Efficiency of an electric winch system engineering essay

In this assignment I will be planning and carrying out an investigation to find out how the efficiency of an Electric Winch System varies when lifting different weights.

Background Information

As I will be mainly talking about efficiency in this report, it is essential to understand what efficiency means in physical terms. According to the Oxford Dictionary of Physics, (2005), efficiency is ‘ a measure of the performance of a machine, engine, etc,. being the ration of the energy or power it delivers to the energy or power fed to it. In general, the efficiency of a machine varies with the conditions under which it operates and there is usually a load at which it operates with the highest efficiency’.

Efficiency = Useful energy transferred from the machine / Energy transferred to the machine x 100

The efficiency of a system can be calculated if the total energy used is known, and how much of it has transferred into useful forms, in this case by the form of rotational kinetic energy. Efficiency is usually given in a form of ratio but it is more useful to convert this into a percentage in order to perceive what percentage of the total energy is used to do valuable work.

Aims/Hypothesis

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As with all typical physical experiments, inconveniences do arise when tackling such an experiment. This is because we know that no motor is 100%

efficient and this means not all the input power of the motor is converted useful forms to do work.

In general we say this is because most of the input energy is used to overcome the frictional forces between the moving parts of the motor but in theory this is not really taken into account to a great level when calculating the efficiency. We know this missing gap of non-useful energy exists because when a motor transfers the electrical energy into kinetic energy, it must overcome some forces and in order for it to do this, most of the energy is used up for this principle.

Conservation of energy states that energy cannot be created or destroyed but can be transferred/converted from one form to another. Sound and Heat are forms of energy that has been converted from electrical input energy. This form of energy transfer is not useful when we want the motor to run efficiently because we want all the electrical energy transferred to rotational kinetic energy which will be converted to useful forms like gravitational potential energy to lift the load. However it is not possible to eliminate the transfer of the input energy to wasted energy or account for this when calculating the efficiency because a motor must heat up and generate sound to its surroundings as a direct result, which cannot be measured to a great level of accuracy.

A main cause of energy being wasted in the process is due to a lot of friction in the internal moving parts of the motor and in particular from the coils inside the motor or the pulleys.

Resistance in the wires is also a contributing factor to the un-efficiency of the motor, the higher the resistance in the circuit the less efficient the motor will work. This is due to the heating up of the electrons in the wires by kinetic energy which transfers current from the motor to the transformer/voltmeter/ammeter. The main cause of this resistance is due to motor drawing more current when a heavier load is raised, thus causing a higher resistance and the input energy being wasted in the form of heat and sound as a result. I will be commenting on this further when evaluating my results.

Speculating from this general idea on efficiency, there must be a certain limit to the load the motor cannot lift. It might be able to lift the load by drawing more current as mentioned earlier but this is not particularly efficient as it consumes more power to lift a larger load.

If we want to calculate how and where the energy has been transferred to and possibly predict the outcome, very minute and specific things must be taken into consideration when doing the calculations. Some examples include;

The precise measurement of the distance between the motor and the pulley

The diameter of the pulley

The thickness of the drive belt

The friction between the bearings on the pulley system, The noise level (a form of energy) of the motor, (when lifting weights) and so on

Referring back to some of the things mentioned above and taking the pulley as an example, a pulley is used in most everyday machinery in order to reduce the amount of force needed to do work. The use of pulleys makes the motor more efficient by less fuel/power consumption etc in everyday life. Some examples of this include the use of the pulley systems in cranes, where different numbers of pulleys used in different arrangements give the ability for the crane to lift heavy loads with the least consumption of energy and power by reducing the torque required by the motor. This is due to the force being spread over a greater surface area. So using a pulley in my experiment should in theory allow the motor to do more work with less required energy as opposed to let’s say just the motor lifting the mass by itself without some sort of device attached. This would be apparent when the efficiency is calculated when loads ranging from 0. 1kg – 1. 2kg are lifted.

Research

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Overview

Measuring the efficiency of an electric motor when it is lifting different loads.

This experiment will let me measure with reasonable accuracy how the efficiency of an electric motor varies as it lifts different masses ranging from 0. 1kg – 1. 2kg vertically over a set distance. I will chose to repeat the experiment for two different values for the input power and record the values. With a given voltage, I will measure both the time taken for the mass to rise and the current. With these results, efficiency can be measured and commented upon to prove/disprove whether my theory and the expectations are true.

A brief History of the Electric Motor

According to the Columbia Encyclopaedia, (2006), an electric motor is described as ‘ an an electric machine that converts electrical energy into mechanical energy. When an electric current is passed through a wire loop that is in a magnetic field, the loop will rotate and the rotating motion is transmitted to a shaft, providing useful mechanical work. The traditional electric motor consists of a conducting loop that is mounted on a rotatable shaft. Current fed in by carbon blocks, called brushes, and enters the loop through two slip rings. The magnetic field around the loop, supplied by an iron core field magnet, causes the loop to turn when current is flowing through it’.

Electric motors are manufactured outcomes of the famous 19th century scientist Michael Faraday. He was the discoverer of electro-magnetic induction and electro-magnetic rotations together with some other fundamental findings. His principles and understanding gave engineers the crucial idea needed to build an electric motor and has been hugely improved since. Electric motors play a vital role in making our everyday lives easier, from a simple can opener, washing machine and to a lawnmower; they all use the same design and theory.

How does an Electric Motor work?

The basic principle behind an electric motor is fairly simple. An electric motor is a spinning electromagnet. In a simple electric motor there are several components, 2 permanent curved opposing magnets sit in the inner housing of the motor producing a north and a south pole. In between the magnets sits an armature, consisting of coils of wire, (usually copper or any other flexible metal that is a good conductor), and not physically touching the magnets and at the exposed end of the armature sits a small flywheel. As the current passes through the two ends of the coil in the magnetic field, a magnetic force is produced which in turn causes the commutator to spin. The more current passed through and the higher the magnetic strength of the permanent magnets, the stronger the torque which in essence produces more mechanical energy. Simply, electric motors convert the electrical energy into rotational kinetic energy which is used to do work.

A simple electric motor looks like this

No electric motor is 100% efficient as discussed earlier because they transform most of their energy in order to overcome frictional forces which are un-useful and we say this energy is wasted. Initially speculating and hence using pulley systems for my experiment, I discussed how pulleys can reduce the overall work done by the motor to raise the same mass over a vertical distance.

Although this setup in point of fact comes with its downsides, this waste of energy is compensated by the pulleys reducing the necessary work done by the motor to do useful work.

Pulleys

A pulley is a wheel consisting of bearings which the main circular body sits on. It is used singly or in combinations to transmit energy and motion. Examples in belt drives include pulleys attached to shafts at their axes and the power is transmitted between the shafts by means of belts running over the pulleys. We know that one or more independently rotating pulleys can be used to gain mechanical advantage, especially for lifting weights.

Look at the examples below of a typical pulley system. According to the conservation of energy we know that energy never vanishes but is converted into different forms and in the case of a worn out pulley/bearing, more of the input energy is given off as heat and sound to its surroundings by friction. This means more of the supplied energy to the pulley is converted into useless forms than that used up to do useful work.

Referring to the example on the left, the bearings on the pulley reduce friction in order to increase efficiency. But if these are worn out then as a result more energy will be used up in order to overcome the friction. This will in a sense consume more energy to do useful work.

I will discuss this in more detail when commenting on the acknowledged errors and extension.

Typical pulley system

The above diagram shows a small driver pulley pulling a round larger driven pulley. The overall rpm of the larger driven pulley wheel will be less than the motor pulley and this will therefore alter the speed of the rotation

In the example above, the diameter of the motor pulley is 200mm and the driven pulley is 400m. This means that for every single revolution of the larger pulley, the smaller pulley will rotate twice due to the velocity ratio.

Because efficiency is expressed in terms of power, it is vital to distinguish the definition and to be able to interpret the necessary calculations by understanding the meaning, hence the need for more in-depth meaning to these scientific terms.

Power

Power is the rate at which work is done or the energy transferred. This is measured in watts, (joules per second). In order to be able to calculate the power for a given apparatus or machine, the average voltage and the current must be identified.

REFERENCE!

Voltage

Voltage is commonly referred to as the potential difference and is given the unit of volt (V). One volt is the potential difference between two points which allow 1 joule of energy to transfer when 1 coulomb of charge moves between the points. It is given by the equation V=

Current

Current is the flow of charge and given the unit ampere (A). We say 1 A is a current of 1 coulomb per second, given by the equation I= Q/t. Current is usually measured by its effects and the ampere is defined in terms of its magnetic effect.

Output Energy

Output energy of a device is the input energy of a device or machine which has been transformed into a form that has been used to do work. It is the transfer of energy from one form to another and in the case of a motor lifting a mass, the input electrical energy being transformed to rotational kinetic energy by the motor and that energy converted to gravitational potential energy stored by the mass. Because the mass has been raised to a height opposing the gravity, we say G. P. E is the work done against gravity. This energy is equal to the work which would be required to lift the object to that height with no change in kinetic energy.

G. P. E is given by the formula: m . g . h

Where m= the mass of an object (kg)

g= gravity (9. 806 m/s2)

h= height which the object is raised (m)

Input Energy

Input energy is the energy put into a system to do work. It is measured in joules (J) and given the example of its use in my experiment; it is the energy being transferred to the motor therefore it is calculated by;

Input energy (J) = Average current (A) x Average potential difference (v) x Average time (s).

Resistance

I have mentioned resistance in the wires and referred to as having an impact on the efficiency of a system. According to Collins Gem Physics Dictionary, (1996), Resistance is defined as the ‘ ratio of the potential difference across an electrical component to the current passing through it. It is the measure of the component’s opposition to the flow of electrical charge’. Simply clarifying from this statement, electrons do not take a direct path when moving from one terminal to the other but it encounters countless collisions with the fixed atoms within the conducting material in the wire. The electrical potential difference established between the two terminals encourages the movement of charge; the resistance in the other hand discourages it. Thus the rate at which charge flows from terminal to terminal is the overall result of the combined effect of these two quantities.

There are many factors each contributing to the overall resistance; some examples are the length of the actual wire because the longer the wire, the more resistance is present. Clearly there are more collisions of the electrons in a longer wire which gives more resistance.

Quite the opposite if the wire has an increased cross-sectional area because the charge flows at a much higher rate as opposed to a thinner wire.

An important factor is the actual material the wire is made out of. Different wires have different conductive abilities as some wires are better conductors than others thus offering less resistance to the flow of charge. This resistively in different wire is dependant on the material electronic structure and the temperature.

Formula for calculating the average resistance is V= I. R

Procedure/Experimental Methods

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I have used a standard procedure in order to carry out the experiment. The motor will be connected to the ammeter, voltmeter and the transformer with the ammeter connected in series and the voltmeter in parallel (As shown in the circuit diagram). There would be a constant voltage supplied to the motor in order for it to lift the mass evenly and eliminate any trembles when it lifts fairly heavy loads.

Apparatus Used

4V Electric Motor

2 x G Clamps

Ammeter

Voltmeter

Wires

Mass Hook

10 x 100g Masses

1. 2M String

Transformer

Stop Watch

1M Ruler

Cello tape

In the pulleys used for this experiment, the gearing ratio was 1: 5 because the pulley radius was 0. 05m and the motor flywheel radius was 0. 01m.

Diagram

The above diagram is very similar to my set up. Once the motor has been clamped tightly to the bench and connected to the apparatus as described above, It should be connected to the pulley system, (As shown in the diagram), This should also be positioned accordingly and clamped to the edge of the table. A piece of heavy duty string reaching the floor should be connected to the end of the pulley system and cello taped so it is secure and doesn't slip off. The other end should be attached to the hook mass and the starting mass should be placed on the hook.

(I have set the voltage at 4V and have constantly adjusted the input energy at this rate throughout the experiment). As the power supply is switched on, the time it takes for the mass to travel 0. 78M was timed using a stop clock and the amps read on the ammeter. The voltage was monitored to make sure a steady supply of 4 voltages was running to the motor.

Once the load has risen 0. 78M, the timing was stopped and the data recorded in the following table.

Mass (Kg)

Average Time (s)

Height (M) (± 0. 02M)

Average Voltage (V)

(± 0. 15V)

Average Current/I (A)

(± 0. 30A)

Power (W) (Voltage. Current)

Input (J) (I. t. v)

Output (J) (Mass. Gravity. Height)

Efficiency (%) (Output/Input. 100)

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Variables

Constant

Current

Load

Time

Voltage

Mass

Length of string

Length of the wires

Height

In order to identify and gather accurate results, I have repeated the experiment 3 times in order to obtain and average out of the three runs.

Circuit Diagram

Results

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Calculations and Formulas

Below are some of the equations I have used in my calculations to determine the efficiency and what they conclude.

Efficiency = x 100% Where and are energy input and output

Mass. Gravity. Height gives the total energy output in joules

Current. Voltage. Time gives the total energy input in joules

Voltage. Current gives the average power used

Results

(4V)

Mass (N)

Average Time (s)

Height (M)

Average Voltage (V)

Average Current/I (A)

Power (W) (Voltage. Current)

Input (J) (I. t. v)

Output (J) (Mass. Gravity. Height

Efficiency (%) (Output/Input. 100)

0. 1

1. 41

0. 78

4

1. 77

7. 08

9. 9828

0. 7644

7. 66

0. 2

1. 77

0. 78

4

2. 15

8. 6

15. 222

1. 5288

10. 04

0. 3

2. 16

0. 78

4

2. 41

9. 64

20. 8224

2. 2932

11. 01

0. 4

2. 31

0. 78

4

2. 53

10. 12

23. 3772

3. 0576

13. 08

0. 5

2. 96

0. 78

4

3. 06

12. 24

36. 2304

3. 822

10. 55

0. 6

3. 97

0. 78

4

3. 25

13

51. 61

4. 5942

8. 90

0. 7

5. 9

0. 78

4

3. 52

14. 08

83. 072

5. 3508

6. 44

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Estimated Errors

Mass: ± 1%

Time: ± 0. 3s

Height: ± 0. 004m

Voltage: ± 0. 15V

Current: ± 0. 30A

Graphs

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Analysis/Discussion

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In this experiment, we know that the energy must be conserved and therefore the input electrical energy put into the motor must be equal to the amount of the energy out.

This principle is true if there was no friction in the system but it is clear that the energy used to overcome this friction is in actual fact greater than the energy converted to gravitational potential energy to lift the mass. When the motor is lifting lighter masses, the amount of current drawn is also small as seen in the table but as the mass is increased the current increases in order to supply extra torque needed to lift the mass. This increase is not proportional to the mass in any way.

The motor was at its most efficient when the mass it was raising was 0. 4kg. The efficiency was just over 13% so we can deduce that 87% of the energy has been wasted and as mentioned, from the conservation of energy this 87% has been converted to different forms in order to overcome the opposing forces (mainly friction, sound and air resistance). As the mass is increased from 0. 4kg the efficiency decreases as predicted in my initial hypothesis. This is due to the more rotational kinetic energy that is required to turn the motors fly wheel to lift the mass. As a direct result if the rotational kinetic energy increases there must also be an increase in friction and I can confidently agree that this is true since the efficiency is declining after 0. 4kg.

And looking at the table, it is clear that the current drawn by the motor also increases together with a decrease in efficiency after 0. 4kg. As the current is increased, the resistance is also increased and this increases in resistance in the wires uses up the input energy to be wasted in the form of heat, thus reducing the overall resistance of the motor.

Why the efficiency is low when the motor lifts a lighter mass?

Referring back to my hypothesis and looking back at the graph, when the motor is lifting a lighter load the efficiency does not increase.

When the motor lifts a lighter load, it does so in a shorter period of time and by drawing in less current. Because it takes less time for the mass to reach the desired height, it must be spinning faster. When the motor spins faster there is an increase in the amount of heat and sound generated and this form of energy can only come from one source and that is the input electrical energy. Summarizing from this, as the motor spins at a faster rate, more of the input energy is converted to heat and sound and less energy is transformed into doing useful work (gravitational potential energy).

The motor is only at its most efficient when certain conditions are met. When the mass lifted was 0. 4kg the motor was spinning at a slower rate but at the same time drawing more current and by this increasing resistance. Resistance does not contribute greatly to the efficiency of the motor but the major factor into this is the friction and the heat generated in the internal parts of the motor. This uses up more of the input energy as opposed to the resistance because the heat generated by resistance is fraction of that generated by the motor. The trend in the graph and table verifies this.

There is a lot of friction in the system and examples of this exist between the string and the motor spindle, in the wires and in the motor itself. When a larger mass is lifted by the motor, this causes a tension in the string and this creates a friction which results in heat to the surroundings. The increase in mass also makes the motor vibrate and as a result gains kinetic energy and since this energy came from the input energy, it lowers the overall efficiency of the motor.

Sources of Error

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Surely there are other errors contributing to the overall results.

The timing for the lighter load was difficult since it took very short amount of time for the load to cover the vertical distance. This reaction time would have had slight effect on calculating the input energy as this is dependant on time.

The readings taken from the ammeter and the voltmeter had errors due to the split change in the values it was difficult to get an ideal value, thus the need to take 3 results in order to get an average.

As the string wounded up, it changed the gearing because the overall diameter changed as a result. This merely would have changed the speed of the motor, giving an unreliable result.

There are also anomalous trends in the graph of power consumed and the average time taken for the mass to rise. This trend is obvious in the graph as it does not rise in a pattern like the other values. This exists when the mass the motor is lifting is 0. 3kg and I consider this result to be unreliable as it doesn’t match with the rest. Although one of the results seem odd, it doesn’t mean the rest of the results are unreliable, because this can be down to many factors including the actual motor itself. The motor perhaps did not operate as it should have when lifting that certain mass or drawing a certain current, between 2. 20 – 2. 50Amps. Even though there seems to be an anomaly with this value, the experiment was repeated 3 times to give me this result.

Extension Work

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In general my experiment went rather well and using the results gave me the ability to make some useful conclusions.

If I had more time I would like to have tried different experiments with different pulley setups in different arrangements. I could have tested different loads with and without the extra pulley system and this would have given me more informative results that would most probably support my initial speculation and hypothesis on using the pulley system.

Another experiment would have been to use a more powerful motor to lift weights ranging from very small to very large over a longer distance. This would give me the trend and plotting this on a graph would probably give me the line of best fit and from this I could predict the outcome for different masses and compare the actual value with the predicted value.