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Energy in a Flywheel

Further Science for Engineers (ACHA4007)

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Introduction

This experiment studies the motion of a weight hanger, the resulting acceleration, and the energy transformations associated with a flywheel. The key objective is to determine the flywheel's moment of inertia by measuring and calculating potential energy (PE), kinetic energy (KE), acceleration, and velocity.

Experimental Procedure

Equipment:

- Bearing Block/ Pulley Block
- Flywheel
- Magnetic Rule
- Weight Hanger
- Weights
- Plastic Guide

1. Setting up Experiment:

Plastic Guide: The plastic guide is securely attached to the bottom of the weight hanger to control its movement and ensure a consistent path.

Cord Length: The cord may be pre-cut, however, if not, the weight hanger needs to fall through a vertical distance of just under 290mm. This drop allows for measurable motion during the experiment.

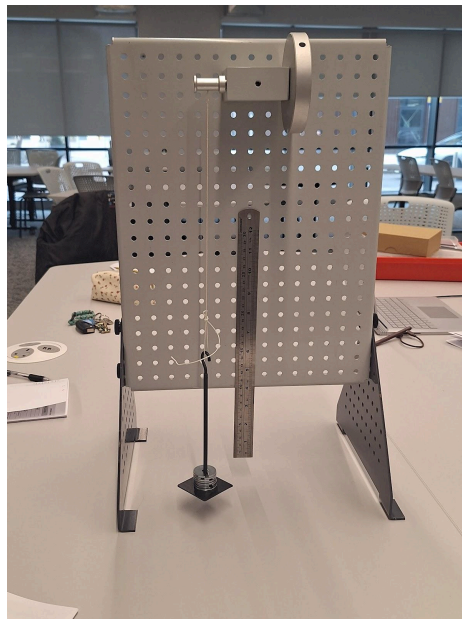


Figure 1: Experimental Setup of Flywheel (Photo by Bekka Pratt, 2025)

2. Measuring Distance and adding Mass

Magnetic Rule: After the weight hanger has fallen, position the magnetic rule behind it so that the 0mm mark on the rule aligns with the plastic guide at the bottom of the weight hanger.

Adding Mass: A total of 100g of mass is added to the weight hanger, consisting of 90g in additional masses. This mass is used in subsequent calculations for potential energy and forces acting on the system.

3. Lifting the Weight Hanger

Raising the Hanger: Slowly turn the flywheel to lift the weight hanger. The weight hanger is lifted until the bottom reaches the 280mm mark on the magnetic rule. This height is used as the starting point for the fall, providing a consistent reference for time measurements.

4. Measuring Time and Heights

Time Measurement: The stopwatch measures the time it takes for the weight hanger to fall from the 280mm position to the 0 mm position. After reaching 0mm, the weight hanger rises back to its maximum height (h_2). Repeat the process multiple times to obtain an average time for both the fall and rise, improving the accuracy of the results.

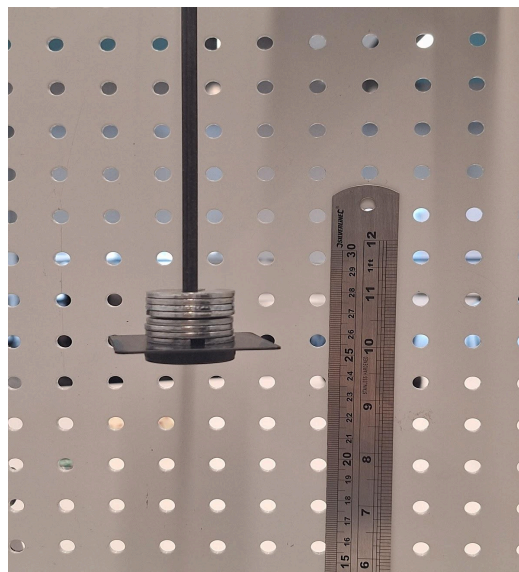


Figure 2: Closer setup of weight hanger. (Photo by Bekka Pratt, 2025)

Results

Time (seconds)

kg/trials	1	2	3
0.0	0	0	0
0.1	4.16	3.17	4.23
0.2	2.85	2.72	2.66
0.3	2.41	2.34	2.53
0.4	2.01	2.07	2.27
0.5	2.13	1.68	2.20

Table 1: Time to fall and rise in seconds. (Own Data, 2025)

Height (mm)

kg/trials	1	2	3
0.0	0	0	0
0.1	248.5	250	255
0.2	255	260	265
0.3	265	267	262.5
0.4	255	245	255
0.5	247	247	240

Table 2: Height of final fall

Analysis

Calculations

In this experiment, nine different calculations were conducted. A flywheel experiment is commonly used to analyse the moment of inertia and angular motion properties by allowing a mass to fall, unwinding a string wrapped around the wheel. The energy stored in a flywheel is calculated by the equation, $KE = \frac{1}{2}I\omega^2$, where KE represents Kinetic Energy, ω is angular acceleration, and I is expressed as $I = kmr^2$. I is the result of K (the inertia constant of the flywheel), m is the mass (kg) and r is the radius. (Pauel, 2023).

The Potential Energy loss (PE_{loss}) represents the total energy lost during both the downward and upward motion of the flywheel. If the mass returns to its original height (h_1), all kinetic energy is transferred back to the mass, making potential energy equal to kinetic energy. However, due to friction in the bearing block and other factors some energy is lost, preventing the mass from reaching its original height. The potential energy loss is calculated as: $mg(h_1 - h_2)$. To better compare this with kinetic energy, particularly the downward motion, the potential energy loss is adjusted by multiplying by the height ratio: $PE\ loss\ (adjusted) = PE\ loss \times h_1/(h_1 + h_2)$.

Graphical Data

Looking at the graph, the data points to a positive correlation between torque and angular acceleration, this is shown as when the angular acceleration increases, the torque also increases. This suggests a direct proportionality between the two variables. The equation of the best-fit line is $y = 0.0004x - 0.0015$, which closely follows a linear trend. This suggests that torque and angular acceleration are linearly related, which is consistent with Newton's 2nd law for rotational motion "Newton's Second Law may be extended to include rotational motion: torque is equal to the moment of inertia times the angular acceleration." (torque = Inertia x angular acceleration), where torque is proportional to angular acceleration. The small negative intercept (-0.0015) suggests a minor systematic error or frictional losses in the system. The slope (0.0004) represents the moment of inertia of the system, determining how the flywheel responds to applied torque.

Conclusion

Heavier masses should, theoretically, result in larger PE losses due to increased gravitational PE. However due to the following factors, the losses increase only up to a certain point.

Increased Frictional Losses

As mass increases, the forces acting on various components of the system also increase, which often results in higher frictional losses.

Bearing Friction: The bearings that support the flywheel must handle not only the rotational forces but also the additional weight that comes with a heavier mass. This increased load puts extra pressure on the bearings, which leads to more friction between the bearing surfaces. Friction, in turn, dissipates some of the energy as heat, reducing the system's efficiency. The more friction there is, the more energy is lost as thermal energy rather than being converted into useful kinetic energy.

Cord Tension: In systems that involve a cord or a rope mechanism to drive the flywheel, heavier masses increase the tension in the cord. Higher tension results in increased friction where the cord makes contact with pulleys or other parts of the system, further contributing to energy loss. This additional tension can also lead to wear and tear, requiring more maintenance and increasing the frequency of friction-induced losses over time.

Energy Loss at Rest (Static Friction): Before the flywheel starts moving, friction in the bearings or contact points causes energy to be wasted in the form of heat. This means that any attempt to rotate the flywheel will require overcoming this initial resistance. To overcome this, 'the flywheel is placed inside a vacuum containment to eliminate friction-loss from the air and suspended by bearings for a stable operation.' (Bolund, Bernhoff and Leijon, 2005)

Energy Loss During Motion (Kinetic Friction): Even when the flywheel is moving, kinetic friction continues to dissipate energy, albeit at a lower rate than static friction. This leads to gradual slowing down of the flywheel if the applied force is not maintained.

Impact on Flywheel Efficiency: The more friction there is, the more energy is lost as heat, which reduces the overall efficiency of the flywheel. For a flywheel to be most efficient, friction needs to be minimized, which is why high-quality bearings, lubricants, and low-friction materials are used in many flywheel designs.

Air Resistance becomes more significant.

As the flywheel's mass increases, it tends to spin faster (assuming the same energy input). Faster spinning means that air resistance, or drag, becomes a more significant factor in energy losses.

Higher Speed = More Drag: Drag force is proportional to the square of the velocity. This means that as the flywheel spins faster, the air resistance acting against it increases exponentially. For example, doubling the speed of the flywheel results in four times the drag force. While this is true for all objects in motion, the impact is particularly noticeable at higher speeds, which are common in heavier flywheel systems. The faster the flywheel spins, the more energy is dissipated in overcoming air resistance.

Effect of Shape and Surface Area: The design of the flywheel also influences the magnitude of air resistance. A larger, less aerodynamic flywheel will experience greater drag. For a heavier flywheel,

even if the design is more aerodynamic, the increased speed will still lead to greater drag forces, compounding the energy losses.

The comparison between the given nominal values and the calculated value of I is an 80% similarity with the nominal value of 0.0005 and the calculated value of I being 0.0004. The discrepancy in the results could be due to the frictional losses, although this experiment assumes minimal friction, friction in the bearings, pulley or air resistance could lead to energy loss. As well as, potential measurement errors in timing and height measurements, which could be due to human reaction time when using a stopwatch which would impact the recorded fall times.

The small negative intercept (-0.0015) suggests minor systematic measurement errors which can be easily rectified by having a camera set up in slow motion to capture the exact height measurements.

Evaluation

The flywheel experiment aimed to investigate rotational motion by measuring the moment of inertia and angular velocity of a flywheel. While the experiment provided valuable insights into energy conservation and rotational dynamics, several factors influenced the accuracy and reliability of the results.

Accuracy and Reliability

The results generally followed the expected trend, with angular velocity increasing as predicted by the equations of motion. However, discrepancies arose due to measurement limitations. The moment of inertia, calculated from experimental data, was slightly different from theoretical values, suggesting minor inaccuracies in mass distribution or measurement errors.

Strengths

The setup of the experiment effectively demonstrates the conversion of gravitational potential energy (GPE) into kinetic energy (KE). The use of a falling mass provides a controlled way to transfer energy into the flywheel.

The drop height (280mm) is fixed, allowing for precise calculations of initial energy. The rotational motion of the flywheel can be measured. (Angular velocity and moment of inertia).

Sources of Error:

Timing Errors: The reaction time of the person measuring the fall time of the weight hanger may be the reason for inconsistencies with the time measurements, which could impact the recorded times and create anomalies.

String Slippage: Slippage means that not all of the falling mass's gravitational force is transferred to the flywheel, resulting in a lower angular velocity. If slippage occurs then it can cause irregular acceleration, making it difficult to accurately measure the relationship between time, velocity and rotational motion.

Further Work

If the experiment were to be repeated in the future with unlimited time and resources, several improvements could be made to enhance the quality of the results. First, conducting more trials would help confirm any trends found in the original and provide a larger data set from which to conclude. This would help minimise any outliers' impact and improve the findings' reliability.

Additionally, it would be valuable to explore factors like friction and air resistance, as these could have influenced the results. By controlling or measuring these variables more precisely, a clearer understanding of their effect on the experiment could be achieved.

Furthermore, using higher-precision measurement tools would significantly improve the accuracy of the data collected. Tools such as timing gates and high-speed cameras would allow for more precise measurements of time and height. Slow-motion cameras could also be used to track fast-moving objects with greater accuracy, eliminating the potential for human error in the process.

Incorporating these improvements would provide more reliable data and a deeper insight into the core principles being investigated.

References

Bolund, B., Bernhoff, H. and Leijon, M. (2005) 'Flywheel energy and power storage systems,' *Renewable and Sustainable Energy Reviews*, 11(2), pp. 238. Available at: <https://doi.org/10.1016/j.rser.2005.01.004>. (Accessed on: 21 March 2025)

Pauel, T. (2023) *Technology*, *QuinteQ Energy*. Available at: https://quintegenergy.com/technology/#:~:text=The%20energy%20stored%20in%20a,%3D%20k%20*%20m%20*%20r2. (Accessed: 12 March 2025).

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H1 (m)	0.28
G (m/s2)	9.81
C (m)	0.0408
R (m)	0.0065
I (kgm^2)	0.0005
I	0.0005

Mass (kg)	PE (J)	Time to fall and rise (seconds)	Height (m)	Weight (mg)	PE loss adjusted (J)	Falling Time (seconds)
kg	J	s	m	N	J	s
0	0	0	0	0	0	0
0.1	0.27468	3.853	0.25116	0.981	0.0149141	2.031
0.2	0.54936	2.743	0.260	1.962	0.0203467	1.422
0.3	0.82404	2.427	0.26483	2.943	0.0229442	1.247
0.4	1.09872	2.117	0.25166	3.924	0.0585670	1.115
0.5	1.3734	2.003	0.24467	4.905	0.0924814	1.069

Acceleration (m.s-2)	Velocity (m.s-1)	Velocity (rad.s-1)	Angular Acceleration	Torque	Kinetic Energy (KE)
m/s^2	m/s	rad/s^2		Nm	J
0	0	0	0	0	0
0.135745259	0.276	42.45961522	20.88388601	0.006288	0.423301883
0.276826632	0.394	60.63420017	42.5887126	0.012393	0.863243663
0.359960161	0.449	69.14184079	55.37848638	0.018428	1.122483506
0.450503555	0.502	77.35044737	69.30823919	0.024335	1.404829933
0.490097549	0.524	80.6779741	75.39962294	0.030290	1.528298056

Torque (Nm) against angular acceleration

