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Energy in a Flywheel

Motor Vehicle Engineering Science(ACHA4036)

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1. Introduction

The experiment undertaken was designed to demonstrate the efficiency of a flywheel together with the release of its kinetic energy. By using kinetic energy, flywheels can transfer energy into and out of a revolving mass. There are kinetic and potential energy correlations that are demonstrated within this experiment. The inertia of the flywheel is taken into account by the potential and kinetic energy kit ES9. To determine the extent of the flywheel's total inertia, the experiment investigates the relationship between torque and acceleration.

Flywheels are used to store kinetic energy via rotation. This energy that has been stored can be released in the form of brief bursts or to smooth out fluctuations in speed. In the automotive industry, flywheels are most commonly utilised in applications such as automotive vehicles and industrial machinery. By utilising flywheels, combustion engines are able to maintain their spinning motion between power strokes.

Regenerative braking systems in automobiles are able to save energy by storing and reusing kinetic energy with the assistance of flywheels. (Mehraban, A, Ghanbari, T and Farjah, E. (2024) “Dual-inertia flywheel energy storage system for electric vehicles”)

This experiment uses mass release to transform gravitational potential energy into flywheel kinetic energy.

Falling mass potential energy is:

$$PE = mgh$$

Where m is mass (kg), g is gravity (9.81), and h is vertical height.

A falling mass rotates the flywheel by converting potential energy into rotating kinetic energy.

Flywheel-stored kinetic energy is:

$$KE = \frac{1}{2}I_t\omega^2$$

Where I_t is the total moment of inertia and ω is the angular velocity.

Some potential energy is lost when converted to kinetic energy. Air resistance, bearing friction, and other mechanical losses can cause this.

This calculation uses:

$$PE_{loss} = mgh_1 - mgh_2$$

Where h_1 is the initial height, and h_2 is the height after the flywheel lifts the mass again.

This experiment demonstrates energy conversion through a real-world mechanical mechanism.

2. Experimental Procedure

This experiment was carried out using the Potential and Kinetic Energy Kit ES9. The equipment used consisted of a flywheel mounted to bearings, a mass hanging device, a cord wrapped around the pulley, and a ruler.

1. Secure the flywheel apparatus to the worktop to prevent movement during the experiment, and make sure the shaft is checked to ensure it freely rotates. As shown in Figure 1.

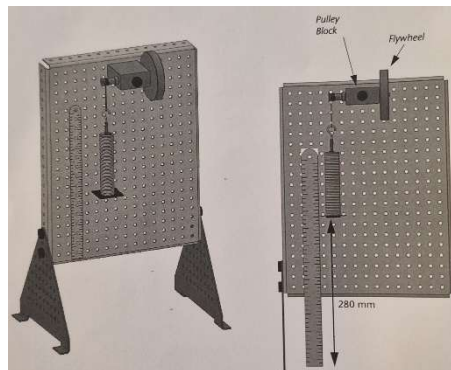


Figure 1

2. There is a break screw attached to the flywheel assembly. Make sure it is fully loosened to avoid restricted rotation. This step is done to ensure that friction is reduced and the measurements are accurate.
3. Wind the length of the cord to the pulley, which is attached to the flywheel. Take care when winding around the pulley so as not to cross over the cord.
4. Attach the weight hanger to the cord and allow it to fall to the bottom position.
5. Attach the ruler to the frame and set the bottom of the weight hanger, which has a mass of 10 g, to 0 mm position.
6. Add 90 g to the weight hanger to make the total weight 100 g.

7. Slowly wind the flywheel up, which lifts the weight, until the bottom of the weight hanger is in line with 280 mm on the ruler. (The winding rotational direction of the weight doesn't matter, i.e. clockwise) As shown in Figure 2.

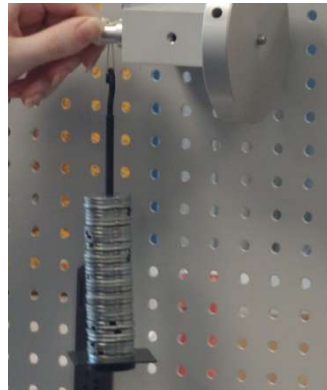


Figure 2

8. Use a stopwatch to measure the time taken for the mass to drop from 280 mm to 0 mm and lift back up to a maximum height (h_2). Repeat this at least 3 times to establish an average result of the time and height (h_2).
9. Repeat steps 7 and 8 while increasing the weight by 100 g for every 3 tests until 500 g is reached.
10. Calculate the Potential Energy (mgh_1), the potential energy loss (adjusted) values, and mg .

Make sure care was taken throughout the experiment to ensure the cord did not slip and all measurements were taken at eye level to minimise errors.

3. Results

Table 1 shows the initial raw results from the experiment.

Mass	Tt	h1	h2
(kg)	(s)	(m)	(m)
0	0	0	0
0.1	3.910	0.28	0.230
0.1	4.710	0.28	0.240
0.1	4.240	0.28	0.240
0.2	3.020	0.28	0.250
0.2	3.120	0.28	0.255
0.2	2.900	0.28	0.250
0.3	2.500	0.28	0.249
0.3	2.600	0.28	0.254
0.3	2.570	0.28	0.250
0.4	2.220	0.28	0.240
0.4	2.240	0.28	0.245
0.4	1.890	0.28	0.245
0.5	1.990	0.28	0.231
0.5	1.980	0.28	0.238
0.5	1.950	0.28	0.237

Table 1

4. Analysis

The purpose of this experiment was to determine the total moment of inertia of the flywheel system by calculating the transformation of gravitational potential energy into rotational kinetic energy. The experiment was conducted using test data. Calculations were made using the mass that was measured, the initial height, the final height, and the total amount of time. Spreadsheets were used to perform these calculations so that there would be fewer errors.

The first set of the analysis involved calculating the gravitational potential energy of the mass at its starting position. This was done using the equation:

$$PE = mgh$$

Gravity is 9.81 meters / second squared, mass is measured in kilograms, and the initial height is measured in meters. When mass is released, the total amount of energy remains available to rotate the flywheel. To determine the potential energy of the ultimate height, the same method was applied, with the second height being subtracted from the total. There is a variation in the motion energy loss.

The potential energy calculated using:

$$PE_{loss} = mg(h_1 - h_2)$$

The value of this number shows the total energy lost from air resistance, bearing friction, and mechanical losses. Both downward and upward movements cause loss.

Adjusted energy loss is calculated using:

$$PE_{loss}(adjusted) = PE_{loss} * h_1 / (h_1 + h_2)$$

This ensures that the energy loss is comparable to the kinetic energy generated only during the downward motion.

Acceleration of the falling mass is now calculated. However, the measurement of the falling time is complex, so the total time taken for the mass to fall and rise again is used. The corrected falling time is calculated using:

$$t_f = t_t * \frac{h_1}{h_1 + h_2}$$

Where 'tt' is the total measured time. Acceleration is calculated using:

$$a = \frac{2h_1}{t_f^2}$$

The maximum velocity of the falling time is calculated using:

$$v = at_f$$

The motion of the mass is directly linked with the rotation of the pulley and the flywheel. This means the linear velocity is converted to angular velocity. This is calculated using:

$$\omega = \frac{2\pi v}{c}$$

Where 'c' is the circumference of the pulley (0.0408 m). This is used to calculate the rotational speed of the flywheel.

To calculate the total moment of inertia of the flywheel, the torque relationships need to be applied. The force in the cord is calculated using:

$$F = mg - ma$$

This allows for the difference between the gravitational force and the force that is required to accelerate the mass. The torque is applied to the flywheel using:

$$\tau = Fr$$

Substituting for F gives:

$$\tau = (mg - ma)r$$

Angular accelerations equal to the acceleration of the moving mass divided by the pulley radius:

$$\alpha = \frac{a}{r}$$

Combining all these equations results in:

$$(mg - ma)r = I \frac{a}{r}$$

This equation can be best seen in Figure 3. Along with the gradient, which equals the total moment of inertia.

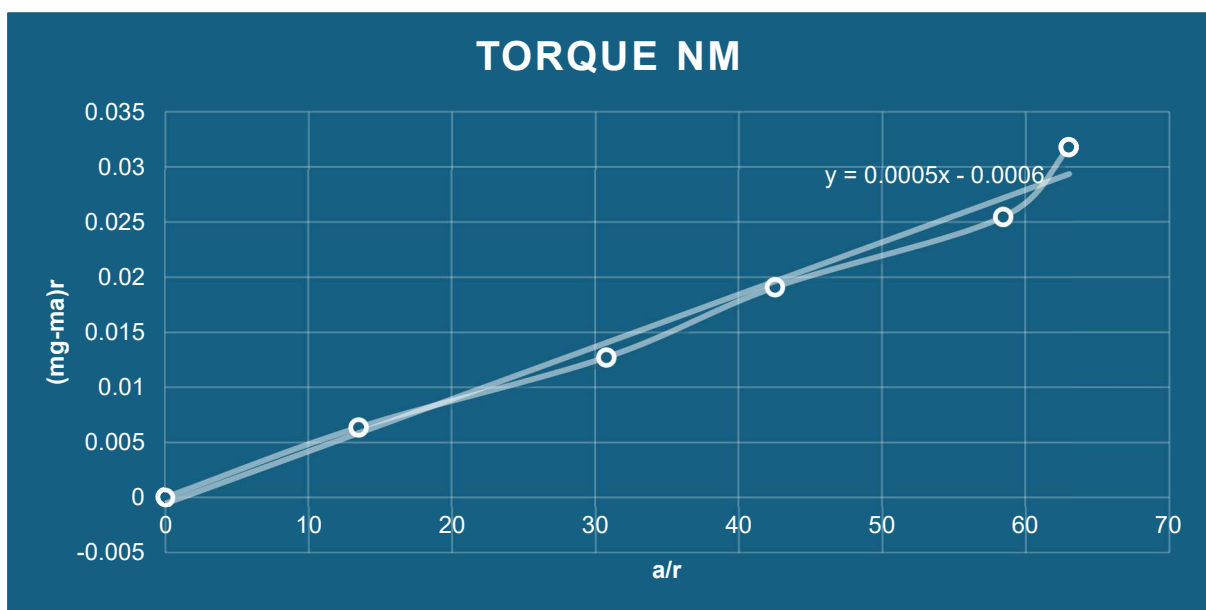


Figure 3

Plotting $(mg-ma)r$ against a/r is the subject of the graph that can be found in Figure 3. The entire moment of inertia of the flywheel can be determined by just looking at the gradient of this graph, as the theory suggests.

The relationship between angular acceleration and torque is demonstrated by a trend line that contains a linear pattern. The torque-to-angular acceleration ratio of the flywheel is exceeded when the weight is greater than 500 grams. A peculiarity was discovered in the graph.

The gradient line on the graph illustrates the overall inertia of the flywheel and its components.

The data was entered into a spreadsheet to calculate acceleration, torque, velocity, and angular acceleration.

Mass	Initial PE	T _t	h ₁	h ₂	mg	PE loss Adjusted	T _f	Acceleration	v	ω	Torque	α	KE
(kg)	J	s		m	N	J	s	m/s ²	m/s	rad/s	Nm	Rad/s ²	J
0	0	0	0.28	0	0	0	0	0	0	0	0	0	0
0.1	0.275	4.29	0.28	0.237	0.981	0.149	2.323	0.088	0.204	31.378	0.006	13.507	0.089
0.2	0.549	3.01	0.28	0.252	1.962	0.289	1.587	0.200	0.317	48.844	0.013	30.778	0.152
0.3	0.824	2.56	0.28	0.251	2.943	0.435	1.348	0.276	0.372	57.344	0.019	42.535	0.177
0.4	1.099	2.12	0.28	0.243	3.924	0.588	1.132	0.379	0.430	66.179	0.025	58.437	0.195
0.5	1.373	1.97	0.28	0.235	4.905	0.746	1.072	0.409	0.439	67.603	0.032	63.051	0.190

Table 2

The calculated potential energy was higher than the kinetic energy due to the friction in the bearings and air resistance acting on the flywheel.

h ₁ (m)	0.28
g (m/s ²)	9.81
c (m)	0.0408
r (m)	0.0065
I (kgm ²)	0.0005

Table 3

5. Conclusion

The experiment shows how the flywheel system converts potential energy into rotational kinetic energy. When the mass was freed, gravitational potential energy became kinetic energy. Friction losses prevent the mass from returning to its former height, according to the experiment.

The results confirm the mass-energy relationship. As mass increases, so does kinetic energy. The graph confirms the torque-angular acceleration relationship predicted by the theory.

The system lost energy, demonstrating that real systems are inefficient.

The experiment confirms flywheel energy storage equations and energy conversions within practical limits.

6. Evaluation

The experiment demonstrates the conversion of potential energy into rotating kinetic energy via the flywheel device. Upon the release of the mass, gravitational potential energy transformed into rotational energy. Frictional losses inhibit the mass from reverting to its original height, as demonstrated by the experiment.

The findings validate the mass-energy equivalence principle. Kinetic energy increases with mass. The graph validates the theoretical link between torque and angular acceleration.

The system experienced energy loss, illustrating the inefficiency of real systems.

The experiment validates the equations of flywheel energy storage and the principle of energy conservation within practical constraints.

7. Further Work

If there were additional time and resources available, there are several ways in which the experiment could be performed better. To obtain findings that are more specific, it is possible to utilise an electronic time and measuring machine.

It is possible to use low-friction bearings in conjunction with a heavier flywheel. These enhancements would result in an increase in the experiment's accuracies of precision.

8. References

TecQuipment Ltd. (2012) Potential and Kinetic Energy Kit ES9: Engineering Science Guidance Notes. Nottingham: TecQuipment Ltd

Mehraban, A, Ghanbari, T, and Farjah, E. (2024) “Dual-inertia flywheel energy storage system for electric vehicles” IETs Electric Power Applications

9. Abbreviation

Abbreviation	Description
ω	Angular Velocity
g	Gravity
h	Height
I	Inertia
Kg	Kilogrammes
KE	Kinetic Energy
m	Mass
mm	Millimetres
PE	Potential Energy
t	Time