TED ANKARA COLLEGE FOUNDATION HIGH SCHOOL

PHYSICS HL – EXTENDED ESSAY

"EFFECT OF FRICTION ON EFFICIENCY"

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1 ABSTRACT

This experimental study investigates the effect of friction on the efficiency of a pulley system. Efficiency of systems is affected by problems like friction, which is also a major problem for energy consumption in the world. In a pulley system consisting of an electric motor, fixed pulleys and a load; "Does changing the number of pulleys in a pulley system affect friction and hence efficiency of the system to alter?" question is tested. The experiment was made in two parts. First, revolutions per minute (rev/min – rpm) pattern of the electric motor was plotted on a graph. After deciding the voltage for second part, the effect of friction on the efficiency of the pulley systems was investigated. For that, the number of pulleys attached to the system was increased step by step and how high (meters) the 0.1 kg mass is pulled in 1 minute time by the electric motor is measured. Comparing theoretical height and measured height values gave the energy loss at the system. According to the *law of conservation of energy* that loss should be due to the effect of friction. So, the efficiency of the system was calculated using the data gathered. The results were plotted on a graph and they showed that as the number of pulleys in the system increases from 1 blue pulley to 5 black & 5 blue pulleys step by step, the efficiency of the system decreases from 99.598 % to 96.185 %. Those results show that increasing number of pulleys in a pulley system affects friction to increase and hence efficiency of the system to decrease.

Word count: 265

2 CONTENTS

3 INTRODUCTION

With ever increasing demand, energy is crucial especially in today's world. From the existence of human kind, people always needed and used energy in many different areas and forms in their life. One of the important areas, where energy is used, is for doing work. While doing work, it is also important to do it as easy as possible. For that, people build systems, tools, machines etc. With those, people are able to construct, transport and manufacture easily.

Since it is obvious that energy is crucial for doing work, the importance of using that energy efficiently is an indisputable fact too. That has always been an important aspect in physics and engineering. Today, the question is how we can get the most out of everything we do. To accomplish that, the system, machine, tool, etc. need to be efficient. There are many facts that affect the efficiency negatively and cause some amount of energy that is transformed to work to be lost. The major problem that people encounter and will always have to face on earth is friction.

I've been thinking about this problem for a while. However, my practical knowledge and experience were not enough to see and understand to what extent friction might cause problems in daily life or in the scope of engineering, which I'm personally interested in. Also my goal is to be an engineer and work on how systems and machines use energy to generate work. I want to understand and find solutions for problems like friction. So, I found that topic worth studying for its universal importance.

A pulley system, which has several application areas like in mining industry or at construction sites, is a suitable system to integrate my thoughts and investigate the effect of friction. From a simple system consisting of an electric motor, pulleys and a mass, how friction affects the efficiency of the system can be studied. So the research question I came up with is: "Does changing the number of pulleys in a pulley system affect friction and hence efficiency of the system to alter?" Theoretically; with respect to the law of conservation of energy, if there is a change in the efficiency of the system when more pulleys are attached, friction should be the source for losing that energy since there would be no other external force on the system. Through the experiment, this theory is to be investigated.

3.1 LAW OF CONSERVATION OF ENERGY

This fundamental law of physics, states that total amount of energy in an isolated system remains constant. Neither energy can be created from nowhere nor destructed completely. In an isolated system, energy given to system equals to energy given out. In that process, electrical energy might be transformed to heat energy for example but the total energy is conserved.

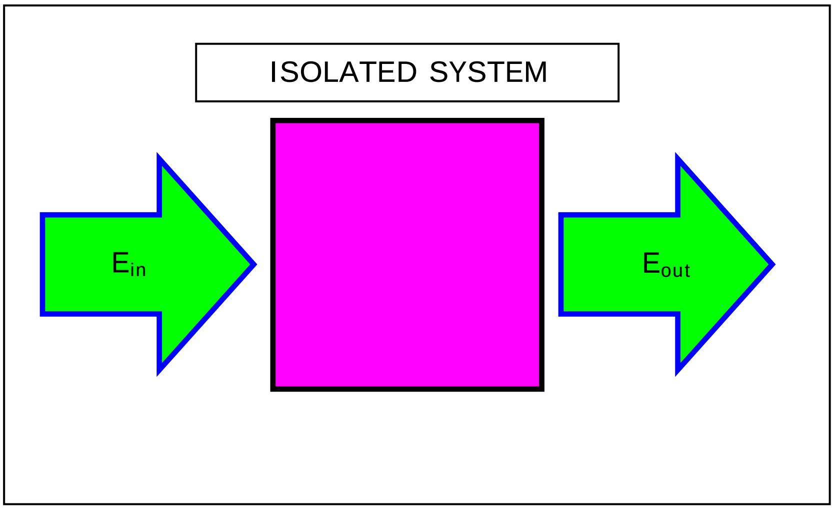


Figure 1: Energy diagram for an isolated system.

3.2 EFFICIENCY

Efficiency simply shows output to input ratio. In physics, **mechanical efficiency** shows the ratio of work output to work input. Since work is the amount of energy transferred by force acting through a distance, efficiency can also be described as; ratio of energy output to input.

$\frac{E_{out}}{E_{in}} = k$ This equation gives that ratio. For percent ratio, result is multiplied by 100.

There are several factors affecting mechanical efficiency. Friction may name as the major one.

3.3 ROPE AND PULLEY SYSTEMS

Rope and pulley systems are; a rope transmitting linear motive force (as tension) to a body through one or more pulleys for pulling it, often against gravity. They are used for gaining mechanical advantage i.e. doing work easier. The weight of a load can be distributed to several pieces of rope but there is just one whole length of and the force is exerted on it. Note that for doing the same amount of work, the rope should be pulled for a longer distance in that system.

The types of pulley systems are;

1. *Fixed Pulley System*: The axle of the pulley is fixed at one place. A fixed pulley only changes the direction of the force applied to do 'work' on the load. The mechanical advantage in this system is equal to 1 which means, the force applied on one end of the rope is the same as that being applied on the load.
2. *Movable Pulley System*: The axle of the pulley is free to move in space. While one end of the load is attached to some fixed object, force is applied at the other end. The mechanical advantage of a movable pulley is equal to 2 which means, the force applied on the free end of the pulley doubles the force being applied on the load.
3. *Compound Pulley*: Combination of fixed and movable pulley systems. A compound pulley system has mechanical advantage greater than 2. [1]

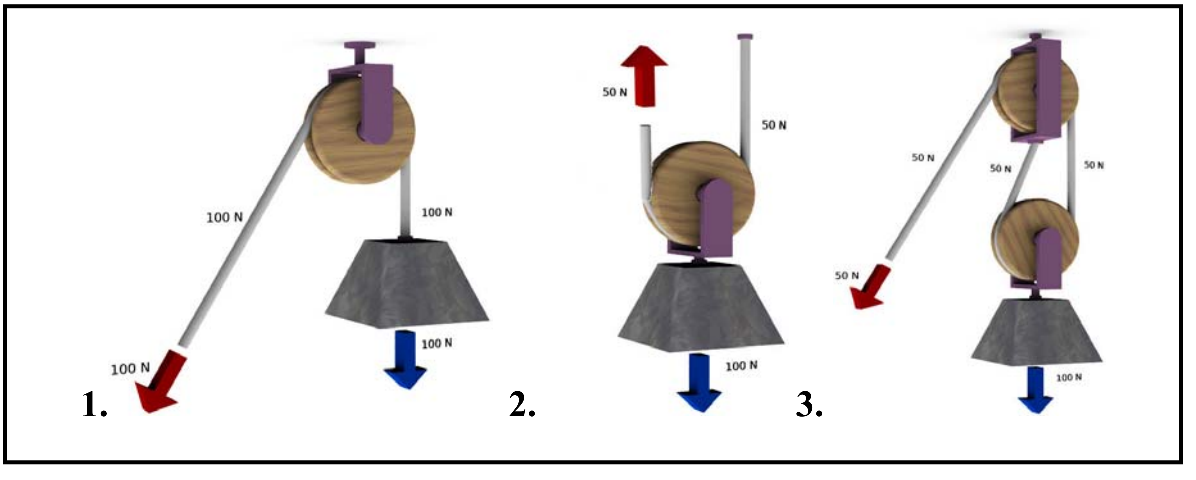


Figure 2: pulley types

[1] *"Simple Machines: Pulley Systems". www.buzzle.com, latest update: 22 May. 2009, date accessed: 28 Feb. 2010, [http://www.buzzle.com/articles/simple-machines-pulleys-system.html]*

3.4 FRICTION

Friction is the force resisting the motion of a surface over another.

The type of friction happens in a pulley is named as sliding friction or rolling resistance, which both related with kinetic friction. First, kinetic friction force is basically the resistance force when a body having a mass is moved along a surface i.e. friction generated from movement. Initial kinetic friction force is always constant as long as the object moves;

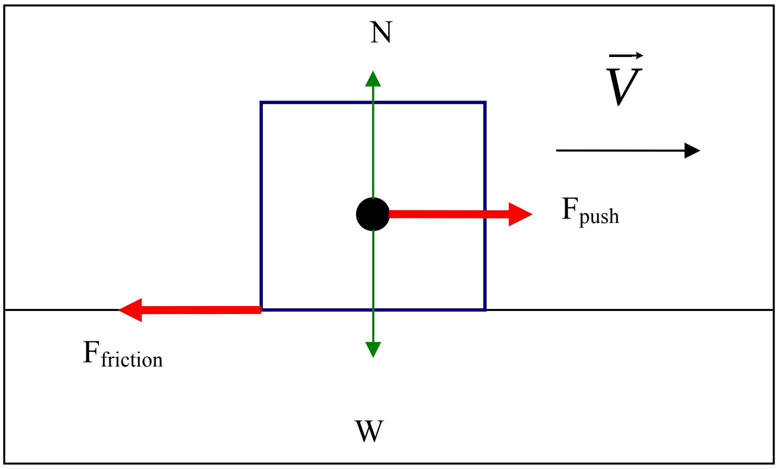


Figure 3: Free body diagram showing the forces on a box pulling along a surface.

The magnitude of the force of friction depends on two factors, the normal force “N” and the coefficient of kinetic friction “μ_k”. Its magnitude is not related with how fast the object is sliding.

If there are two points where friction exists at pulley; where cable or rope meets the pulley surface and in the rotational mechanism of the pulley. It is usually assumed as pulleys have no mass and friction but in real application they indeed have mass and friction. That friction comes from the interaction of the surface materials used i.e. pulley surface and rope, and pulley surface and axle. The following is the free body diagram of a pulley. The forces on it (including friction) can be seen here;

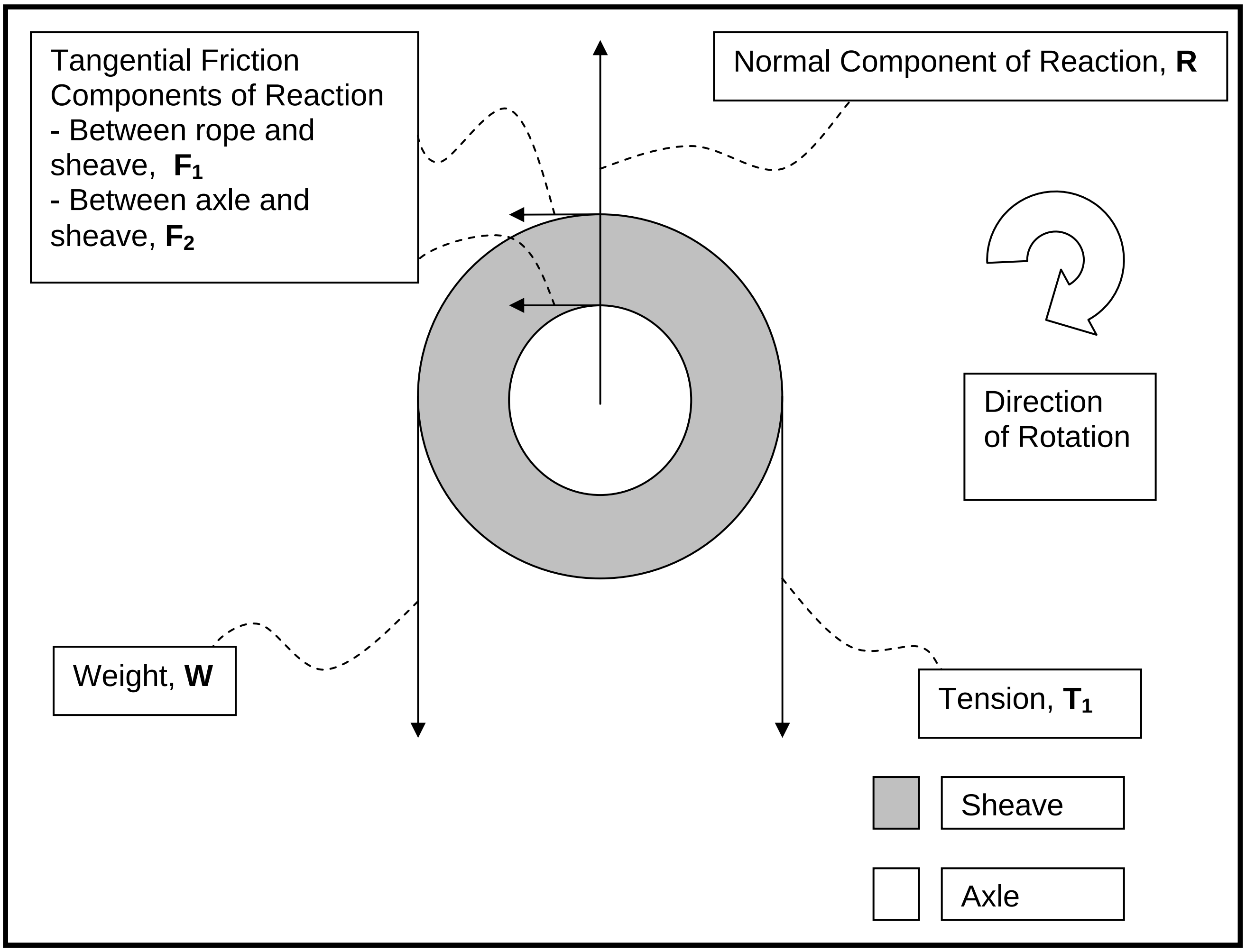


Figure 4: Free body diagram of a pulley showing the acting forces on it. Two friction components are for the specified direction of rotation.

With that figure, two sources of friction can be seen as; while the pulley is rotating with the acting force on it (**T_1**) to pull the weight (**W**), friction is generated at the point rope meets the sheave and slips. Also, while the sheave is rotating on the axle, it slips and generates friction. Those two components are named as **F_1** and **F_2** on the figure 4.

4 BODY

4.1 AIM

To investigate the effect of friction on the efficiency of a pulley system.

4.2 RESEARCH QUESTION

Does changing the number of pulleys in a pulley system affect friction and hence efficiency of the system to alter?

4.3 HYPOTHESIS

Increasing the number of pulleys attached to the system will also increase amount of friction and hence decrease the efficiency of the pulley system.

4.4 KEY VARIABLES

Part 1; Electric Motor Test

Independent Variable: Voltage coming to electric motor.

Dependent Variable: 1 revolution time of electric motor.

Controlled Variable: Type of electric motor (brand: Nostop 25GA370-12560-500, 12VDC, 7.5rpm, 40mA, maximum torque: 15kg.cm), conductor wires (bronze, one side clip-end, other side plug-end), Digital DC power supply (brand: GENMAK, serial no: GK 05151 084, Volt 220 AC, Hz. 50, Power: 30W max, min. reading 0.1V, max. reading 15V), type of stopwatch (min. 0.01 sec)

Part 2; Pulley System

Independent Variable: Number of pulleys attached to the system.

Dependent Variable: Height of the standard mass pulled by the electric motor (0.1kg)

Controlled Variable: Voltage coming to electric motor, standard mass (0.1kg), type of rope, gravitational acceleration (all experimental process done at the same place), type of the pulleys (standard blue and black fixed pulleys.), Type of electric motor (brand: Nostop 25GA370-12560-500, 12VDC, 7.5rpm, 40mA, maximum torque: 15kg.cm), conductor wires (bronze, one side clip-end, other side plug-end), Digital DC power supply (brand: GENMAK, serial no: GK 05151 084, Volt 220 AC, Hz. 50, Power: 30W max, min. reading 0.1V, max. reading 15V), type of stopwatch (min. 0.01 sec)

4.5 PROCEDURE

The experimental part of this essay was done in two parts. In the first part, the electric motor's voltage versus revolution per minute behavior was investigated. The reason is to test if the motor has the performance values written on it and to have an equation for being able to use any voltage value in part 2. In the next part, trials for measuring the effect of friction on the efficiency were made.

The procedure for part 1 is;

4.5.1 Procedure 1:

- Attach the motor to the holder deck.
- Stabilize the deck to the table using a pincer.
- Connect the conductor wires to the motor and the power supply.
- Turn on the power supply and adjust the voltage (for example 6.0 V)
- Indicate or mark a specific point on the rotating part of the motor.
- Start the stopwatch when that point passes in front of your eye line in its rotation.
- Stop the stopwatch when it passes again, it should have completed one rotation.
- Note the time and repeat that measurement for 10 times.
- Note all 10 trials' results.
- Decrease the voltage completely to 0.0 V and turn off the power supply after trials are finished.

Before starting part 2, the voltage value to be used in all trials should be decided to use it as controlled variable (same for all trials). I decided to use 12.0 V and the procedure was modified so. The reason for such decision is discussed conclusion and evaluation part.

The procedure for part 2 is;

4.5.2 Procedure 2:

While just the motor is pulling the mass-no pulleys are attached;

- Attach the electric motor to the holder deck.
- Stabilize the deck to the table using a pincer.
- Connect conductor wires to motor and power supply.
- Turn on the power supply and adjust the voltage to 12.0 V and then turn off the power supply. Make sure the voltage is standing still at 12.0 V before turning it off.
- Tie the rope to the sheave attached to the motor strongly.
- Tie the 0.1kg mass to the other end of the rope.
- Adjust the length of the rope so that the rope is not loose and the mass will just touching the ground horizontally.
- Start the stopwatch and turn on the power supply at the same time.
- While the motor is working, make sure the rope is not wrapping up to a second layer. It must wrapping on the pulley attached to the motor regularly.
- Turn off the power supply after one minute.
- Measure the height of the mass from ground using the ruler. Make sure the ruler and the mass hanging above, leveled horizontally.
- Read the height and note down.
- Repeat that procedure for 10 times and note all 10 trials’ results.

While the motor is integrated to the pulley system and the rope is tied to mass through the pulleys;

- Attach the electric motor to the holder deck.
- Stabilize the deck to the table using a pincer.
- Connect conductor wires to the electric motor and the power supply.
- Turn on the power supply and adjust the voltage to 12.0 V and then turn off the power supply. Make sure the voltage is standing still at 12.0 V before turning it off.
- Tie the rope to the pulley attached to the motor strongly.
- To build up the pulley system, use other two pincers. Attach them to the table so that there will be a space of a length of metal bar.
- Attach two metal bars vertically to the pincers.
- Attach the other two metal bars to the vertical ones, using small pincers horizontally. One of them should be standing at the bottom and the other should be on the uppermost part.
- Attach one blue pulley to the metal bar at the bottom using small pincer.
- Pass the rope around the blue pulley and tie the other end to the 0.1kg mass.
- Adjust the length of the rope so that the rope is not loose and the mass is just touching the ground horizontally.
- Start the stopwatch and turn on power supply at the same time.
- While motor is working, make sure the rope is not wrapping up to a second layer. It must wrapping on the sheave attached to the motor regularly.
- Turn off the power supply after one minute.
- Measure the height of the mass from ground using the ruler. Make sure the ruler and the mass hanging above, leveled horizontally.
- Read the height and note down.
- Repeat that procedure for 10 times and note down all 10 trials' results.

In the other trial groups, 1 black pulley, 1 black & 1 blue pulley, 2 black & 2 blue pulleys, 3 black & 3 blue pulleys, 4 black & 4 blue pulley and finally 5 black & 5 blue pulleys are attached to the system. For each trial group, 10 trials are done. To attach the black pulleys, use the pincers with a hook on top and attach them to the upper bar. (For further details see the pictures.)

4.6 RAW DATA OF PART 1 (PROCEDURE 1)

Trial Number	Time (seconds ±0.01)
1	15.20
2	15.39
3	15.31
4	15.28
5	15.24
6	15.37
7	15.35
8	15.19
9	15.23
10	15.29

Table 1: Time results for 1 revolution of electric motor when 6.0 ± 0.1 V is applied.

Trial Number	Time (seconds ±0.01)
1	13.03
2	13.05
3	13.12
4	13.14
5	13.10
6	13.13
7	13.03
8	13.11
9	13.15
10	13.07

Table 2: Time results for 1 revolution of electric motor when 7.0 ± 0.1 V is applied.

Trial Number	Time (seconds ±0.01)
1	11.35
2	11.31
3	11.30
4	11.35
5	11.30
6	11.44
7	11.40
8	11.42
9	11.36
10	11.37

Table 3: Time results for 1 revolution of electric motor when 8.0 ± 0.1 V is applied.

Trial Number	Time (seconds ±0.01)
1	10.17
2	10.10
3	10.04
4	10.14
5	10.13
6	10.10
7	10.07
8	10.00
9	10.13
10	10.10

Table 4: Time results for 1 revolution of electric motor when 9.0 ± 0.1 V is applied.

Trial Number	Time (seconds ±0.01)
1	9.06
2	9.10
3	9.09
4	9.01
5	9.02
6	9.06
7	9.15
8	9.08
9	9.04
10	9.10

Table 5: Time results for 1 revolution of electric motor when 10.0 ± 0.1 V is applied.

Trial Number	Time (seconds ±0.01)
1	8.19
2	8.15
3	8.24
4	8.16
5	8.17
6	8.15
7	8.23
8	8.12
9	8.15
10	8.22

Table 6: Time results for 1 revolution of electric motor when 11.0 ± 0.1 V is applied.

Trial Number	Time (seconds ±0.01)
1	7.49
2	7.46
3	7.53
4	7.56
5	7.47
6	7.48
7	7.54
8	7.55
9	7.48
10	7.49

Table 7: Time results for 1 revolution of electric motor when 12.0 ± 0.1 V is applied.

4.7 RAW DATA OF PART 2 (PROCEDURE 2)

Trial Number	h (meters) (±0.001)
1	0.498
2	0.497
3	0.497
4	0.498
5	0.497
6	0.498
7	0.497
8	0.498
9	0.499
10	0.498

Table 8: Motor itselef - 0.1kg - 12V - 1 min

Trial Number	h (meters) (±0.001)
1	0.495
2	0.497
3	0.497
4	0.496
5	0.497
6	0.494
7	0.496
8	0.496
9	0.496
10	0.495

Table 9: 1 blue pulley - 0.1kg - 12V - 1 min

Trial Number	h (meters) (±0.001)
1	0.494
2	0.493
3	0.495
4	0.495
5	0.494
6	0.493
7	0.494
8	0.492
9	0.495
10	0.494

Table 10: 1 black pulley - 0.1kg - 12V - 1 min

Trial Number	h (meters) (±0.001)
1	0.492
2	0.490
3	0.489
4	0.491
5	0.493
6	0.491
7	0.491
8	0.490
9	0.489
10	0.493

Table 11: 1 blue & 1 black pulley - 0.1kg - 12V - 1 min

Trial Number	h (meters) (±0.001)
1	0.490
2	0.488
3	0.491
4	0.491
5	0.490
6	0.489
7	0.490
8	0.486
9	0.489
10	0.490

Table 12: 2 blue & 2 black pulleys - 0.1kg - 12V - 1 min

Trial Number	h (meters) (±0.001)
1	0.488
2	0.486
3	0.487
4	0.484
5	0.487
6	0.488
7	0.486
8	0.485
9	0.488
10	0.488

Table 13: 3 blue & 3 black pulleys - 0.1kg - 12V - 1 min

Trial Number	h (meters) (±0.001)
1	0.486
2	0.485
3	0.481
4	0.479
5	0.480
6	0.481
7	0.488
8	0.483
9	0.482
10	0.480

Table 14: 4 blue & 4 black pulleys - 0.1kg - 12V - 1 min

Trial Number	h (meters) (±0.001)
1	0.478
2	0.480
3	0.480
4	0.480
5	78
6	0.479
7	0.479
8	0.480
9	0.481
10	0.478

Table 15: 5 blue & 5 black pulleys - 0.1kg - 12V - 1 min

4.8 ANALYSIS OF THE DATA

Before analyzing data in part 1, the mean time value of ten trials for each trial group (for each value of applied voltage) was calculated. The results are as in the following table;

Applied Voltage - Volts (± 0.1)	6.0	7.0	8.0	9.0	10.0	11.0	12.0
Average Time of 10 Trials - seconds (± 0.01)	15.29	13.09	11.36	10.10	9.07	8.18	7.51

Table 16: shows the average (mean) time of 10 trials done in part 1 for each trial group (value of applied voltage altering). All the data for calculating the average values are taken from tables 1 – 7.

Using the data in table 16, revolution per minute pattern of the electric motor was developed. That requires a simple calculation of proportion. The results and sample calculations were as following;

Applied Voltage- Volts (±0.1)	Revolutions/minute (±0.01)
6.0	3.93
7.0	4.58
8.0	5.28
9.0	5.94
10.0	6.61
11.0	7.34
12.0	7.99

Table 17: shows the results for part 1, revolutions per minute values for each applied voltage value to the motor. Uncertainty of rev/min part is the greatest value calculated which is for 12.0 V, so taken as standard for all.

An example calculation is;

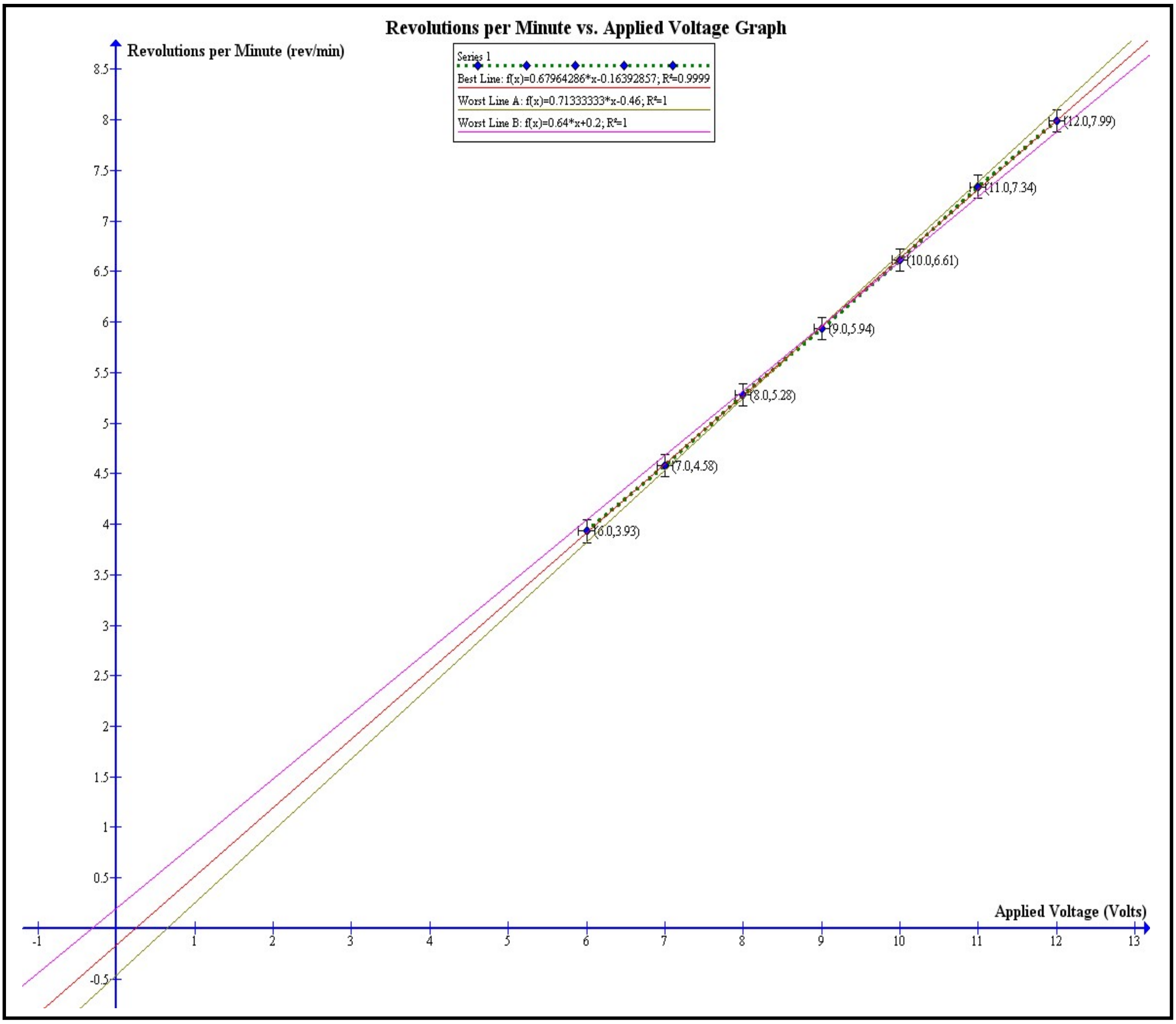
- For 12.0 Volts;

(60.00 sec/min X 1 rev) / 7.51 sec = 7.99 rev/min

or;

- For 8.0 Volts;

(60.00 sec/min X 1 rev) / 11.36 sec = 5.28 rev/min



Graph 1: Revolutions per minute versus applied voltage graph for part 1 (procedure 1). All the values are taken from table 17. Best line and worst lines are drawn with the help of technology. (Graph Version 4.3, Ivan Johansen, 2007©)

This graph is plotted for having the equation of revolutions per minute versus applied voltage pattern. By having the equation stated as "Best Line" (F(x) = (0.67964286).x-(0.16392857)), the value of revolutions per minute for any applied voltage within the pattern and motor's limit, can be calculated for applications in experiment.

Having that equation enables the usage of any applied voltage. I decided to use 12.0V for Part 2.

Before analyzing part 2, the mean height value of ten trials made in each of 8 different trial groups (system setups) were calculated. The results were as in the following table;

Setup Description	Average Height Value of 10 trials – meters ± 0.001
Just Motor	0.498
1 Blue Pulley	0.496
1 Black Pulley	0.494
1 Blue & 1 Black Pulley	0.491
2 Blue & 2 Black Pulley	0.489
3 Blue & 3 Black Pulley	0.487
4 Blue & 4 Black Pulley	0.483
5 Blue & 5 Black Pulley	0.479

Table 18: shows the average height value of 10 trials made in part 2 for 8 different system setups. All the data for calculating the average height value are taken from tables 8 – 15.

In the analysis of part 2, energy loss at different system setups and the efficiency of the system was calculated.

The table showing the results of energy loss for the described system setups is as following;

Mass (kg)	Gravitational Acceleration (m/s^2)	h (m) (±0.001)	h' (m) (±0.001)	h - h' (m) (±0.002)	Energy Loss (m.g.(h-h')) (joules) (±0.002)	Descriptions
0.1	9.807	0.502*	0.498	0.004	0.004	Just Motor
0.1	9.807	0.498	0.496	0.002	0.002	1 Blue Pulley
0.1	9.807	0.498	0.494	0.004	0.004	1 Black Pulley
0.1	9.807	0.498	0.491	0.007	0.007	1 Blue & 1 Black Pulley
0.1	9.807	0.498	0.489	0.009	0.009	2 Blue & 2 Black Pulley
0.1	9.807	0.498	0.487	0.011	0.011	3 Blue & 3 Black Pulley
0.1	9.807	0.498	0.483	0.015	0.015	4 Blue & 4 Black Pulley
0.1	9.807	0.498	0.479	0.019	0.019	5 Blue & 5 Black Pulley

Table 19: showing the results of energy loss at the described system setups on the right. Uncertainties of height values are due to the possible error on the ruler used for measuring. Uncertainty of (h-h') value is the sum of uncertainties of "h" and "h'". Uncertainty of energy loss is due to the sum of uncertainties of values used (m, g and h-h')

* : uncertainty of that value is different (±0.0.051). Discussion and explanation are done in error calculation section.

Some facts to note about the table 19 are;

There are 8 different setups and descriptions are written on the right. Measured height (h') values are taken from table 18. There are two different cases for theoretical height (h) values. First, for the "just motor" setup, the theoretical height is calculated. For the rest of them, the result of the first trial group is taken because other setups are prepared when all the pulleys are connected after the motor. Further discussion and explanation are done in conclusion section.

How theoretical height value was calculated for the first setup is as following;

To find how high the electric motor would pull the mass in one minute, the values needed to calculate were;

- Applied voltage and the rev/min value for that voltage.
- Radius of the sheave attached to the motor.

- When 12V is applied, the motor makes 7.99 rev/min
- The radius of the sheave attached to the motor (r) is 0.010 m

Theoretical height value "h" can be found by;

Height of the mass = length of the circumference of sheave. Revolutions per time

$$h = 2.\pi.r.N$$

$$h = (2).(\pi).(0.010m).(7.99rev / \min)$$

$$h = 0.502m$$

To calculate the energy loss, gravitational potential energy formula, which is $E_p = m.g.h$ was used. There are two different height values in the results (table 19) which are theoretical and measured height values. If the gravitational potential energy is calculated using those two values, their difference will give the amount of lost energy. The equation can be organized as following to give that result;

$$E_{lost} = m.g.(h - h')$$

An example calculation is (for 1 black pulley);

$$E_{lost} = (0.1kg).(9.807m/\mathrm{s}^2).(0.498m - 0.494m)$$

$$E_{lost} = 0.004\,joules$$

According to the aim of the experiment, how the efficiency of the system changes must be found. To find the percent efficiency, this formulation can be used;

$\left(\frac{E_{out}}{E_{in}}\right).100 = efficiency\%$. The output energy is the gravitational potential energy that the mass gains. The input energy is the gravitational potential energy the mass expected to gain with respect to the theoretical height (h') value. Since there was no other external force on the system, that ratio should show how the efficiency of the system changes due to the effect of friction.

An example calculation for 3 blue & 3 black pulleys is as following;

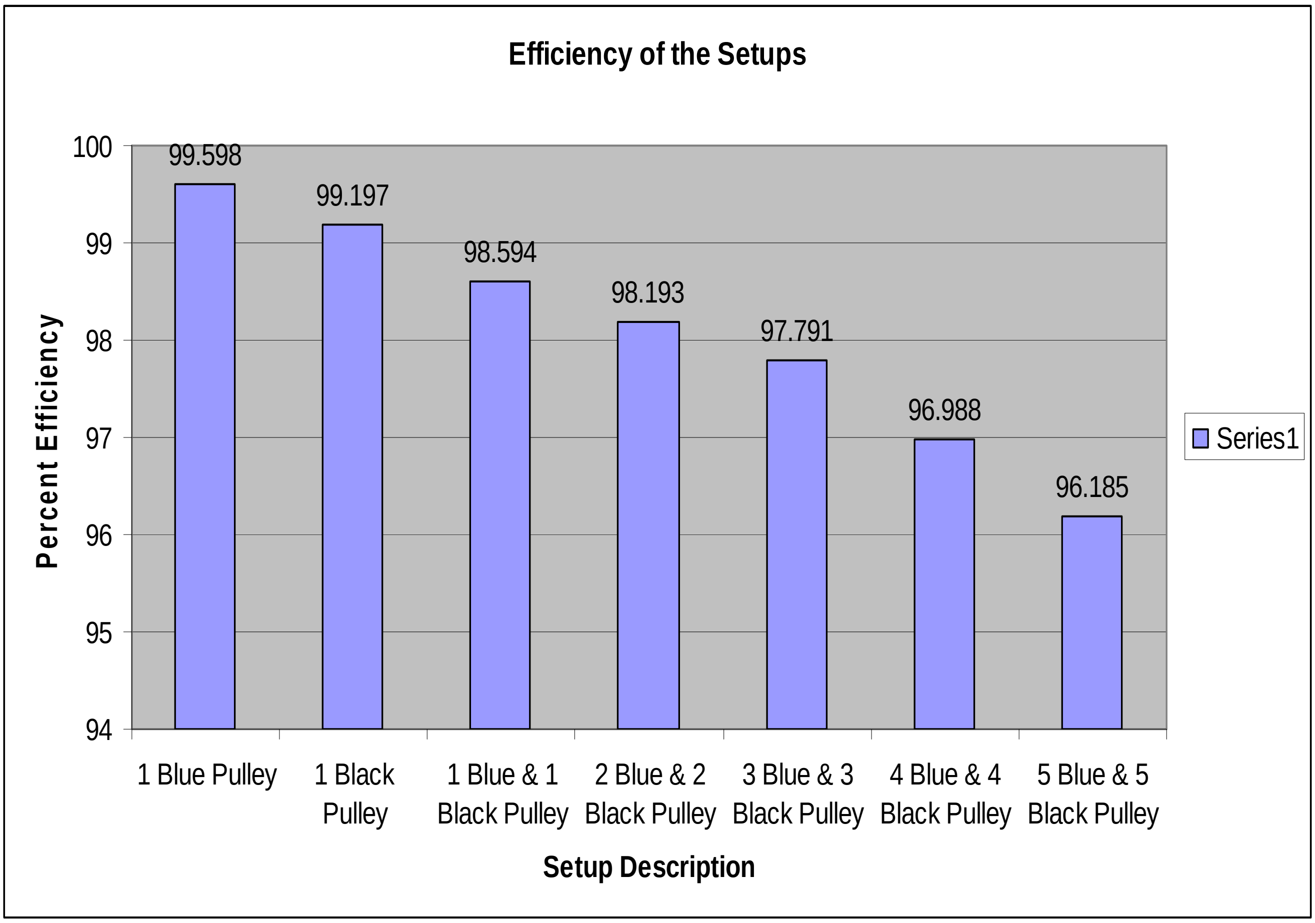
$$Efficiency = \left(\frac{E_{out}}{E_{in}}\right).100 = \left(\frac{m.g.h'}{m.g.h}\right).100 = \left(\frac{(0.1).(9.807).(0.487)}{(0.1).(9.807).(0.498)}\right).100 = 97.791\%$$

The results for all the system setups can be seen at the following table;

Descriptions	Mass (kg)	Gravitational Acceleration (m/s^2)	h (m) (±0.001)	h' (m) (±0.001)	Efficiency (%)
1 Blue Pulley	0.1	9.807	0.498	0.496	99.598
1 Black Pulley	0.1	9.807	0.498	0.494	99.197
1 Blue & 1 Black Pulley	0.1	9.807	0.498	0.491	98.594
2 Blue & 2 Black Pulley	0.1	9.807	0.498	0.489	98.193
3 Blue & 3 Black Pulley	0.1	9.807	0.498	0.487	97.791
4 Blue & 4 Black Pulley	0.1	9.807	0.498	0.483	96.988
5 Blue & 5 Black Pulley	0.1	9.807	0.498	0.479	96.185

Table 20: showing the results of efficiency of the pulley system for all the system setups.

The following graph is plotted for observing the change in the efficiency of the pulley system. It can be seen that, as the number of pulleys attached to the pulley system increases, the percent efficiency value of the system decreases.



Graph 2: showing the percent efficiency change with the varying system setups.

Plotted by Microsoft ® Office Excel 2003.

4.9 ERROR CALCULATION

For part 1, the result found was revolutions per minute value of the motor. The source of error could affect that result was the uncertainty in time measuring, which is ±0.01 seconds. Calculation of error for that uncertainty would give the systematic error.

1 revolution of motor takes place at 15.29 ± 0.01 seconds. In 60.00 seconds then, the motor will make 3.93 revolutions;

(60.00) / (15.29) = 3.93

If there is a ±0.01 seconds uncertainty in 15.29 seconds, then there will be ±0.001 uncertainty in 3.93 revolutions per minute;

(0.01) / (15.29) = (X) / (3.93)
X = 0.003 (can be written as 0.01 in 2 decimals)

If the same calculation is done for all results, the following error values will be obtained;

Applied Voltage – Volts ± 0.1	Systematic Error Value of rpm
6.0	0.003
7.0	0.003
8.0	0.005
9.0	0.006
10.0	0.007
11.0	0.009
12.0	0.011

Table 21: showing the systematic error values of rpm for applied voltages.

It can be seen that no value passes ± **0.01 error** when written in **2 decimals**. So, percent systematic error for the results in part 1 can be calculated as;

Example calculation for 9.0 volts applied to motor:
±0.01 error for 5.94 revolutions of motor yields to **0.17%** systematic error.
(((100) . (0.01)) / (5.94)) = **0.17**

If the same calculations are done for all results, the systematic error values will be as following;

Applied Voltage - Volts ± 0.1	Percent Systematic Error Value of rpm
6.0	0.25%
7.0	0.21%
8.0	0.19%
9.0	0.17%
10.0	0.15%
11.0	0.14%
12.0	0.13%

Table 22: showing the percent systematic error value of rpm for applied voltages.

For part 2 – Pulley systems, the result found is the percent efficiency of the system. The source of error could affect that result is the uncertainty in height measuring which is ±0.001 meters. Calculation of error for that uncertainty, would give the systematic error.

An example calculation of efficiency for 3 blue & 3 black pulleys was;

$$Efficiency = \left(\frac{E_{out}}{E_{in}}\right).100 = \left(\frac{m.g.h'}{m.g.h}\right).100 = \left(\frac{(0.1).(9.807).(0.487)}{(0.1).(9.807).(0.498)}\right).100 = 97.791\%$$

Here, "h" and "h'" values both have an uncertainty of ±0.001. The other values (mass and gravitational acceleration) are standard values and don't have any uncertainty. In a division involving uncertainties like; $\frac{(x \pm \Delta x)}{(y \pm \Delta y)} = z \pm \Delta z$ To find the uncertainty of the result (Δz) the following equation should be solved which is $\frac{\Delta x}{x} . \frac{\Delta y}{y} = \frac{\Delta z}{z}$. Note that in the calculation of efficiency here in this experiment, there are more than 1 dividend and divisor values so, be careful when calculating the quotient "z". If all setup's errors are calculated via those equations, their systematic errors are found as;

Setup Description	Percent Error of Efficiency
1 blue pulley	0.400%
1 black pulley	0.403%
1 blue & 1 black pulley	0.406%
2 blue & 2 black pulley	0.407%
3 blue & 3 black pulley	0.409%
4 blue & 4 black pulley	0.412%
5 blue & 5 black pulley	0.416%

Table 23: showing the percent error of efficiency for all setups.

Description of the marked data in table 19:

That data has an uncertainty value different from rest of the data because, for “just motor” setup, theoretical height value was calculated differently. Theoretical height value was found via;

Height of mass = length of circumference of sheave . revolutions per time

$$h = 2.\pi.r.N$$

$$h = (2).(\pi).(0.010m).(7.99rev/\min)$$

$$h = 0.502m$$

Here, the radius of the pulley has an uncertainty of ±0.001m and the uncertainty in rev/min value was found as ±0.01 in the part beginning at this section. If the systematic error calculation is done with respect to the equations $(x \pm \Delta x).(y \pm \Delta y) = (z \pm \Delta z)$ and $\frac{\Delta x}{x}.\frac{\Delta y}{y} = \frac{\Delta z}{z}$, the error is calculated as following;

$$\frac{0.001}{0.010} + \frac{0.01}{7.99} = \frac{\Delta z}{0.502}$$

Δz = ±0.051

5 CONCLUSION AND EVALUATION

Throughout this experimental study, how friction affects the efficiency of a pulley system is investigated. The results for research question, which is "Does changing the number of pulleys in a pulley system cause friction and hence efficiency of the system to alter?" are gained. They showed; efficiency of the system definitely changes when number of pulleys attached to system is altered. Increasing the number of pulleys decreased the efficiency as hypothesized. As mentioned in the research question, this experiment was also designed for observing the change in the amount of friction in the system. Results and integration of those results with the information given at the beginning showed the goal is accomplished. It's observed that increasing the number of pulleys also means increasing the surface area of interaction of surfaces and hence increase in the amount of friction. Friction can be named as, source for energy loss at the system as a result.

An explanation about the planning and results of the experiment is, in part 1; the motor is tested in order to get an equation that enables the usage of any voltage value in the experiment. I decided to use 12.0 Volts in part 2 because, as you can see in results and error calculation, the revolution per minute value found is appropriate (very close to a whole number - 7.99) and its error is the lowest between other voltages tested (0.13%). That has improved the precision of results in part 2. As you can see, results in part 2 have a very small percent systematic error value with respect to the resultant values (ex: 0.416% error for 96.185% efficiency value).

The significance of the topic can be seen well if real life applications of this kind of system are considered. Especially in construction sites and mining industry, pulley systems are widely used. If in a small system like the one used in this experiment loses its efficiency about 4 – 5 % when the friction is increased just a little, that means a very significant loss of energy, power and money in a size of a system pulling tons of masses to tens of meters. In a world where fuel, energy and money is extremely important, efficiency and factors affecting the efficiency negatively like friction, should be carefully treated.

Although the results are very precise and the systematic error is very small, there are some points that might be evaluated for future and further applications. The systematic error was found very small but there is a greater amount of experimental error because sources of observational error are great. The major one is, while doing the trials in part 2, I turned off the power source myself when I see 1 minute on the stopwatch. Although I tried to be very careful, my possible lack of accuracy cannot be ignored. For the accuracy of the experiment, a timer can be plugged to the power source so that it will shut off exactly after 1 minute. On the other hand, the error I could have done is likely to cancel out since I did many trials and hence it is random error. That means, the positive and negative errors will each other. There is a similar situation in part 1 too. Since I measured the time of one revolution of motor by watching a certain point on sheave, there is a source of error which is generated from my point of view and hand-eye coordination. An improvement can be made as; attaching a counter to the end of motor would give rev/min. value with no need to make calculations. However, it should be also noted that using such system will have the same sources of error for shutting down the power. A combination of those two improvements could make the accuracy of the experiment much more.

There are some improvements can be made for the materials used which would decrease the systematic error. First, more precise measurement devices can be used for measuring height and time. Secondly, using fixed pulleys attached to normal pincers instead of pincers with a hook on top (which enables them to move) can be better. Another improvement can be made for the type of rope used. The type I used was likely to get loose and I needed to put some effort to adjust it. A tighter rope type can solve this problem.

A further question to investigate in this system can be how the efficiency of the electric motor is affected by friction, instead of the efficiency of the pulley system. For that, the input energy can be measured as electrical energy. Another investigation can be made to see if the efficiency of the pulley system alters when different types of pulleys (movable or compound) are used in the same system. The type of the rope used in the experiment can also be investigated for if having an effect on the friction and efficiency. Lastly, the effectiveness of lubricants on friction reduction can be tested.

6 REFERENCES

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7 APPENDICES

APPENDIX A: Materials

- Electric motor (Brand: Nostop 25GA370-12560-500, 12 VDC, 7.5 rpm, 40 mA, maximum torque: 15 kg.cm)
- Sheave of a sewing yarn
- 0.1 kg standard mass
- Rope (at least 1.50 m)
- 5 blue fixed pulleys
- 5 black fixed pulleys
- Ruler, 0.5 m long (±0.001 m)
- Digital DC power supply (brand: GENMAK, serial no: GK 05151 084, Volt 220 AC, Hz. 50, Power: 30 W max, min. reading 0.1 V, max. reading 15 V) (±0.1 V)
- 2 bronze conductor wires with one clip-end and one plug-end
- 3 table pincers
- 4 metal bars
- 10 small pincers
- 5 small pincers with a hook on the top
- Stopwatch (±0.01 sec)

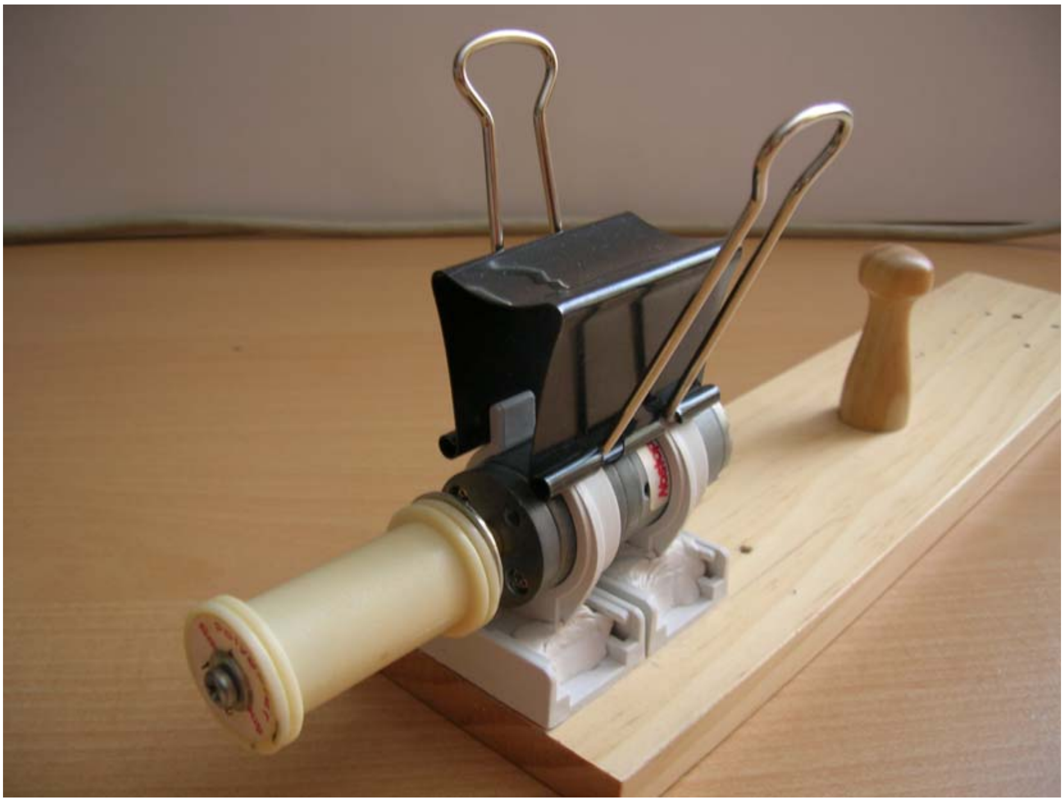
For all calculations, TI-84 Plus (Serial Number: 2428017881 S–0807H) manufactured by Texas Instruments® was used.

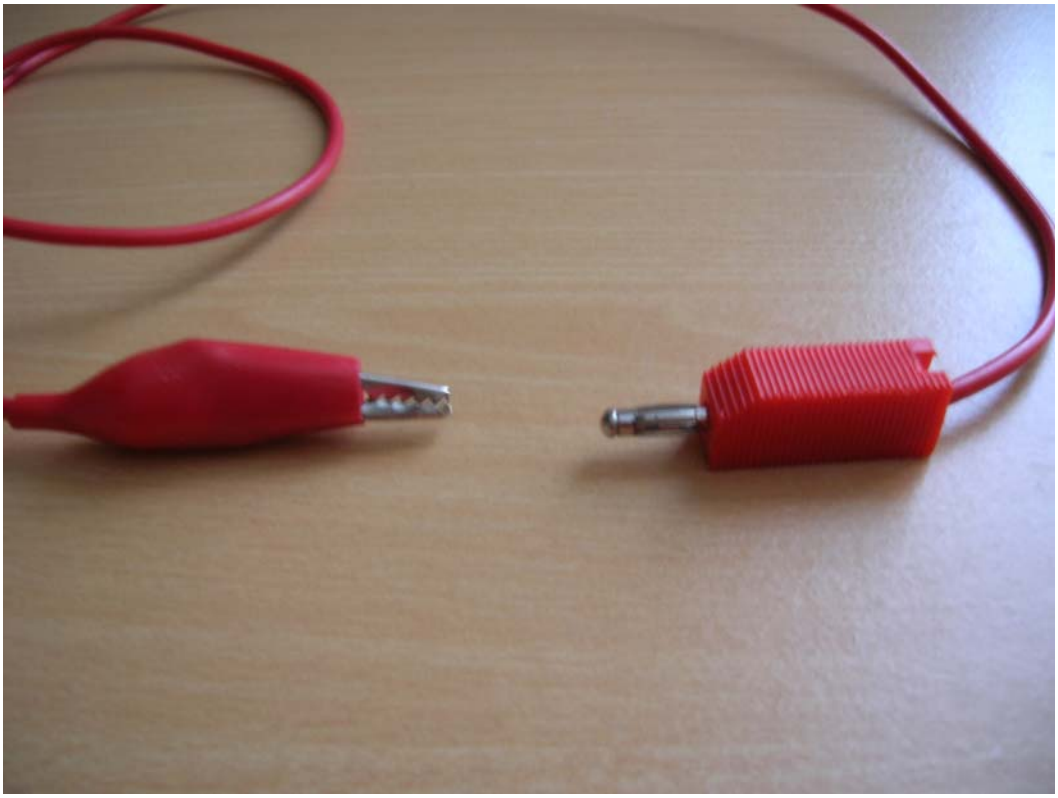
Additionally;

The motor itself was not suitable to use in the system since it doesn't stand still because of its round shape. That's why; a wooden deck was manufactured. A piece of wood, parts of a hook and pincer were used. (See pictures for further details.)

Also, the electric motor's rotating end was not suitable for holding the rope. A special part to overcome that problem using the sheave of a sewing yarn was manufactured. (See pictures for further details.)

APPENDIX B: Pictures






DC POWER SUPPLY
0 - 15 Volt
VOLTAGE Adj.
POWER
OUTPUT