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Energy in a Flywheel Experiment

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1 Introduction

This assignment is a report of an experiment to measure the energy acting on rotating mechanical components such as flywheels or crankshafts. In this experiment the energy acting on a flywheel was calculated, weights falling from a pulley attached to the flywheel were recorded for total time T_t and height returned to H_2 . To then determine the kinetic $K.E$ and potential $P.E$ energy stored in the flywheel. To ensure reliable and consistent results multiple attempts were completed on each weight tested. The times and heights of each attempt were then averaged out to find the linear acceleration, velocity, angular velocity, torque applied, and angular acceleration these figures were then used to work out the $P.E$ and $K.E$ stored in the flywheel. This specific experiment is directly equivalent to a flywheel KERS (Kinetic Energy Recovery System) which has been used in various motorsports categories such as Formula 1 and the World Endurance Championship. With the KERS (Kinetic Energy Recovery System) recovering lost kinetic energy from the vehicles drivetrain under braking to be stored as electrical energy in the battery to be deployed later in the lap providing greater acceleration and torque, this gives the experiment relevance to industry (FIA F1 2009) (Bolund, Bernhoff and Leijon, 2007).

2 Experimental Procedure

Equipment 2.1

During this experiment, a potential and kinetic energy kit supplied by TecQuipment was used. The kit included a flywheel and pulley system which were connected via a bearing, calibrated masses of 0.01kg each, a magnetic ruler to measure the drop and fall heights, a stopwatch to measure the time to fall and rise and, a 0.29m piece of string. the apparatus was then connected to a board which was sat on the workbench.

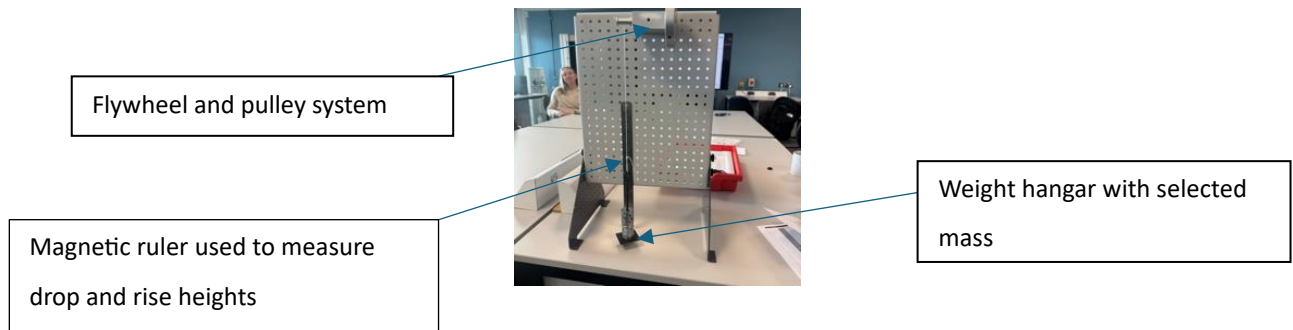
Setup 2.2

The string was then wrapped around the pulley, and the free end of the string was then attached to the weight hanger which weighed at 0.01kg. The drop height was then measured using the magnetic ruler from the initial drop height H_1 which was 0.28m.

Method 2.3

1. Selected mass added to hangar
2. Initial drop height measured
3. Selected mass released from H_1
4. Time taken to fall and rise T_t measured and height returned to H_2 noted
5. Repeat 3 times for each selected weight
6. Average H_2 and T_t calculated

(Figure 1) Experimental Setup



3 Data processing 2.4

The linear acceleration was calculated using SUVAT acceleration equations assuming that acceleration was constant (Hibbeler,2016)

$$s = \frac{1}{2} at^2 \quad a = \frac{2s}{t^2}$$

final linear velocity was then calculated using.

$$v = u + at$$

Angular velocity was then calculated using.

$$\omega = \frac{v}{r}$$

Torque applied to the flywheel was calculated using.

$$T = (mg - ma)r$$

The moment of inertia (I) was determined from the gradient of the graph (figure 1) torque vs angular acceleration

$$T = I \alpha$$

The kinetic energy $K.E$ of the flywheel could then be calculated using

$$ke = \frac{1}{2} I\omega^2$$

Safety 2.5

The utmost amount of care was taken to ensure the experiment was completed in a safe manner without injuries.

4 Results

In this chapter of the paper, we will look at the raw data values gathered during the experimental section of the assignment.

(Table 1) Raw data values collected

Mass (KG)	H1.1 (M)	H1.2 (M)	H1.3 (M)	T1 (S)	T2 (S)	T3 (S)
0.1	0.245	0.245	0.245	4.31	3.92	4.48
0.2	0.26	0.262	0.25	2.9	2.77	2.75
0.3	0.255	0.26	0.265	2.37	2.31	2.57
0.4	0.248	0.247	0.245	2.19	1.97	2.18
0.5	0.228	0.17	0.24	1.99	2.3	1.78

(Table 2) Set values used for calculations

h1(m)	0.28
n/s ²)	9.81
c(m)	0.0408
r(m)	0.0065
g/m ²)	0.0005
l(kg/m ²)	4.696*10 ⁻⁴

5 Analysis

During the following section, the experimental results were analysed and compared with reference results provided by TecQuipment. The data obtained (Table 3) enabled construction of the torque versus angular acceleration graph (Graph 1).

The graph shows the linear relationship between torque and angular acceleration. This is consistent with the theoretical relationship between the two figures described by the rational form of Newtons second law (Young and Freedman, 2016).

The equation of the trend line (Graph 1) ($y=0.000395x-0.00955$) is what gives the nominal moment of inertia (I) value of (0.000395kg/m^2). The (-0.00955 NM) value shows a resistive torque in the system, most likely due to air or bearing resistance. In an ideal frictionless experiment, the results would follow the gradient line perfectly.

Comparison between gravitational potential energy P_E and rotational kinetic energy K_E (Table 3) shows that for the values (0.2,0.3,0.5kg) the calculated K_E values were consistently slightly lower than the available P_E . This behaviour was expected as the energy losses can be attributed to friction and air resistances. This showed that K_E and P_E values calculated for these points were correct and contributed to an overall successful experiment and supported the validity of TecQuipment's model.

For weights (0.1 and 0.4kg) the calculated K_E values slightly exceeded the initial P_E values. This non-physical result showed scientific uncertainty, most likely occurring due to a timing inaccuracy across the three attempts completed at these weight categories.

Although slight anomalies occurred during the experiment the overall trend with values calculated remained consistent with expectations (Graph1/2) and data points (0.2,0.3,0.5kg). With slight overestimations occurring for points (0.1,0.4kg) overall results remained consistent with TecQuipment's results for this experiment.

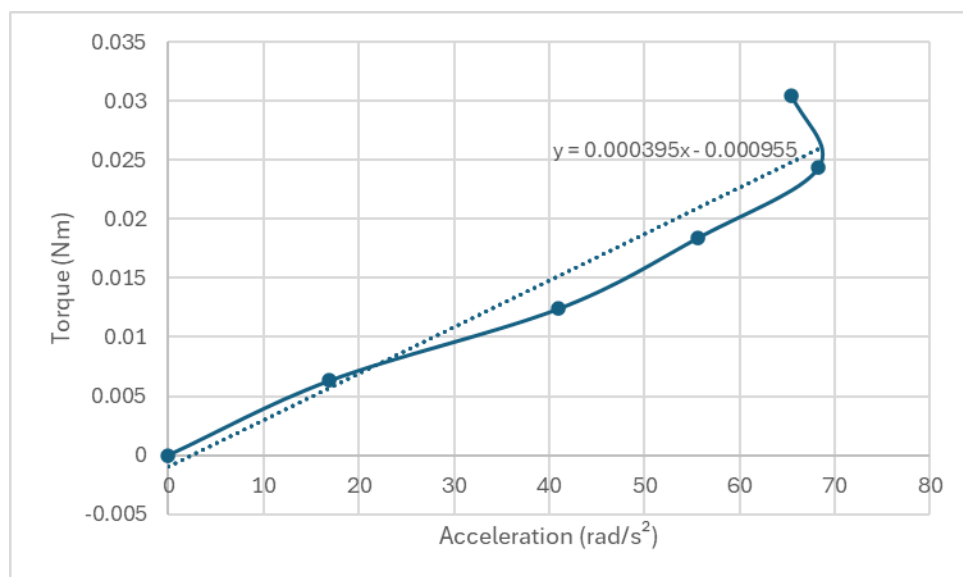
Although some inconsistencies occurred in the final graph the nominal inertia value calculated which was 0.000395 compared to TecQuipments value of 0.0005 which compares well with the 0.000395 nominal (I) value calculated by the author by 0.000105. Overall, this proves the consistency of TecQuipments experiment is repeatable despite inconsistencies occurring in the authors results.

Frictional torque which was a constant 0.000995Nm during this experiment took away a percentage of the falling masses $K.E$ for example at 0.1 kg applied torque is 0.006305Nm this divided by the constant frictional torque gives us the percentage of which the friction is taking away from the overall $K.E$ at the specific weight for example at 0.1kg the total percentage taken away from the overall $K.E$ of the falling mass is $0.000995/0.006305 \times 100 = 15.76\%$ approximately the $K.E$ losses to friction become significantly less at higher weights for example at 0.5kg $0.000995/0.0305 \times 100 = 3\%$ frictional losses.

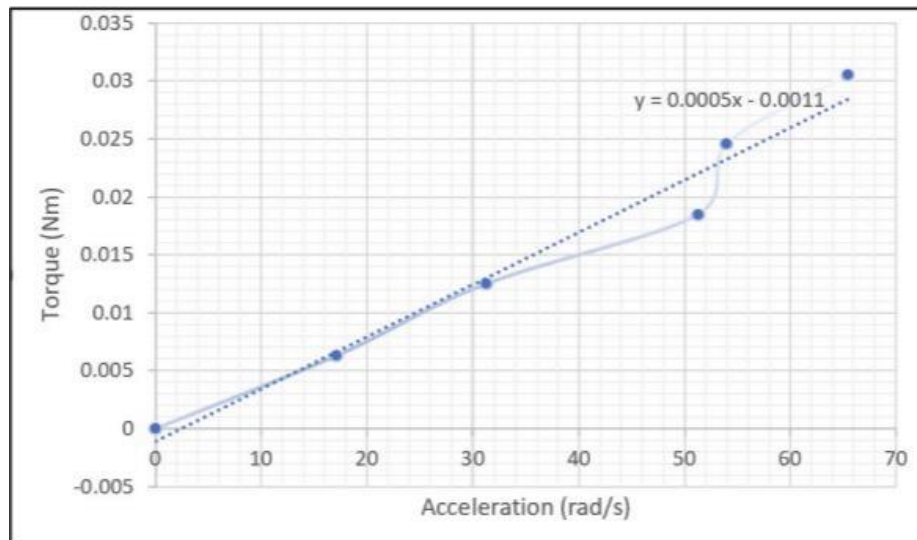
(Table 3) Authors calculated results

Mass	Initial PE	Tt	h2	mg	PE loss adjusted	tf	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
0.00	0	0	0	0	0	0	0	0	0	0	0	0
0.10	0.27468	4.23	0.245	0.981	0.034335	2.256	0.1100	0.2482	38.2269	0.006305	16.92764	0.34311
0.20	0.54936	2.8	0.261	1.962	0.037278	1.449	0.2667	0.3864	59.5099	0.012406	41.02391	0.83153
0.30	0.82404	2.39	0.258	2.943	0.064746	1.244	0.3619	0.4502	69.3321	0.018424	55.68361	1.12867
0.40	1.09872	2.11	0.246	3.924	0.133416	1.123	0.4439	0.4986	76.7809	0.024352	68.29127	1.38422
0.50	1.3734	2.02	0.213	4.905	0.328635	1.147	0.4255	0.4881	75.1701	0.030500	65.45604	1.32675

(Graph 1) Authors torque vs angular acceleration graph



(Graph 2) TecQuipments torque vs angular acceleration graph



9 Conclusion

In conclusion, the experiment successfully investigated the relationship between gravitational potential energy and angular kinetic energy in a flywheel system. Results obtained from the torque vs angular acceleration graph produced a moment of inertia of 0.000395 kg/m^2 which compared closely to TecQuipments reference result of 0.0005 kg/m^2 showing only a slight difference of 0.000105 kg/m^2 .

Although some minor inconsistencies occurred during the data collection part of the experiment, particularly at weight 0.1 and 0.4kg where overall kinetic energy exceeded potential energy, the overall trend remained consistent with theoretical expectations. These slight inconsistent results can likely be attributed to experimental error such as timing errors, bearing friction or air resistance.

The experiment also determined that frictional losses have a greater effect at lower masses as the constant resistive torque in the system represented a larger percentage of the applied torque at these low masses.

Overall, despite minor experimental errors occurring, the experiment successfully demonstrated how gravitational potential energy is transferred into rotational kinetic energy in a flywheel system, with overall results produced being closely matched to manufactures and theoretical data.

10 Evaluation

Overall, the experiment broadly demonstrated the theoretical relationship between gravitational potential energy and rotational kinetic energy in a flywheel system. However, some inaccuracies were observed during the experiment particularly with weights 0.1 and 0.4kg where rotational kinetic energy was calculated to be greater than the overall gravitational potential energy which suggested an experimental error during the data gathering part of the experiment likely due to slight timing inaccuracies when recording total time as well as losses due to friction in the bearings in the pulley/flywheel setup. Although these inconsistencies did occur for weight 0.1 and 0.4 kg overall for weights 0.2, 0.3, and 0.5 kg remained somewhat consistent with theoretical expectations. Unfortunately, the I value calculated did differ from TecQuipments results for I by 0.000105kg/m^2 giving the overall difference approximately 16% smaller than results provided. In most cases a 10% margin for error would be acceptable unfortunately due to this the results for this experiment are not credible. The errors in the experiment are most likely due to friction or timing uncertainty when measuring the time for the weight to fall and rise.

11 Future Improvements

Many improvements could be made to improve the data gathering part of the experiment if it was to be repeated. One key improvement being the use of electronic timing equipment like high-speed cameras or motion sensors to accurately measure the total time. Additionally ensuring bearings in the pulley/flywheel are lubricated and running smoothly would improve results and provide more comparable results to data provided by TecQuipment.

12 References

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