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Energy in a Flywheel

Further Science for Engineers (ACHA 4007)

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1. Introduction

This report covers a technical insight into a kinetic energy experiment carried out to observe the effects of varied masses being accelerated by gravity, which in turn rotates a flywheel of known properties, collecting data to prove and validate given values of the flywheel.

The experiment contains converting gravitational potential energy into rotational energy, storing energy within a flywheel as kinetic energy, finally raising the weight (mg) again showing conservation of energy where energy cannot be created or destroyed only transformed also considering where energy in the system could be lost (transformed). (Stallo, 1960)

2. Experimental Procedure

The apparatus required to conduct the research experiment was provided in the potential and kinetic energy kit ES9, the first step was to assemble the kit according to the ES9 guidance booklet ensuring everything was assembled level and securely to try to reduce errors.

The cord was precut by the UWTSD lecturer who provided the kit this was cut at such a length that allowed the weight hanger to drop 0.29m, the extra length ensures the weight hanger is centred to the pulley axle eliminating unnecessary movement in other planes.

A magnetic rule was then placed on the chassis of the test rig and zeroed so that 0mm was at the bottom of the stroke of the weight hanger (with no weights attached), as shown in figure 2.

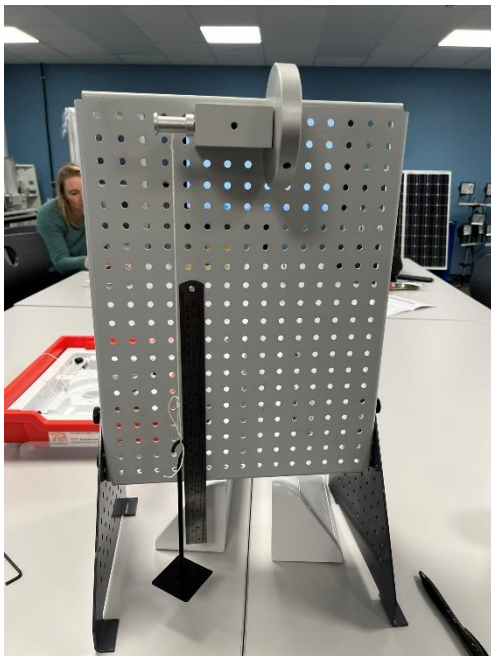


Figure 2- Assembled Test Station

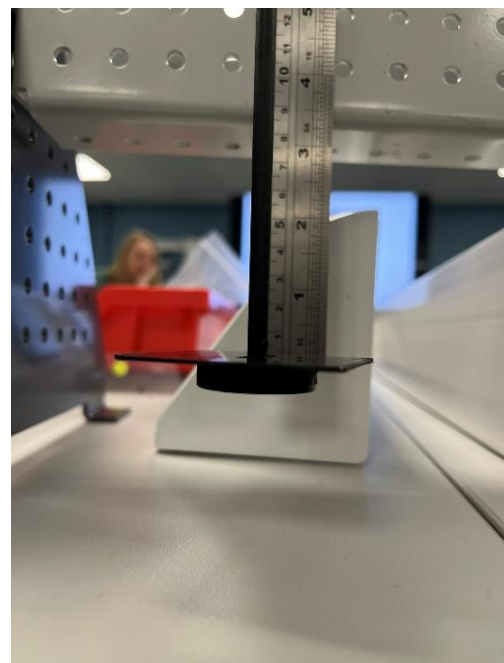


Figure 1 - Zeroing the Rule to the bottom of the Stroke

The desired data was for weights between 0.1 and 0.5 Kg in 0.1Kg increments; to get to the starting value, 0.09 Kg needed to be added to the weight hanger, as the hanger body itself weighed 0.01Kg, shown in figure 4.

The next step is to record data, by rotating the flywheel to raise the weight hanger until the bottom of the hanger was level with 0.28m, this is the drop height (h_1) as shown in figure 3.

The rest of the process is to use a stop watch to record the total time taken for the weight set to drop from the h_1 point to the 0 point (bottom of its stroke) and return up to its maximum height (h_2), taking note of the total time taken for this process and the height it returned to being h_2 .

This was repeated 3 times for each weight set (0.1 Kg to 0.5 Kg) to obtain an average cycle time and an average return height (h_2) any results that were obscured by human error were discarded at this stage and re taken.

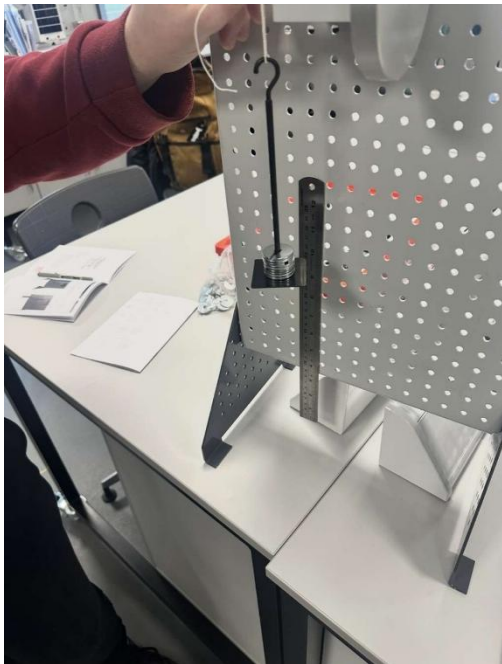


Figure 3 - Weight Hanger being set to 280mm (h_1).

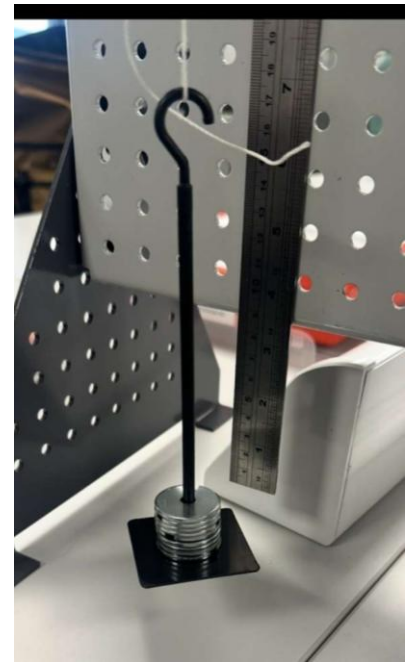


Figure 4 - Weight hanger with 0.09 Kg added.

3. Results as Raw Lab Data

Table 1 Shows the Raw data collected in the lab by following the methodology in section 2 written in excel for legibility purposes.

Table 1- Raw lab data Collected

Mass (Kg)	Time to Fall and Rise 1 (s)	h2 1 (m)	Time to Fall and Rise 2 (s)	h2 2 (m)	Time to Fall and Rise 3 (s)	h2 3 (m)
0.1	5.05	0.24	4.55	0.237	4.45	0.238
0.2	3.01	0.255	3.15	0.255	3.15	0.253
0.3	2.83	0.255	2.86	0.255	2.55	0.255
0.4	2.53	0.252	2.36	0.248	2.2	0.254
0.5	2.03	0.227	2.06	0.225	2.01	0.23

Table 2 – Table of Constants

h1 (m)	0.28
g (m/s²)	9.81
c (m)	0.04084
r (m)	0.0065

4. Analysis of Raw data

4.1 Calculating Values using the data collected.

Table 3 - Calculated Values Using Collected Lab Data

Mass m (Kg)	PE mgh ₁ (J)	Average Time to Fall and Rise t _{ta} (Seconds)	Average h ₂ (m)	mg (N)	PE loss Adjusted (J)	Falling Time T _f (Seconds)	Acceleration a (ms ⁻²)	Velocity v (ms ⁻¹)	Angular Velocity ω (rads/s ⁻¹)	Torque (mg-ma)r N/m	α/r rad/s ²	KE J
0	0	0	0	0	0	0	0	0	0	0	0	0.000
0.1	0.275	4.68	0.238	0.981	0.022	2.53	0.087	0.221	34.05	0.006	13.5	0.257
0.2	0.549	3.10	0.254	1.962	0.026	1.63	0.212	0.344	52.98	0.012	32.6	0.623
0.3	0.824	2.75	0.255	2.943	0.039	1.44	0.271	0.390	59.93	0.019	41.7	0.797
0.4	1.099	2.36	0.251	3.924	0.059	1.25	0.361	0.450	69.18	0.025	55.5	1.061
0.5	1.373	2.03	0.227	4.905	0.143	1.12	0.445	0.499	76.77	0.030	68.4	1.307

Table 2 shows an average of the raw data collected (table 1) being used to calculate other values that are relevant to the inertia experiment carried out, all of which will eventually allow us to obtain a calculated inertia value.

One of the most critical yet most simple calculations is the Gravitational Potential Energy (PE) calculation as this is either directly or indirectly involved in all the calculations, gravitational potential energy is the stored energy in an item that can be accelerated by gravity is raised above a given datum. (Smith and Holroyd, 1968)

The P.E calculation is (Mass * Gravity * h₁) some of which are values in our table of constants (Table 3), this however can be where error starts to appear, as the constant of h₁ is meant to be 280mm however this was set by human hands so there is the possibility of variance, this was tried to be minimised by using the same member to do this part for every recording however cannot be ruled out, furthermore there was not the facility to validate the accuracy of the provided weights.

The constant values for gravity, h₁ and the circumference were all provided in the ES9 kit, using the PE calculation allows us to know how much energy is stored in the weight block before it drops and accelerates itself and the flywheel.

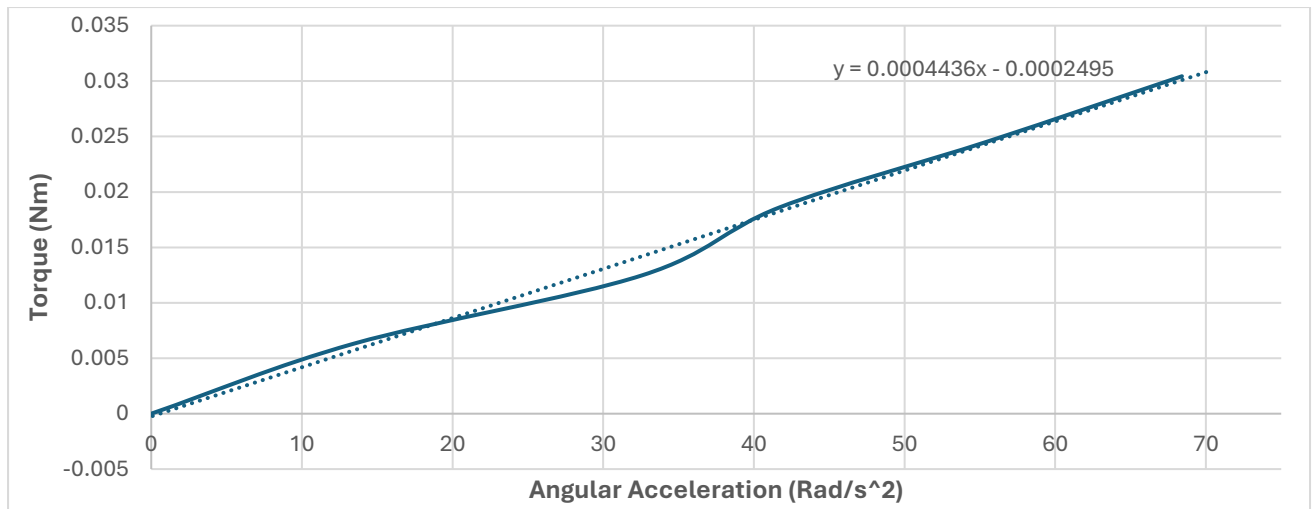


Figure 5 -A plot of Torque over Angular Acceleration (calculated)

The Graph in Figure Six shows a plot of the calculated Torque over Calculated Angular Acceleration, using the data from the experiment.

There is a few ways to calculate torque the most straightforward option $T = I\alpha$, (T = Torque, I = Inertia, α = Angular Acceleration), however one of the objectives of this experiment is to obtain an inertia value, if we use the given combined inertia of the rotating assemblies in ES9 (0.0004696 Kg/m²), the calculated Inertia will return to this value as it is already given, so instead $((mg - ma) \cdot r)$ is used this allows to calculate torque without an inertia value, in this scenario the acceleration of the falling weight due to gravity is used this links back to the original potential energy due to the weights being raised.

When calculating angular acceleration (α) in the flywheel the equation used is $\alpha = \frac{a}{r}$ which is the acceleration of the moving mass divided by the pulley radius, when this value was obtained, it allowed for a plot to be developed (figure 6) and a trendline to be calculated, there is a general trend showing that as the angular acceleration increased the torque also increases, both the trendline and plot are relatively linear within our working resolution however the plot does have some more deviation, this could be due to errors in our procedure and the working environment.

4.2 Calculating the moment of Inertia from the data set.

Looking at the calculated values we can take $T = I\alpha$ and rearrange it to become $I = \frac{T}{\alpha}$, there is now enough calculated data to satisfy the equation with the moment of inertia being torque value per unit of angular acceleration, this is what is plotted in the graph therefore the equation of the trendline of the graph which is displayed in figure 6, therefore the value of Inertia is calculated to be 0.0004436 Kg/m².

4.3 Calculating Kinetic Energy

The kinetic energy equation for angular motion $KE = \frac{1}{2}I\omega^2$, can now be satisfied using our experimental values.

Table 4 -Calculated Kinetic Energy taken from Table 3

KE (J)
0.000
0.257
0.623
0.797
1.061
1.307

4.4 Potential Energy

Table 5 - Mass and Kinetic energies from table 3

Mass Kg	PE mgh 1 (J)	PE Loss (J)	PE loss Adjusted (J)
0	0	0	0
0.1	2.747	0.040	0.022
0.2	5.494	0.050	0.026
0.3	8.240	0.073	0.038
0.4	10.987	0.112	0.059
0.5	13.734	0.258	0.142

5.0 Conclusion

Looking at the data in Table 5, the relationship between accelerated mass and kinetic energy is that as the accelerated mass increased (also increasing the potential energy), the kinetic energy also increases. The potential energy loss also increases for the downward stroke, the loss adjusted potential energy also increases, this accounts for taking in the full down up cycle by including the height ration in the PE loss equation.

The ES9 Kit mentions that increasing the mass should give large PE losses until a certain amount of mass, possibly implying that at a given mass, the PE loss does not increase or that it exponentially starts to decrease to the point that it is not noticeable, the data found in the experiment does support part of this, however the data set is not large enough or possibly does not have the resolution to show this.

The table also shows that as the mass increases, other relating values also increase such as the angular velocity and torque of the flywheel.

However, as the mass increases the fall and cycle times decrease due to the higher velocity and larger acceleration values.

5.1 Comparing Inertia Values

The Nominal value of inertia was calculated by adding the values from Table 2 – Nominal Weights of the TecQuipment ES9 Guidance document, using value from the flywheel ($3.862 * 10^{-4} \text{ Kgm}^2$) and the value from the pulley ($0.834 * 10^{-4} \text{ Kgm}^2$), giving a total of 0.0004696 Kgm^2 .

The value of inertia from the equation of the line of the data set is 0.0004436 Kgm^2 , these numbers are different however they're close enough for the difference to be accounted for within the practice of the experiment, using the percentage error equation, $\text{Percentage Error} = \left(\frac{\text{Calculated Inertia} - \text{Nominal inertia}}{\text{Nominal Inertia}} \right) * 100$, we can look at

our difference value as a percentage. $\frac{0.0004436 - 0.0004696}{0.0004696} * 100 = 5.5\%$

A percentage error of 5.5% is a satisfactory amount given the very basic measuring techniques used within the experiment.

(Cuemath, no date)

6.0 Evaluation

Throughout the experiment there were several procedures followed to minimise error.

6.1 Friction in the flywheel

There was no account for friction in the flywheel, throughout the experiment so this was ignored, however, to keep consistency throughout, the flywheel was always wound up in the same direction, in case the internal resistance of the rotating assembly was different depending on direction of rotation.

6.2 Keeping Personnel Constant

To reduce human error, each member involved in the practical kept the same job role throughout to keep practices of different components consistent.

6.3 Elimination of interfered data

Any test runs that were deemed to be affected by actions of any one involved in the experiment were either not recorded or eliminated from the raw data at the point of test.

7.0 Further investigation

7.1 The Human Element

To improve the accuracy of the investigation the biggest variables to remove would be the human aspects of measuring.

Instead of using a human as a drop mechanism, a mechanical drop mechanism could be used, this would increase accuracy by increasing the consistency of the release, furthermore an electronic drop mechanism could also be used to trigger the start of the stop watch removing the communication timings between the operations when done by humans.

A highspeed camera could be used to replace the human eye measuring the h_2 value, this could also be linked into the timing data and drop mechanism so then the data can be reviewed at extremely high resolution and frame rate.

7.2 Validation and Accuracy of Components

Another area that could improve the investigation would be to increase the quality of the components and validating the accuracy, such as the string used had a noticeable amount of elasticity, using a much stronger nylon rope could help reduce the inaccuracy by reducing stretch past the datum point which in turn would increase then accuracy of the time, the less energy absorbed by the string the better.

High accuracy scales could also be used to validate the weight of the hanger & weights, as the variance in weights were unknown, this could be eliminated by weighing the hanger with every mass change to know we are absolute with the weight values within the calculations throughout the experiment to prevent carried errors.

8.0 References / Bibliography

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