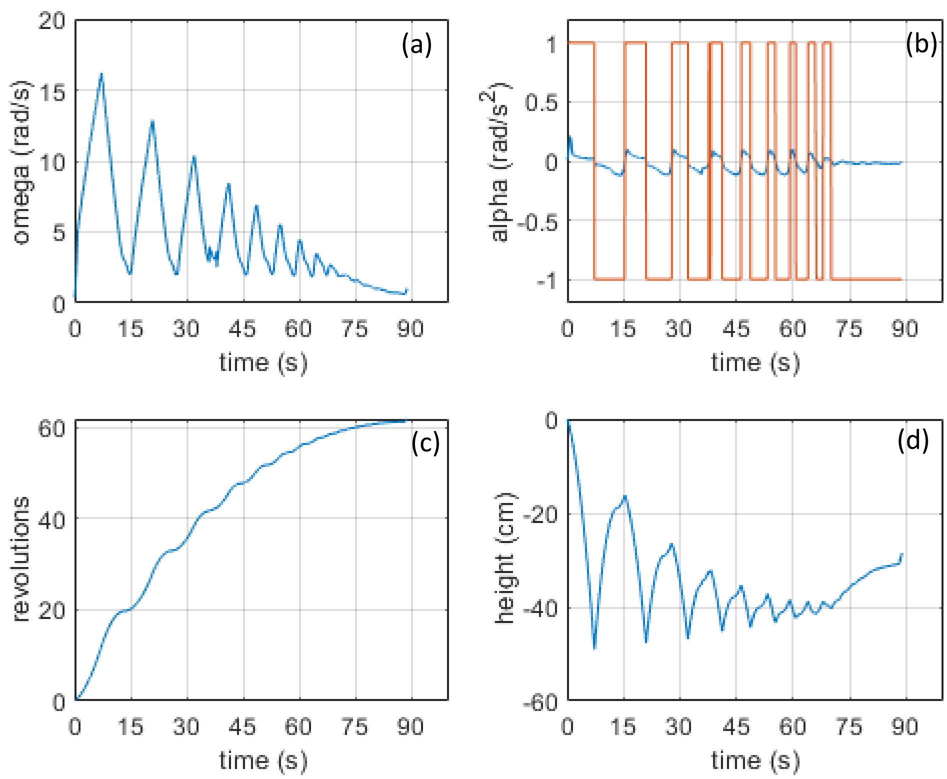

Figure 4: (a) Filtered angular velocity verses time. (b) Filtered angular acceleration verses time. (c) Revolutions (cw or ccw) verses time. (d) Depth verses time.

Phase 2: Quantifying energy loss due to frictional torque:

The energy or frictional loss is specified by the following simple relation

$$\mathrm{E} = \mathrm{mgh}.$$

Since in each bounce, the height decreases and this relates to energy loss

$$\Delta E = mg(\Delta h).$$

So, the energy loss per revolutions is given by

$$\frac{dE}{dV} = mg\frac{dh}{dV}$$

Where, ***'V'*** denotes the revolutions of the disc.

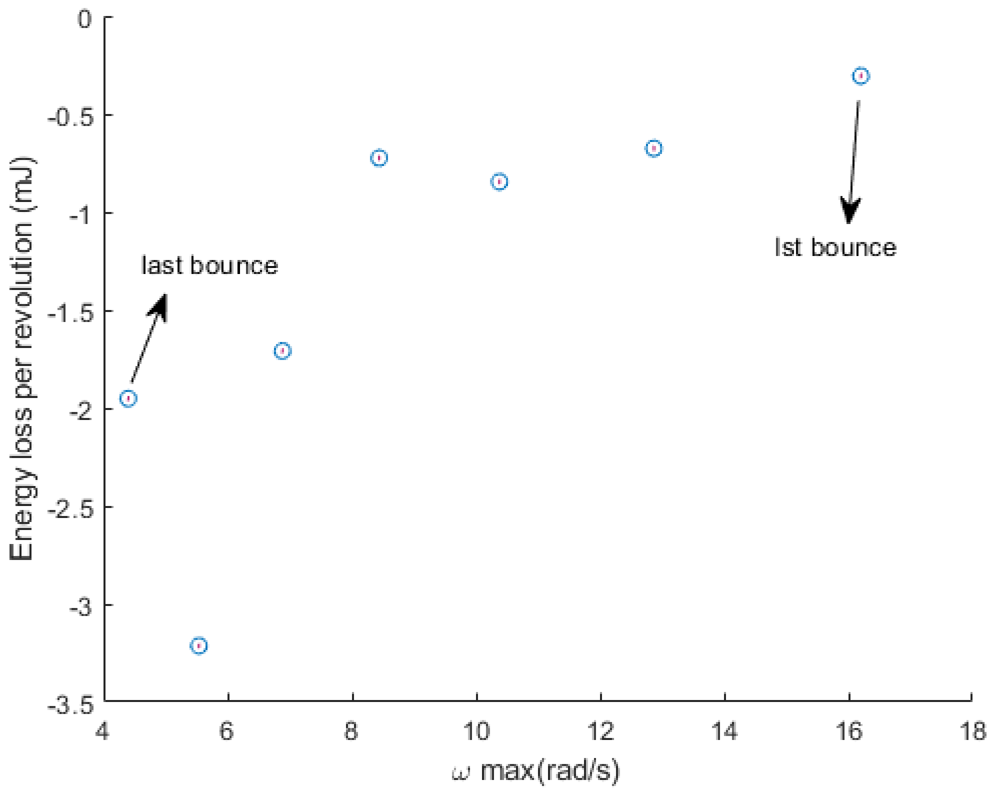

Figure 5: The energy loss in each revolution verses maximum ω achieved in bounce

- Figure 5 suggests that the energy losses per revolutions have almost a linear relationship which indicating that the frictional torque is proportional to angular velocity.

5. Total Energy loss

The total energy loss of mass while moving downward from a height of H= 0.0713 m can be calculated from the following relation

$$\boldsymbol{MgH = \{Total\ energy\ loss\} + I\omega^2}.$$

In this setup the mass of M = 0.496 Kg is allowed to move downward from a height H = 0.713 m and when it touched the ground the angular velocity at that moment have been recorded to be

$\boldsymbol{\omega}$ = 18.45 rad/sec. This is for the first bounce only.

The moment of inertia was I = 5.0×10^{-3} and the acceleration due to gravity is taken as g = 9.8 m/sec^2.

$$\boldsymbol{\{Total\ energy\ loss\ in\ the\ first\ bounce\} = MgH - I\omega^2}$$
$$\boldsymbol{\{Energy\ loss\} = (1.76\ \pm 0.01)\ J}$$

Which is 50.72 % of the total energy. Other percentage losses can be found accordingly.

Conclusion:

The experiment has been performed using Matlab programs to observe the frictional loses in rotational motion. The results and plots of this experiment explain the decline of angular velocity with time and it peak values also become smaller due to decrease in moment of inertia. The linear relationship between energy loss and angular velocity indicates that frictional forces are due to friction in the axle only.