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**PRINCE MOHAMMAD BIN FAHD UNIVERSITY**

**College of Engineering**

**Department of Mechanical Engineering**

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## **Senior Design Project Report**

**Fabrication of a cone clutch to measure the output torque at different engagement angles and improved efficiency.**

**In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering**

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## **Abstract**

Clutches in a power transmission system plays a role of transferring power from a driver shaft to the driven shaft. However, cone clutches are used for low peripheral speeds but high torque and the angle of the peripheral mating cone disc ranges from 10 degrees to 15 degrees depending on the optimal conditions like the friction material used on the peripheral cone, the amount of torque required and the amount of acceptable losses. Also, the spring which engages the clutch plays a secondary role in order to keep a persistent contact between the driver and driven discs, based on the spring constant or it's stiffness, the output could vary if load is also applied to the driven shaft. Since, cone clutches are manufactured based on only one peripheral angle and one spring of a certain stiffness, in case of varying torque requirements these clutches are prone to slippage especially if the load is increased on the driver shaft while keeping a constant input from the driven shaft. Based on such a need to overcome the slippage and mechanical losses, this project focuses in analyzing the maximum the clutch can withstand just before the verge of being completely resistive to the input load. Moreover, we will be also be looking forward to improve the efficiency of the system to some extent which can reduce the losses if faced.

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## List of Acronyms

<b><math>F_n</math></b>	<b>Normal Force</b>
<b><math>F_a</math></b>	<b>Axial Force</b>
<b><math>f</math></b>	<b>Friction</b>
<b><math>R</math></b>	<b>Mean Radius</b>
<b><math>r_1</math></b>	<b>Outer Radius of Cone</b>
<b><math>r_2</math></b>	<b>Inner Radius of Cone</b>
<b><math>\mu_k</math></b>	<b>Coefficient of Kinetic Friction</b>
<b><math>\mu_s</math></b>	<b>Coefficient of Static Friction</b>
<b><math>T</math></b>	<b>Torque</b>
<b><math>\eta</math></b>	<b>Efficiency</b>

## List of Figures

Figure # 1.4: Double Cone Clutch at the bottom assembly of a bobbin carriage.....	7
Figure # 3.3: Calculation Schematics for Cone Clutch.....	19
Figure # 3.3: Calculation Schematics for Cone Clutch.....	19
Figure # 3.4: Cone Clutch Section View Schematics.....	22
Figure # 3.4 (a): Machined Female Cones (Left: $14.5^{\circ}$ & Right: $12.5^{\circ}$ ).....	23
Figure # 3.4 (b): Machined Male Cones (Left: $12.5^{\circ}$ & Right: $14.5^{\circ}$ ).....	23
Figure # 3.4 (c): Table of Materials with their friction properties [7].....	24
Figure # 3.4(d): Spring.....	25
Figure # 3.4(e): Spline Shaft.....	25
Figure # 3.4(f): CAD Model of Prototype after 70% Completion.....	26
Figure # 3.4(g): CAD Model of Prototype (Section View).....	26
Figure # 3.4(h): Exploded View of Prototype w/ BOM.....	27
Figure # 3.5: Machining of Female Cone.....	28
Figure # 3.5 (a): Manufactured/ Machined Components.....	29
Figure # 4.1.1: Tachometer.....	30
Figure # 4.1.2: Digital Weight Scale.....	31
Figure # 4.2.1(a): Torque Comparison ( $14.5^{\circ}$ ).....	33
Figure # 4.2.1(b): Torque Comparison with 10 mm spring deflection.....	34
Figure # 4.2.1(c): Torque Comparison with 20 mm spring deflection.....	35
Figure # 4.2.1(d): Torque Comparison with 30 mm spring deflection.....	36
Figure # 4.2.1(e): Torque Comparison with 40 mm spring deflection.....	37
Figure # 4.2.1(f): Power Transmission Efficiency Graph ( $14.5^{\circ}$ ).....	39
Figure # 4.2.2(a): Torque Comparison ( $12.5^{\circ}$ ).....	41
Figure # 4.2.2(b): Torque Comparison with 10 mm spring deflection.....	42
Figure # 4.2.2(c): Torque Comparison with 20 mm spring deflection.....	43
Figure # 4.2.2(d): Torque Comparison with 30 mm spring deflection.....	44
Figure # 4.2.2(e): Torque Comparison with 40 mm spring deflection.....	45
Figure # 4.2.2(f): Power Transmission Efficiency Graph ( $12.5^{\circ}$ ).....	47

## List of Tables

Table # 1.3: Specifications of the Project .....	8
Table # 3.2: Engineering Standards.....	15
Table # 3.2.2 (a): Dimensions of Cones with two different angles.....	16
Table # 3.2.2 (b): Dimensions of Cups with two different angles.....	16
Table # 3.2.3: Dimension of Spline Shaft.....	16
Table # 3.2.4: Dimension of Bearing.....	17
Table # 3.2.5: Dimension of Spring.....	17
Table # 3.2.6: Dimension of Base Plate.....	17
Table # 4.1: Testing Parameters.....	32
Table # 4.2.1: Input and Output Power of Cone Clutch (14.5°).....	32
Table # 4.2.1(a): Torque between Theoretical and Experimental (14.5°).....	33
Table # 4.2.1(b): Torque between Theoretical and Experimental w/10mm (14.5°).....	33
Table # 4.2.1(c): Torque between Theoretical and Experimental w/20mm (14.5°).....	35
Table # 4.2.1(d): Torque between Theoretical and Experimental w/30mm (14.5°).....	36
Table # 4.2.1(e): Torque between Theoretical and Experimental w/40mm (14.5°).....	37
Table # 4.2.1 (f): Input and Output Power of Cone Clutch w/10 mm (14.5°).....	38
Table # 4.2.1 (g): Input and Output Power of Cone Clutch w/20 mm (14.5°).....	38
Table # 4.2.1 (h): Input and Output Power of Cone Clutch w/30 mm (14.5°).....	38
Table # 4.2.1 (i): Input and Output Power of Cone Clutch w/40 mm (14.5°).....	39
Table # 4.2.2: Input and Output Power of Cone Clutch (12.5°).....	40
Table # 4.2.2 (a): Torque between Theoretical and Experimental (12.5°).....	40
Table # 4.2.2 (b): Torque between Theoretical and Experimental w/10mm (12.5°).....	41
Table # 4.2.2 (c): Torque between Theoretical and Experimental w/20mm (12.5°).....	42
Table # 4.2.2 (d): Torque between Theoretical and Experimental w/30mm (12.5°).....	43
Table # 4.2.2 (e): Torque between Theoretical and Experimental w/40mm (12.5°).....	44
Table # 4.2.2 (f): Input and Output Power of Cone Clutch w/10 mm (12.5°).....	45
Table # 4.2.2 (g): Input and Output Power of Cone Clutch w/20 mm (12.5°).....	46
Table # 4.2.2 (h): Input and Output Power of Cone Clutch w/30 mm (12.5°).....	46
Table # 4.2.2 (i): Input and Output Power of Cone Clutch w/40 mm (12.5°).....	46

## Table of Contents

<b>Chapter # 1: Introduction</b> .....	7
<b>1.1 Project Definition</b> .....	7
<b>1.2 Project Objectives</b> .....	7
<b>1.3 Project Specifications</b> .....	8
<b>1.4 Project Applications</b> .....	8
<b>Chapter # 2: Literature Review</b> .....	10
<b>2.1 Project Background</b> .....	10
<b>2.2 Previous Work</b> .....	10
<b>2.3 Comparative Work</b> .....	11
<b>Chapter # 3: System Design</b> .....	13
<b>3.1 Design Constraints and Design Methodology</b> .....	13
<b>3.2 Engineering Design Standards</b> .....	15
<b>3.3 Theory and Theoretical Calculations</b> .....	18
<b>3.4 Product Subsystems and selection of Components</b> .....	22
<b>3.5 Manufacturing and Assembling (Implementation)</b> .....	28
<b>Chapter 4: System Testing and Analysis</b> .....	30
<b>4.1 Experimental Setup, Sensors and data acquisition system</b> .....	30
<b>4.2 Results, Analysis and Discussion</b> .....	32
<b>Chapter 5: Project Management</b> .....	48
<b>5.1 Project Plan</b> .....	48
<b>5.2 Contribution of Team Members</b> .....	50
<b>5.3 Project Execution Monitoring</b> .....	52
<b>5.4 Challenges and Decision Making</b> .....	53
<b>5.5 Project Bill of Materials &amp; Budget</b> .....	54
<b>Chapter 6: Project Analysis</b> .....	55
<b>6.1 Life-Long Learning</b> .....	55
<b>6.2 Impact of Engineering Solutions</b> .....	56
<b>6.3 Contemporary Issues Addressed</b> .....	57
<b>Chapter 7: Conclusion &amp; Future Recommendations</b> .....	58
<b>7.1 Conclusion</b> .....	58
<b>7.2 Future Recommendations</b> .....	58
<b>8. References</b> .....	59

# Chapter # 1: Introduction

## 1.1 Project Definition

This project is intended to fabricate an existing cone clutch mechanism in order to improve its efficiency and analyse the behaviour of torque acting against speed at two different cone angles of  $12.5^\circ$  and  $14.5^\circ$ . Since, most cone clutch angles range within  $10^\circ$  to  $15^\circ$ , we have selected two cone angles to compare their results with respect to torque and how much efficiency can be improved by a means of a linear actuator acting parallel to the spring against the cone clutch engagement which will account for the loss in friction while at high speeds. Since, these types of clutches were widely used in the early 20<sup>th</sup> century in the pre-war stages, our project will try to deduce their implications to be met in the modern world. Furthermore, parameters such as friction lining, output maximum torque versus the angular speed, contact angle, contact surface area on the peripheral of the cup and cone and the spring for disengagement/engagement are the vital elements in this whole mechanism. In order to test the fabricated existing cone clutch mechanism for the purpose of analysis, the components selection and the parameters adjustments would surely play quite a significant role in approaching our purpose of undergoing through the amount of time and effort we will be putting in as a team.

## 1.2 Project Objectives

Our project our team is based on the following objectives:

- Improve the cone clutch mechanism.
- Analyze the losses at two different cone angles (12.5 & 14.5).
- Determine the output torque produced by a means of an in-built dynamometer mechanism.
- Improve the efficiency of the cone clutch by externally exerting force via spring to the cone.

### 1.3 Project Specifications

The project is based on the idea of pilot testing/testing rig which will have an onboard rope brake dynamometer mechanism at the end of the shaft to measure the torque at any given speed. Furthermore, it also consists of two linear actuators, piston cylinder based and a power screw based, respectively. One of the actuators will be used to engage and disengage the clutch while the other will be used to linearly displace the spring within a range of some millimetres to compensate for the lost friction while at high speed operation. Following table # 1.3, illustrates some of the dimensions according to which our project will be constructed.

Part	Dimension
Cone Angles	12.5 <sup>0</sup> and 14.5 <sup>0</sup>
Cup Angles	12.5 <sup>0</sup> and 14.5 <sup>0</sup>
Shaft Radius	35 mm
Shaft Length	400 mm
Motor	1.5 kW
Engagement/Disengagement Spring	Thickness: 4.5mm, OD: 67mm, Length: 154mm
Base Plate	Length: 1000mm & Width: 600mm
Linear Actuator for engagement and disengagement	Load: 1500N, Stroke: 254mm & Speed: 8mm/s
Linear Actuator for Spring Compression	Load: 900N, Stroke: 152.4mm & Speed: 6mm/s

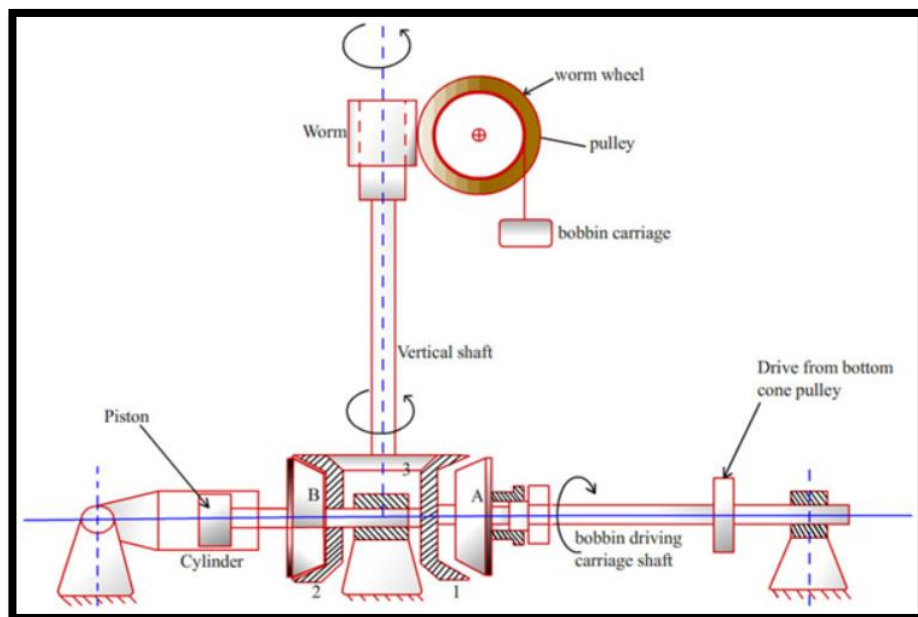
*Table # 1.3: Specifications of the Project*

### 1.4 Project Applications

Since, cone clutches are quite obsolete now in the modern world, there are still some areas of interest where these types of clutches still play a key role in power transmission. To name some;

- They are used in some race cars where torque is prioritized over speed.
- These types of clutches are also used in some very heavy-duty off-road vehicles for extreme torque and to tackle steep approach angles on a hill.

- In case of modern daily driving cars, these clutches are not used as such but the concept of cone clutch is widely applied in synchronizers working in a gearbox.
- They are also used in textile industries in bobbin carriages. (Figure # 1.2)
- Basically, any aspect of engineering where there is a need to transmit high torques at relatively lower peripheral speeds is where there can be a presence of cone clutches.



***Figure # 1.4: Double Cone Clutch at the bottom assembly of a bobbin carriage***

## **Chapter # 2: Literature Review**

### **2.1 Project Background**

To begin with, in modern day mechanical equipment where there is a need of power transmission through a mechanical mechanism like a clutch, each type of clutch is selected on the basis of the requirements of a specific kind of purpose. As in our case, we are interested to fabricate an already designed and manufactured cone clutch mechanism to study the torque variation upon increased speeds. As cone clutches are mostly used in places where there is a need of high torque instead of speed, sometimes speed may also be given priority along torque in order to transmit power within a range of variable flexibility. This is why, our team is trying to improve its torque availability at considerably higher rpms by using an actuated external assistance in order to compensate for the losing coefficient of friction as kinetic friction decreases. So, these types of clutches could be revived and reborn within some applications of our daily life.

### **2.2 Previous Work**

Cone clutches may be quite an old mechanism which was discontinued in some areas due to the constraints it was not able to overcome. Since, it has a wedging action of engagement and disengagement of power transmission, it has an ability to produce a very amount of torque as compared to a disc clutch of the same size. However, when it comes to high speed, this is where these clutches face some difficulties in maintaining the frictional contact at higher angular speeds.

Not much have been done in regards to cone clutch mechanisms since in the daily modern lives, there has been many effective types of clutches been manufactured like wet-disc clutches, dry-disc clutches, multiplate clutches, etc. capable enough to transfer the required amount of torque and speed at any given rpms. Since, these were mostly common in the automobile sector in the pre-war stages, nowadays, only the concept of cone clutches remains with a few exceptions in heavy industries, lawn mowers and in extreme off-road vehicles.

Similarly, a group of Indian researchers worked on Ansys in order to design a cone clutch mechanism by adjusting the parameters such as cone/cup angle, area of

contact, etc. The existing cone clutch they work on was capable of producing 50-55 Nm of torque whereas, the group managed to work on simulating the cone clutch mechanism that was able to produce 65 Nm of torque effectively without any fluctuation [1].

Additionally, as the performance of cone clutches depend entirely on the type of frictional material used, a research study was conducted in 1991 in regards to analyze and observe mathematically the friction between wedging bodies in a cone clutch mechanism and to obtain the limit circumferential forces acting. The main problem was that classical mathematical approach was taken and some very clear yet solvable problems were ignored. By technically working out a mathematical relation, this problem was reverted and new frictional studies emerged between the wedging bodies which remain in contact purely on the basis of friction [2].

The above mentioned previously done work provides our team an insight of the parameters to take into consideration during material selection and designing criteria which would be followed by the constraints we would have to be accustomed to as we would be aiming to produce considerably higher torque at unusually higher rpms.

### **2.3 Comparative Work**

In order to set a benchmark for our project, there was a need to expose ourselves in to the environment where we wanted to gather knowledge, skills, expertise and some very crucial information which would help us achieve our goal. So, we had to look into previously done cone clutch projects which provided us with some of the most interesting facts which was obtained as a result from their experimentation and results.

Firstly, a senior year project was taken as a reference from Prince Muhammad Bin Fahd University in which a group of five designed a cone clutch that was driven by a 2 HP electric motor. Now, that group just focused on developing and manufacturing this mechanism for the soul purpose of awareness. However, no output torque was obtained or measured by the team instead they focused on the losses between input and output angular speeds, which fell well within the range of 2-5% frictional losses. Moreover, they also used the contact angle of  $12.5^{\circ}$  which is what mostly used in most

of the cone clutches. As a part of their recommendation, we will be focusing on fabricating the mechanism in such a way that we can measure the output torque and also develop a small actuated system to somewhat improve the frictional contact at higher speeds [3].

Finally, our team also did a bit of a research where we managed to come across a German Holding by the name “Hoerboiger” who are known for making performance parts in the sector of automobiles. They have managed to redefine the concept of a cone clutch which surprisingly will be used in automatic transmissions of vehicles to give maximum output by consuming very less fuel. As we are well-known about the torque effective nature of such clutches, presumably, they’d be aiming to provide low end torque on city cars [4].

## **Chapter # 3: System Design**

### **3.1 Design Constraints and Design Methodology**

#### **3.1.1 - Geometrical Constraints:**

Since the moment we decided to take on this project and modify it to our design we realized quickly that the parts were really heavy. It would make it hard to move from one place to another without two members being there to help each other. Therefore, serious weight reduction was carried out to make it easier to transport around. Subsequently, we are fabricating most of the parts instead of designing a new one, we had limited space on the base plate. Due to our plan to attach actuators on the side and on the back of the shaft. Moreover, we had to develop an alternative way to attach the dynamometer vertically on top, in order to make it easier for transportation and reduce weight.

#### **3.1.2 - Sustainability:**

Our prototype is aimed to be used at indoor conditions, it is very easy to handle and can be used by anyone. Proper and periodic maintenance will sustain it for a significant amount of time. Similarly, bearings and motor parts may require some maintenance after operation as it would be exposed to the atmosphere and sand particles could entrap between the lubricated surfaces. If the friction material has worn off after some time, it should be replaced, in our case we used a layer of 3mm cork blend. Cone Clutches were substituted by disk multi-plate clutches, but that does not mean cone clutches are frowned upon. In fact, cone clutches are still in use today in rallying and extreme off-road vehicles and sports cars too.

#### **3.1.3 - Environmental:**

There are numerous types of clutches in the industry, like single and multi-plate clutches or centrifugal and semi-centrifugal clutches. Cone clutches are friction clutches. They are trouble-free in production and are easy to disengage. However, the driving and driven shafts must be flawlessly coaxial for efficient operation of the clutch. This requirement is more critical for cone clutches compared to single plate

friction clutch. Cone Clutches offer significantly lower fuel consumption and increased power. They are easy to handle and have universal application possibilities.

### **3.1.4 - Social Impact:**

The end goal for our project is to revive these clutches to be used more commonly in our automobiles. Also, to be utilized further in the industry, especially where there is high torque requirement. Clutch systems nowadays require expensive and a great deal of resources to manufacture and to run. Nevertheless, cone clutch systems require much less resources and are cheaper to maintain, when compared to disk-plate clutches. Cone clutches transfer greater amounts of torque than plate or disk clutches of similar sizes due to the wedging action and enlarged surface area.

### **3.1.5 - Economic:**

Our cone clutch system, may not be as competitive as other systems, but in the long-run it does offer increased power, compact dimensions, easy handling and universal application possibilities. The vital modification between old and new lies in the project solution and how it influences the transmission's efficiency as a whole. Moreover, there is also very minor maintenance required in order to keep the system in an operable state and because of simplicity in its manufacturability, there are less chances of breaking down.

### **3.1.6 - Manufacturability:**

Furthermore, we were able to find a shop to manufacture new sets cones clutches for us and have them be made from Aluminum. We chose Aluminum, due to it being a softer and lighter material, when compared to Low Carbon or Mild Steel. The machining process was very easy and hassle free. Costs can rise depending on material properties and its mechanical properties, since the spline shaft has teeth on one end. The sliding motion of the cone clutches needs attention and care during engagement and disengagement. This might increase the manufacturing difficulty to some extent.

### **3.1.7 - Safety:**

During the engagement of the inner and outer plates while the shaft is running, at times we discover high vibration and noisy sound. Therefore, friction material (cork blend)

is installed that will optimize the required friction. Also, in order to prevent shaft failure, we have to properly align the shaft with the cone clutch, since the spline shaft has teeth on one end to prevent any slippage. Cone clutches are frequently now simply used in small peripheral speed applications, yet they were once shared in vehicles and additional combustion engine transmissions.

### 3.1.8 - Ethics:

As most common projects are completed in accordance to a previously achieved work, there are always fabrications and modifications of distinctive ideas involved in order to make a precise project stand out from the outdated ones accomplished before. Our mission is to fabricate a cone clutch to measure the output torque at different engagement angles. Based on such a need to overcome the slippage and mechanical losses. Moreover, we will be going to improve the overall efficiency of the system to some extent which can reduce the losses if faced.

## 3.2 Engineering Design Standards

### 3.2.1 Introduction

The purpose of this specifications for design is to make users aware of various standards which may be considered during the design process.

The American Society for Testing and Materials (ASTM) standards will be used for classifying what sort of material has been selected, as well as giving the dimensions and stating which material has been designated for each component.

The cone clutch system will be powered by a 1.5-Kilowatt (2 HP) engine, which is mounted on a Rough Iron base.

Below is a list of all the materials used, along with the engineering standard for each component.

<i>Components</i>	<i>Engineering Standards</i>
Cone & Clutch Assembly (12.5° & 1.5°)	ASTM-B211: Aluminum 6061-T6
Spline Shaft	AISI 1045: Carbon Steel (ANSI B92)
Bearings	NSK-6207ZZ
Spring	ASTM-A320: Galvanized Steel

Base Plate	ASTM-A207: Wrought Iron
Friction Lining	TS1521: Cork with Styrene (SBR)
Anti-Vibration Pad	JIS-60 KHS Type: Chloroprene Rubber

*Table # 3.2: Engineering Standards*

### 3.2.2 Cones and Cups

Material: Aluminum 6061-T6

Engineering Standard: ASTM-B211

One of our objectives is to analyze the losses at two different cone angles, 12.5° and 14.5°. So off course each cone will have different dimensions. The dimensions and the of each cone are listed in table 3.2.2 (a) below.

Cone Angle	Outer Diameter	Inner Diameter	Thickness
12.5°	120 mm	109 mm	5 mm
14.5°	122 mm	109 mm	5 mm

*Table 3.2.2 (a): Dimension of Cones with Two Different Angles*

The cups have the same material as the cones, as they were manufactured by the same manufacturer, but they have a slight difference in their dimensions. The dimensions of each cup are listed in table 3.2.2 (b) below.

Cup	Outer Diameter	Inner Diameter	Thickness
For 12.5°	130 mm	109 mm	5 mm
For 14.5°	132 mm	109 mm	5 mm

*Table 3.2.2 (b): Dimension of Cups with Two Different Angles*

### 3.2.3 Spline Shafts

Material: Carbon Steel

Engineering Standard: AISI-1045

Manufacturing Standard Followed: ANSI B92

Shaft Type	Diameter	Length
Driving	35 mm	140 mm
Driven	35 mm	310 mm

*Table 3.2.3: Dimension of Spline Shaft*

### 3.2.4 Bearing

Material: Steel

Engineering Standard: NSK-6207ZZ

Table 3.2.4 shows the dimension of the bearing.

Outer Diameter	Inner Diameter	Width
72 mm	35 mm	17 mm

*Table 3.2.4: Dimension of Bearings*

### 3.2.5 Spring

Material: Galvanized Steel

Engineering Standard: ASTM-A320

Table 3.2.5 shows the measurements of the spring.

Diameter	Thickness	Length	Number of Coils (Active)	Number of Coils (Total)	Distance Between Each Coil
67 mm	3 mm	154 mm	10	12	14.4 mm

*Table 3.2.5: Dimension of Spring*

### 3.2.6 Base Plate

Material1: Wrought Iron

Engineering Standard: ASTM-A207

Table 3.2.6 shows the dimensions of the base plate.

Length	Width	Thickness
1000 mm	500 mm	12 mm

*Table 3.2.6: Dimension of Base Plate*

The following remaining components aren't classified by the ASTM, but a brief description is given for each component.

### 3.2.7 Friction Lining

Material: TS1521 - cork with styrene butadiene rubber (SBR)

Withstands temperature of 110°C.

The purpose of using a friction lining is to generate a frictional force between the cup and cone. So, the material has to withstand a very high temperature as it needs to withstand heat generated from the rotation of the cone.

### 3.2.8 Anti Vibration Pad

Material: Chloroprene rubber

Engineering Standard: JIS 60-KHS type (Japanese Industrial Standard)

The pad has ribs on both sides that which will isolate vibrations, if any, enhancing the overall efficiency of the cone clutch system. It is placed underneath the motor and the bearing housing.

## 3.3 Theory and Theoretical Calculations

### 3.3.1: Cone Clutch Design Calculations

Since cone clutches work on the principle of friction and torque transmitted depending on the cone and cup angles, a necessary range of calculations are carried out which includes the determination of friction coefficient of the friction lining being used, the amount of torque being transmitted if a certain amount of axial force is being applied. Also, a need to determine the dynamometric force which would be essential enough to produce about 5-10% significant losses in torque and speed transmission which would allow us to apply an external force via spring to observe the compensation for the lost frictional contact on the cone peripheral with the clutch.

#### **Coefficient Friction Calculations:**

In order to calculate the coefficient of friction of the lining we are using, it is of cork with styrene embedded between it on aluminum. The technique we used was a traditional one which is used very commonly by placing a piece of the friction lining on the aluminum block and calculating the angle at which the friction is on the verge of slipping. The angle noted was  $23^{\circ}$ .

From below equation of coefficient of friction, it is known that;

$$\mu = \tan\theta$$

$$\mu = \tan(23^{\circ})$$

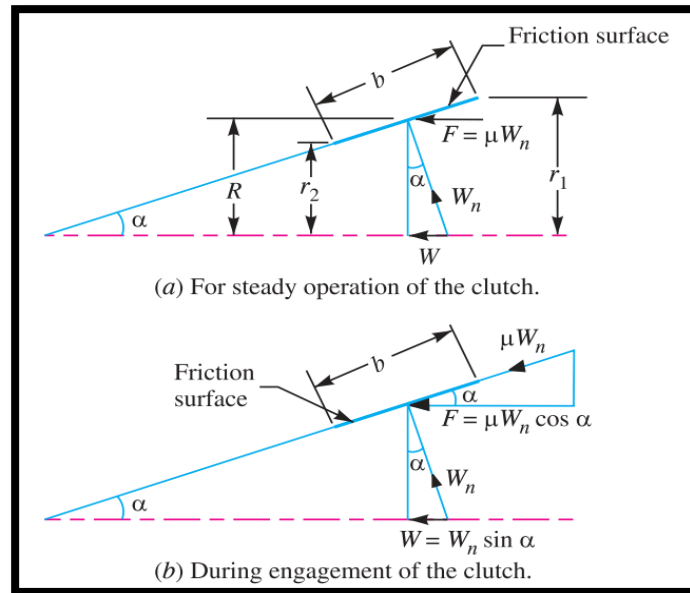
$$\mu = 0.42$$

***Coefficient of Friction of Styrene Based Cork on Aluminum = 0.42***

#### **Mechanical Calculations:**

In order to calculate the axial force and torque being transmitted, there are two theories being used namely Uniform Pressure Theory and Uniform Wear Theory. The uniform-

pressure theory is applicable only when the friction lining is new. When the friction lining is used over a period of time, wear occurs. Therefore, the major portion of the life of friction lining comes under uniform-wear criterion. Hence, in the design of clutches, the uniform wear theory is used [5]. Additionally, a pair of calculations will be carried out for the engagement angles of  $12.5^\circ$  and  $14.5^\circ$  degrees.



**Figure # 3.3: Calculation Schematics for Cone Clutch**

In reference to figure # 3.3, we can first of all calculate the axial force acting on the cone clutch when in engaged form by attaching a weight gauge giving us a reading in kilograms which was converted in newtons and following geometric procedure was followed in order to determine the area of the peripheral engaged along with the normal force applied on the peripheral.

$$F_a = 130 \text{ N}$$

To calculate the Normal force,  $F_n$ ; (from above figure), when  $\alpha = 12.5^\circ$

$$\sin \alpha = \frac{F_a}{F_n}$$

$$F_n = \frac{F_a}{\sin \alpha}$$

$$F_n = \frac{130}{\sin(12.5)}$$

$$F_n = 600.63 \text{ N}$$

For the normal pressure being applied on the whole peripheral area;

$$A = 2\pi R \cdot dr \cdot \text{cosec} \alpha$$

where,  $dr = 5.50 \text{ mm}$ ,  $R = 58.75 \text{ mm}$ ,  $\alpha = 12.5^\circ$

$$A = 2\pi(58.75).(5.50).\operatorname{cosec}(12.5)$$

$$A = 9380.23 \text{ mm}^2$$

Then normal pressure would be;

$$P_n = \frac{F_n}{A}$$

$$P_n = \frac{600.63}{9380.23}$$

$$P_n = 0.064 \text{ N/mm}^2$$

Similarly, when the engagement angle is  $\alpha = 14.5^\circ$

$$\sin\alpha = \frac{F_a}{F_n}$$

$$F_n = \frac{F_a}{\sin\alpha}$$

$$F_n = \frac{130}{\sin(14.5)}$$

$$F_n = 519.21 \text{ N}$$

For the normal pressure being applied on the whole peripheral area;

$$A = 2\pi R.dr.\operatorname{cosec}\alpha$$

where,  $dr = 6.36 \text{ mm}$ ,  $R = 59.18 \text{ mm}$ ,  $\alpha = 14.5^\circ$

$$A = 2\pi(59.18).(6.36).\operatorname{cosec}(14.5)$$

$$A = 9525.025 \text{ mm}^2$$

Then normal pressure would be;

$$P_n = \frac{F_n}{A}$$

$$P_n = \frac{519.21}{9525.025}$$

$$P_n = 0.0545 \text{ N/mm}^2$$

### **According to Uniform Pressure Theory;**

It is very necessary in order to keep the cone and clutch engaged effectively. For that following equations are data are used:

For the calculation of axial force if the data has been provided, following expression is used;

$$F_a = \pi p_n [r_1^2 - r_2^2]$$

Similarly, in order to compute the torque produced on the axial force that has been exerted, following expression is taken into consideration;

$$T = \frac{2}{3} \mu \cdot W \cdot \operatorname{cosec} \alpha \left( \frac{(r_1)^3 - (r_2)^3}{(r_1)^2 - (r_2)^2} \right)$$

Since, we are in the designing stages of the cone clutch, uniform wear criteria is taken into consideration always and in that respect, we would be focusing on Uniform Wear Theory instead of Uniform Pressure Theory as the latter theory is only applicable in conditions when the friction lining is new and unused.

#### **According to Uniform Wear Theory:**

Axial is very necessary in order to keep the cone and clutch engaged effectively. For that following equations are data are used: (*when  $\alpha = 12.5^\circ$* )

$$F_a = 2\pi P_n (r_1 - r_2)$$

$$F_a = 2\pi(0.064)(61.5 - 56)$$

$$F_a = 129.93 \text{ N}$$

Similarly, in the case of determination of torque being able to be produced;

$$T = \mu \cdot F_a \left( \frac{r_1 + r_2}{2} \right)$$

$$T = (0.42) \cdot (129.93) \left( \frac{61.5 + 56}{2} \right)$$

$$T = 3206.022 \text{ N.mm}$$

Also, when the engagement angle  $\alpha = 14.5^\circ$ ;

$$F_a = 2\pi P_n (r_1 - r_2)$$

$$F_a = 2\pi(0.0545)(62.36 - 56)$$

$$F_a = 128.88 \text{ N}$$

Similarly, in the case of determination of torque being able to be produced;

$$T = \mu \cdot F_a \left( \frac{r_1 + r_2}{2} \right)$$

$$T = (0.42) \cdot (128.88) \left( \frac{62.36 + 56}{2} \right)$$

$$T = 3203.389 \text{ N.mm}$$

### 3.3.2: Discussion:

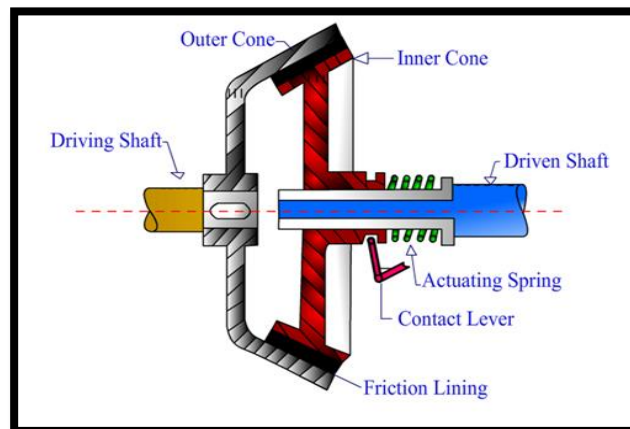
However, since we are also aiming to provide a graphical illustration of torque versus speed for both cone and clutch angles, this would be achieved in the testing and observations section of Chapter # 4, where we study the losses at higher speeds and externally apply an axial force via a stepper motor to achieve some compensation for the lost frictional contact.

An on-board custom dynamometer will also be used to determine and produce the amount of torque on each rpm with and without losses. As, it would effectively follow the main aim of our project.

## 3.4 Product Subsystems and selection of Components

First and foremost, the cone clutch serves the purpose of being a disk or plate clutch, rather than mating two spinning disks, the cone clutch uses two conical surfaces to form torque with the help of friction.

The clutch system is responsible for the torque and power transmission between the engine and transmission shafts which makes it one of the more important part of the engine or car.



*Figure # 3.4: Cone Clutch Section View Schematics*

### Outer Cone

Outer cone which is mainly known as the female cone is wired with the flywheel or the driven shaft of the engine, for this part of clutch has process in rotating condition with engine shaft. Inner part of the outer cone which is shown in the diagram is parallel to friction lines which makes this phenomenon contact with inner cone which allows to

rotate driven shaft at the speed parallel to the speed of the driving shaft. This component was selected to made of aluminum in order to reduce the overall weight of the system.



*Figure # 3.4 (a): Machined Female Cones (Left: 14.5° & Right: 12.5°)*

### **Inner cone**

Basically, this part of the system is more widely known as the male cone, it has connection to the transmission shaft also the gearbox. Outer part of the inner cone is parallel with friction which helps frictional contact between inner and outer cone. The process has these two parts remaining in contact with assistance of pressure springs. When the person operating the car wants to space out transmission box from the engine, he pushes clutch pedal which puts a gap between inner and outer cone resulting in ending the engine to transmission box. If the clutch is pressed, the male cone slides against the spring force and the clutch is disengaged. This component was selected to made of aluminum in order to reduce the overall weight of the system.



*Figure # 3.4 (b): Machined Male Cones (Left: 12.5° & Right: 14.5°)*

## Friction Lining

Friction lining in a cone clutch determines its ability to maintain a consistent and uniform frictional contact between the surfaces of outer peripheral of male cone and inner peripheral of female cone. Since, heavy and industrial clutches use a very high-grade material such as woven asbestos, leather, sintered iron with asbestos, etc. Cork has also been a very good for light loadings and low speeds, which exactly comes according to criteria for our prototype as it is based for low speeds and low loadings since the clutch is also very light [6].

Friction Material <sup>a</sup>	Dynamic Friction Coefficient $f^b$	Maximum Pressure <sup>c</sup>		Maximum Bulk Temperature	
		psi	kPa	°F	°C
Molded	0.25–0.45	150–300	1030–2070	400–500	204–260
Woven	0.25–0.45	50–100	345–690	400–500	204–260
Sintered metal	0.15–0.45	150–300	1030–2070	450–1250	232–677
Cork	0.30–0.50	8–14	55–95	180	82
Wood	0.20–0.30	50–90	345–620	200	93
Cast iron, hard steel	0.15–0.25	100–250	690–1720	500	260

*Figure # 3.4 (c): Table of Materials with their friction properties [7]*

Since, we will be using a cork with styrene embedded in between it, it is not very typical and very common use such materials because of some mechanical properties' constraints being faced. However, it has been experimentally proved that cork will take work per square inch as compared to materials such as leather or woven asbestos [8]. But only when we are operating within low speeds and low loading situations.

## Pressure springs

These are springs which purpose is to cause male and female cone to connect when the clutch pedal is released, When the person operating this car or engine press clutch pedal it will compress the springs which helps to disengage the clutch. When the clutch is engaged friction surfaces of the male cone are surely in contact with that of female cone due to the force of springs. However, the spring that was selected was of a very low stiffness as compared to industrial grade high stiffness springs because our mechanism is solely for the purpose of testing and analyses.



*Figure # 3.4(d): Spring*

### **Spline Shaft**

Female cone is directly attached to the flywheel which is mounted over a solid shaft. Male cone on the other hand is mounted over the splined shaft. This shaft was already manufactured from mild steel and is pretty heavy. Since, this material was cheap, it is also very prone to get corroded if not maintained.



*Figure # 3.4(e): Spline Shaft*

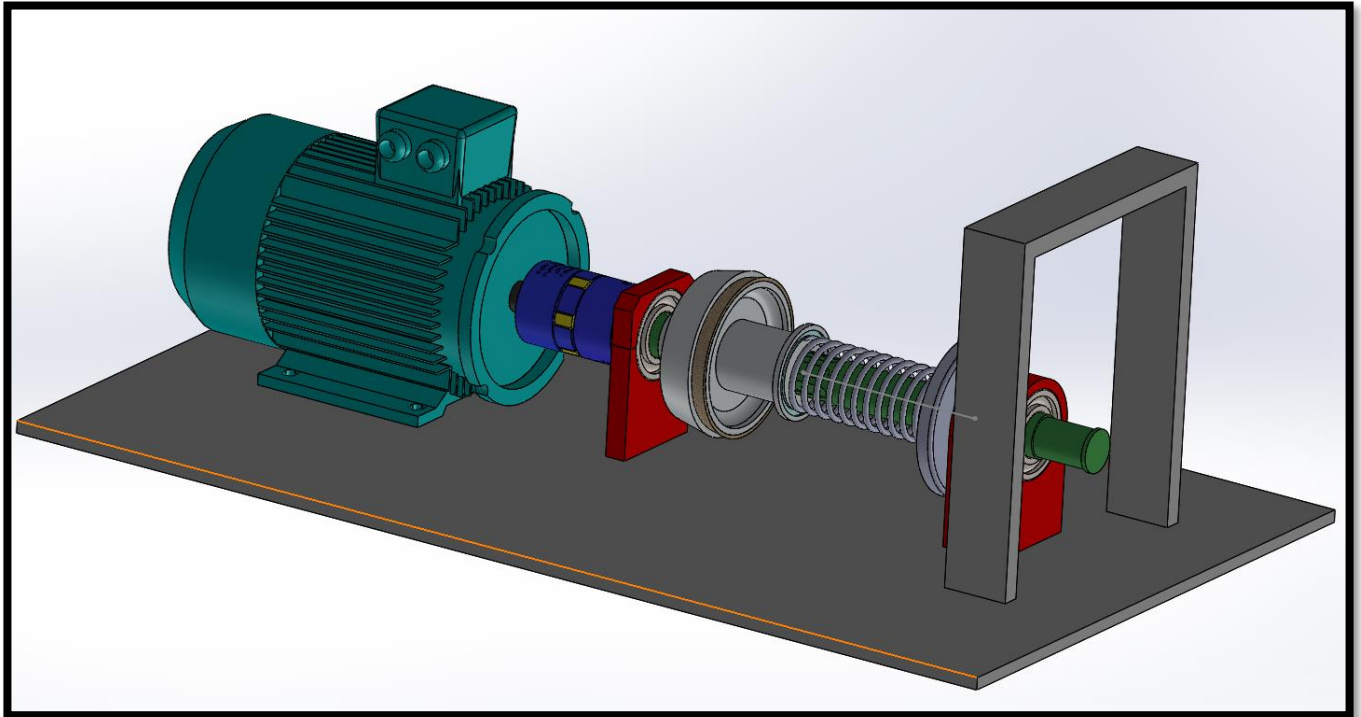
### **Sleeves**

These are the part of the clutch for which inner cone is mounted thus performs to and from motion during engagement and disengages occurrence of the clutches is called the sleeve. They have inner splines attached to the male cone mounted over the splined shaft. A fork will be resting in the sleeve which will be actuated via a D.C. power linear actuator.

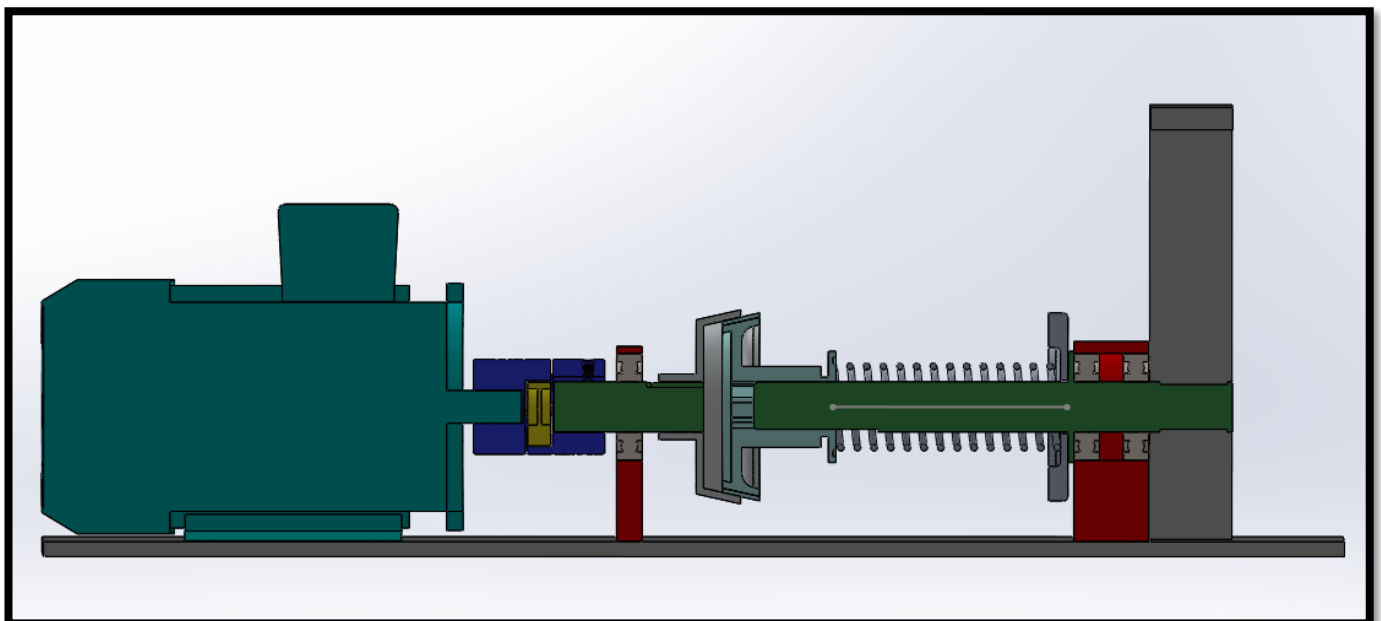
### **Motor**

In order to successfully run and test our clutch prototype, we selected a 2 Hp or 1.5 kW 3-phase, 240 V, A.C. electric motor which is available in the local market very easily.

The motor we selected is from VEMAT organization which is Italian made and is ISO-9001 certified which produces 1680 maximum rpm.



*Figure # 3.4(f): CAD Model of Prototype after 70% Completion*



*Figure # 3.4(g): CAD Model of Prototype (Section View)*

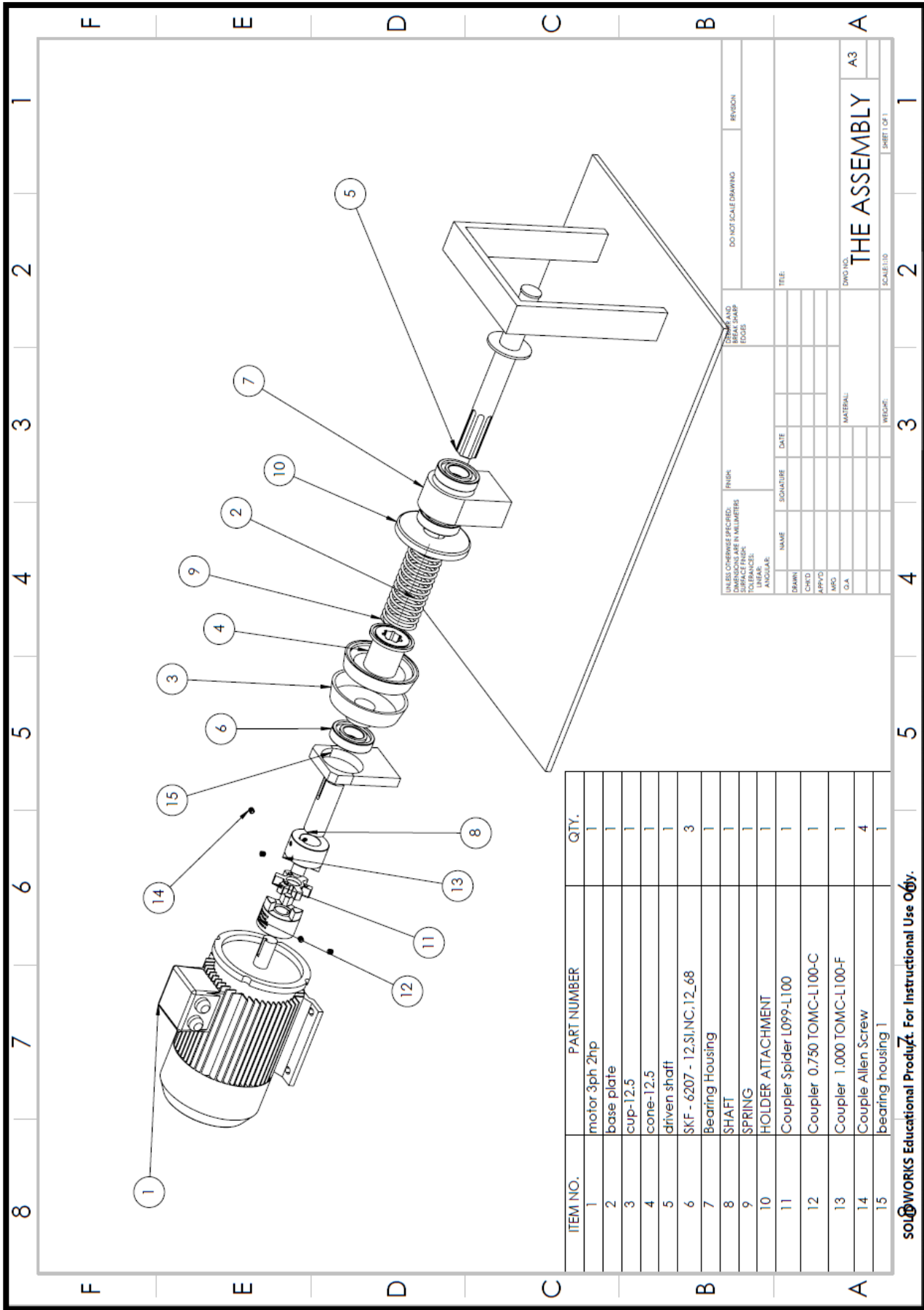


Figure # 3.4(h): Exploded View of Prototype w/ BOM

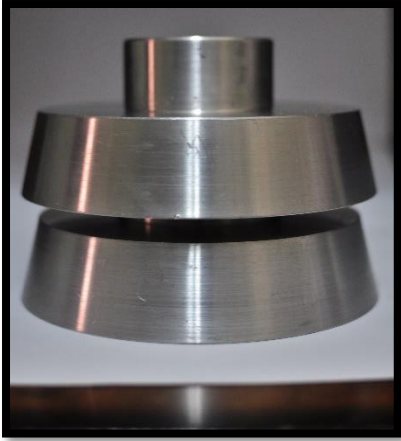
### 3.5 Manufacturing and Assembling (Implementation)

As known the female cone is mounted or placed on the motor or engine shaft. It then transmits power or force from motor to the male clutch. Later the male clutch is mounted on clutch shaft. So, the outskirts of its friction lining are in direct contact to one another. Thus, resulting the male clutch absorbs power from female cone. The clutch shaft is spline shaft on which male cone is slide. Friction material is likewise utilized on female cone for using the grip of both cones. Then the spring is brought to bring male cone back in the wake of utilizing the grip control. Bringing the clutch control being isolated by both cones due to pushing the clutch paddle. Usually both direction of rotating is possible in the cone clutch. Of course, we know that power is transmitted via key, friction and spline in the cone clutch. Moreover, since these clutches are productive for high torque requirements, at higher speeds they can face slippage which loses its overall efficiency in power transmission. Because, engagement angles play a very big role in transmitting high torque a very reasonable range of preference is between 10 and 15 degrees of angle. If the angle is reduced less than 10 degrees, it proves to be very difficult to disengage the clutch once the clutch is engaged because of the wedging action.

Male and Female cones were machined from since the whole system is for the sake of pilot testing and analyzing the study of losses, aluminum was selected to be the best option.



*Figure # 3.5: Machining of Female Cone*



*Figure # 3.5 (a): Manufactured/ Machined Components*

## Chapter 4: System Testing and Analysis

### 4.1 Experimental Setup, Sensors and data acquisition system

#### 4.1.1: Tachometer

Since, our mechanism has rotary parts which mainly includes driving and driven shafts powered by a 3-Phase induction motor. To measure output and speeds of the clutch cone and input speed of the clutch cup we applied in the use of non-contact digital tachometer. Furthermore, the tachometer was used on both cone and clutches of 12.5 and 14.5 degrees in order to analyze. Study and compare the results obtained as most of the post-calculations would include the rpm for the finding the torque and power of our system.

Moreover, the tachometer has following specifications;

#### Specifications:

- Non-Contact Measurement: 50 to 9999RPM  $\pm$  (0.03% + 2)
- Measuring Distance: 50 mm to 250 mm
- Auto Power Off: 30 seconds
- MAX/MIN/AVG Function: Yes
- m/min, m/sec, ft/min, ft/sec, in/min unit selection: Yes
- Data Hold: Yes
- Display Back Light: Yes
- Low Batter Indication: Yes
- Power Supply 2x1.5 AAA Batteries (Excluded)
- Package Size: 19 x 11 x 16 cm/ 7.6 x 4.4 x 2.4 in.
- Package Weight: 288g / 9.6 oz.



**Figure # 4.1.1: Tachometer**

### **4.1.2: Digital Weight Scale**

For this setup, the data collection was conducted in order to determine the force applied at which the clutch engagements start to give up, fail or slip under certain operating conditions and input. For that, we had to use a digital weight scale having a extra safety capacity of 150 kg to avoid over stressing the weight scale if we used a lower capacity weight scale. The dynamometric calculations were majorly calculated and measured from this device since we used a rope brake and a load application lever to exert load on the shaft when in operation. Similarly, to successfully calculate torque after measuring the amount of force from the digital reading we got, torque can be calculated out since we have the shaft diameter which considers in the thickness of the belt for braking and force, we already recorded from the device. So, if we cross multiply force and the perpendicular distance, which is the shaft diameter, we obtained the readings at several speeds.

Furthermore, the digital weight scale used to measure the data in the table above has following specifications;

#### **Specifications:**

- LED Display
- Material: ABS & stainless steel
- Capacity:150 kg / 300 lb
- Double Division value:0-99kg/0.05kg,100-150kg/0.1kg
- Power supply:2 x AAA battery
- Working voltage:2.4V-3.33V
- Working current: backlight on:  $I < 12\text{mA}$ ; backlight off:  $I < 5\text{mA}$
- Shutdown current:  $I < 3\text{uA}$
- Working temperature: $0^{\circ}\text{C} \sim 40^{\circ}\text{C}$
- Weight:0.3KG



**Figure # 4.1.2: Digital Weight Scale**

Testing Parameters	
Tachometer	To obtain the output angular speed (rpm)
Digital Weight Scale	To measure the load for torque calculations

**Table # 4.1: Testing Parameters**

## 4.2 Results, Analysis and Discussion

Data obtained from performing the setups in order to get our system performance figures, following tables have been compiled which illustrates the power, torque and angular speed which are displayed in the tables below.

### 4.2.1 Cone Clutch (14.5°):

Clutch Power at Different Angular Speeds					
Input Shaft			Output Shaft		
Angular Speed (rpm)	Torque (N.m)	Power (W)	Angular Speed (rpm)	Torque (N.m)	Power (W)
295.4	47.7	1500	295.1	5.52	170.5
594.2	23.9	1500	593.2	4.82	299.4
893.1	15.9	1500	892.1	3.63	339
1193.7	11.9	1500	1192.3	3.53	440.6
1491.5	9.55	1500	1490.8	3.08	481
1790.3	7.96	1500	1787.1	1.85	346.6

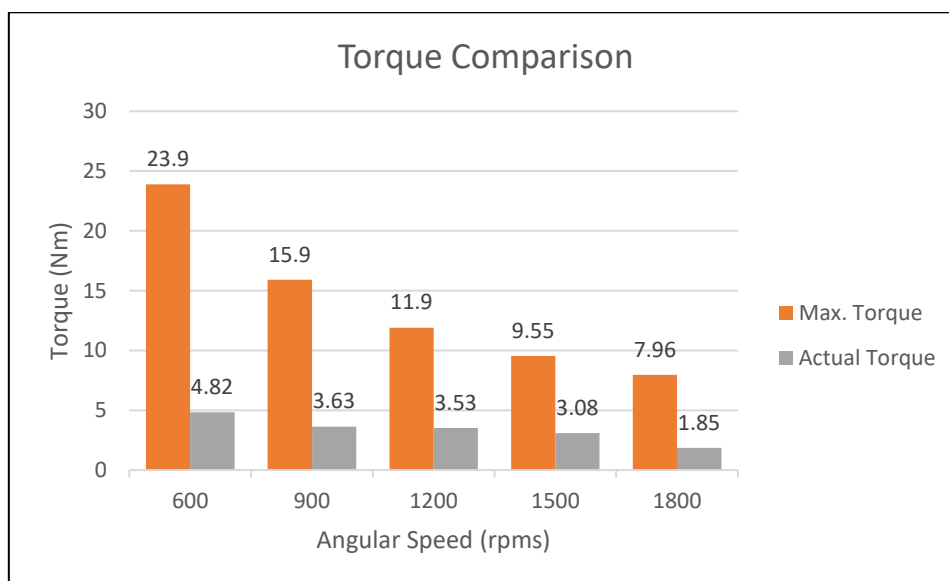
**Table # 4.2.1: Input and Outpower of Cone Clutch**

Following table illustrates us the torque difference or comparison of what our clutch is able to achieve as compared to prescribed motor specifications.

Angular Speeds (rpm)	Comparison	Torque (Nm)
300	Max. Possible	47.7
	Actual	5.52
600	Max. Possible	23.9
	Actual	4.82
900	Max. Possible	15.9
	Actual	3.63
1200	Max. Possible	11.9
	Actual	3.53
1500	Max. Possible	9.55
	Actual	3.08
1800	Max. Possible	7.96
	Actual	1.85

**Table # 4.2.1 (a): Torque Difference between theoretical and experimental**

Table # 4.2(a), it is very prominent that there is a huge difference between actual and maximum possible torque and the reason is due to immense amount of frictional losses, the clutch is not able to withstand high torque and slips. In order to compensate frictional losses, the maximum deflection was maintained at a maximum of 40 mm with intervals of 10 mm and this was primarily done to avoid the spring from compressing into its solid length.



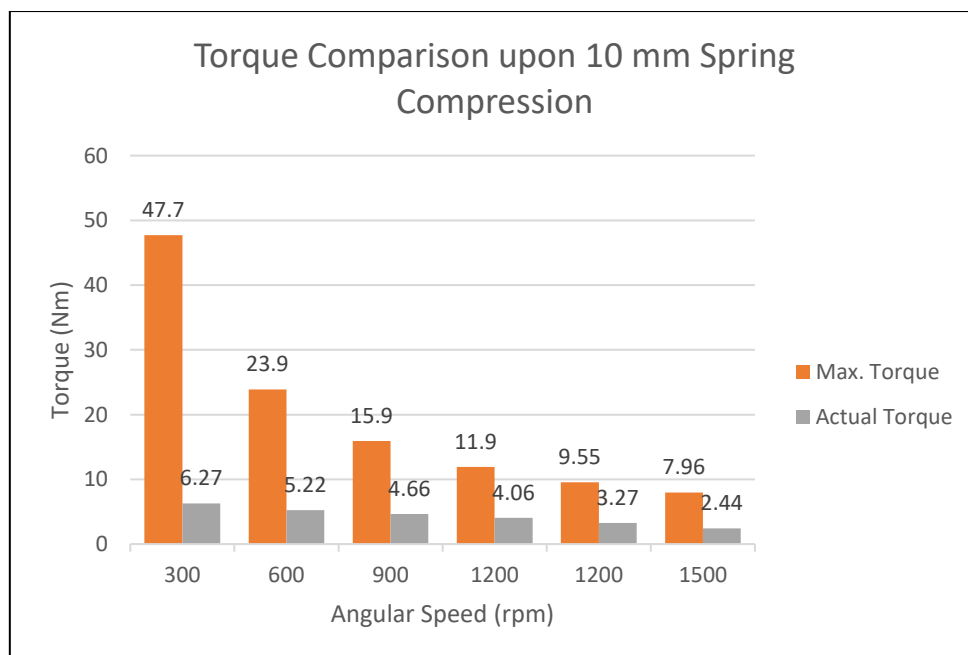
**Figure # 4.2.1 (a): Torque Comparison**

**Spring Deflection 10 mm:**

Angular Speeds (rpm)	Comparison	Torque (Nm)
300	Max. Possible	47.7
	Actual	6.27
600	Max. Possible	23.9
	Actual	5.22
900	Max. Possible	15.9
	Actual	4.66
1200	Max. Possible	11.9
	Actual	4.06
1500	Max. Possible	9.55
	Actual	3.27
1800	Max. Possible	7.96
	Actual	2.44

**Table # 4.2.1 (b): Torque Difference between theoretical and experimental (10 mm Spring Deflection)**

If we take notice of table # 4.2 (b), it is very obvious that the deflection in the spring increases the normal force which directly increases the frictional force on the engagement peripheral. It shows our theory and objective is being successful. However, the increment is very minimal but to improve it more, following deflections were studied.



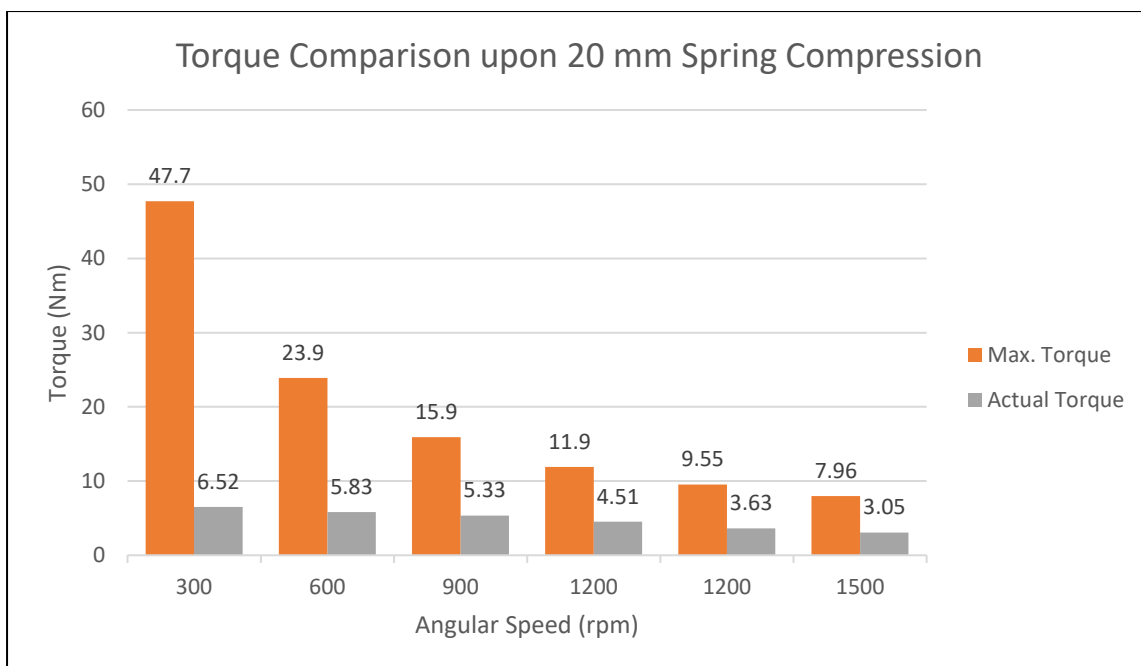
**Figure # 4.2.1 (b): Torque Comparison upon 10 mm Spring Comparison**

**Spring Deflection 20 mm:**

Angular Speeds (rpm)	Comparison	Torque (Nm)
300	Max. Possible	47.7
	Actual	6.517
600	Max. Possible	23.9
	Actual	5.83
900	Max. Possible	15.9
	Actual	5.33
1200	Max. Possible	11.9
	Actual	4.51
1500	Max. Possible	9.55
	Actual	3.63
1800	Max. Possible	7.96
	Actual	3.05

**Table # 4.2.1 (c): Torque Difference between theoretical and experimental (20 mm Spring Deflection)**

From table # 4.2 (c), further deflection in the spring further increases the frictional force. However, we still were getting clutch to slip at higher speeds but an improvement in the overall torque withstanding abilities.

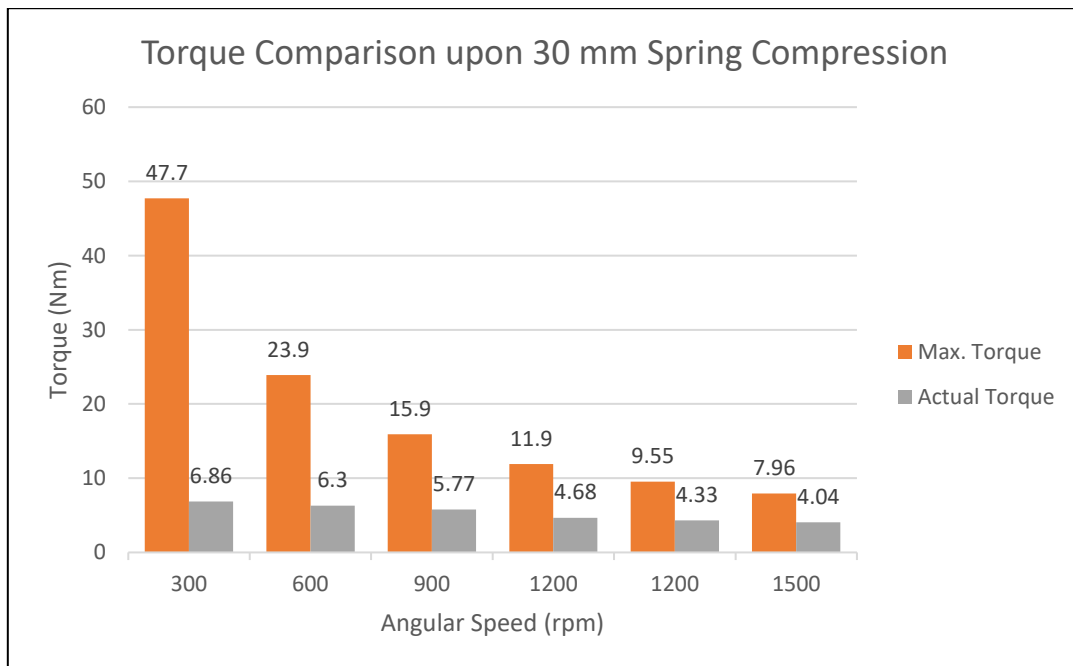


**Figure # 4.2.1 (c): Torque Comparison upon 20 mm Spring Comparison**

**Spring Deflection 30 mm:**

Angular Speeds (rpm)	Comparison	Torque (Nm)
300	Max. Possible	47.7
	Actual	6.86
600	Max. Possible	23.9
	Actual	6.30
900	Max. Possible	15.9
	Actual	5.77
1200	Max. Possible	11.9
	Actual	4.68
1500	Max. Possible	9.55
	Actual	4.33
1800	Max. Possible	7.96
	Actual	4.04

**Table # 4.2.1 (d): Torque Difference between theoretical and experimental (30 mm Spring Deflection)**

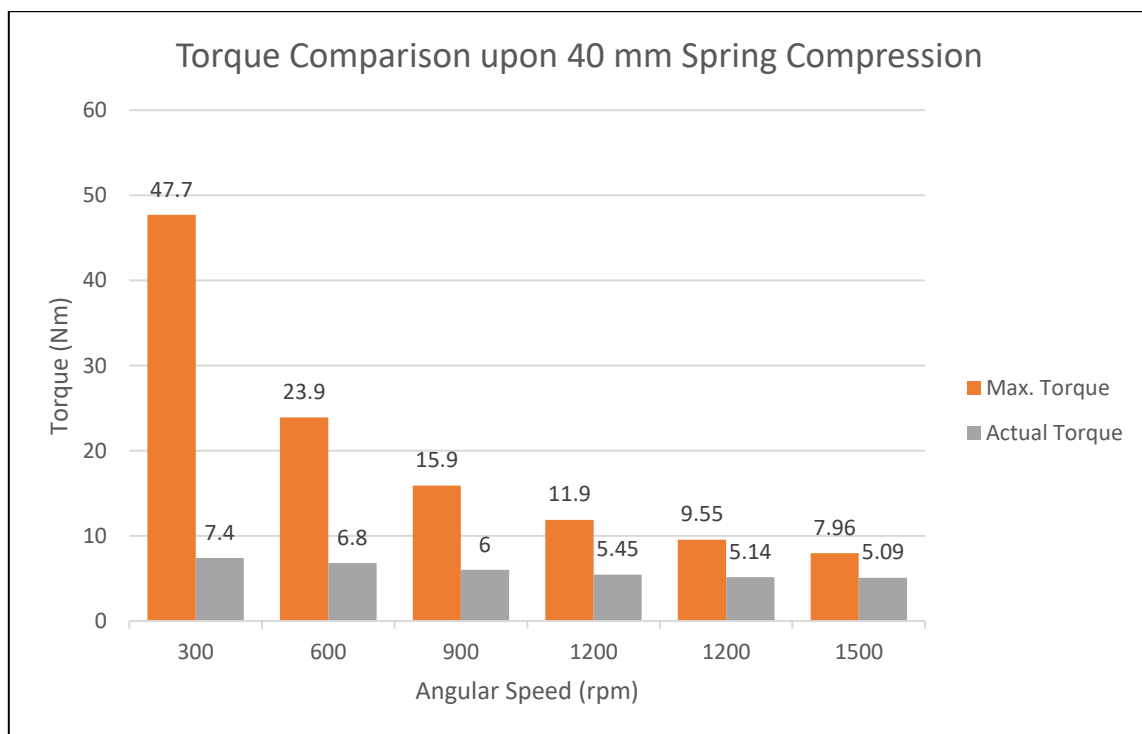


**Figure # 4.2.1 (d): Torque Comparison upon 30 mm Spring Comparison**

**Spring Deflection 40 mm:**

Angular Speeds (rpm)	Comparison	Torque (Nm)
300	Max. Possible	47.7
	Actual	7.40
600	Max. Possible	23.9
	Actual	6.80
900	Max. Possible	15.9
	Actual	6.00
1200	Max. Possible	11.9
	Actual	5.45
1500	Max. Possible	9.55
	Actual	5.14
1800	Max. Possible	7.96
	Actual	5.09

**Table # 4.2.1 (e): Torque Difference between theoretical and experimental (40 mm Spring Deflection)**



**Figure # 4.2.1 (e): Torque Comparison upon 40 mm Spring Comparison**

Clutch Power at Different Angular Speeds (10 mm Spring Deflection)					
Input Shaft			Output Shaft		
Angular Speed (rpm)	Torque (N.m)	Power (W)	Angular Speed (rpm)	Torque (N.m)	Power (W)
295.4	47.7	1500	295.1	6.27	193.76
594.2	23.9	1500	593.2	5.22	324.27
893.1	15.9	1500	892.1	4.66	435.34
1193.7	11.9	1500	1192.3	4.06	506.92
1491.5	9.55	1500	1490.8	3.27	510.50
1790.3	7.96	1500	1787.1	2.44	456.63

**Table # 4.2.1 (f): Input and Outpower of Cone Clutch after increased Spring force**

Clutch Power at Different Angular Speeds (20 mm Spring Deflection)					
Input Shaft			Output Shaft		
Angular Speed (rpm)	Torque (N.m)	Power (W)	Angular Speed (rpm)	Torque (N.m)	Power (W)
295.4	47.7	1500	295.1	6.52	201.49
594.2	23.9	1500	593.2	5.83	362.16
893.1	15.9	1500	892.1	5.33	497.13
1193.7	11.9	1500	1192.3	4.51	563.11
1491.5	9.55	1500	1490.8	3.63	566.70
1790.3	7.96	1500	1787.1	3.05	570.80

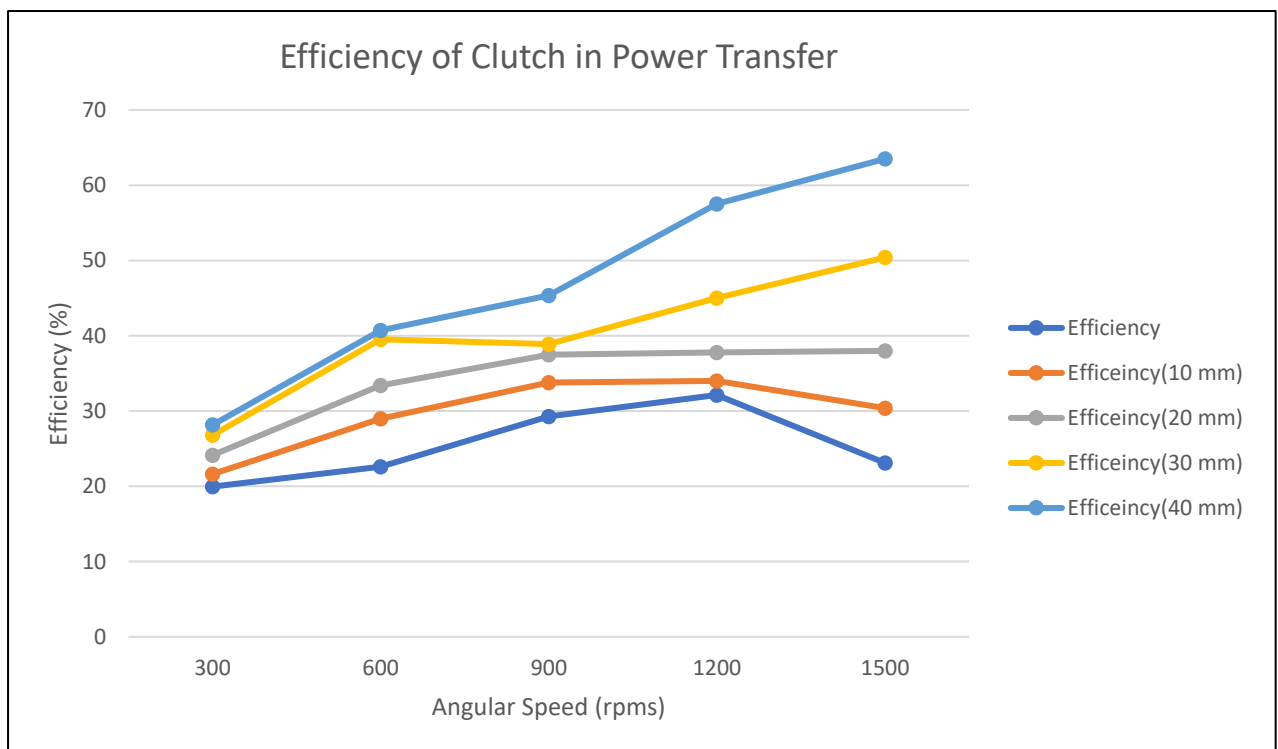
**Table # 4.2.1 (g): Input and Outpower of Cone Clutch after increased Spring force**

Clutch Power at Different Angular Speeds (30 mm Spring Deflection)					
Input Shaft			Output Shaft		
Angular Speed (rpm)	Torque (N.m)	Power (W)	Angular Speed (rpm)	Torque (N.m)	Power (W)
295.4	47.7	1500	295.1	6.86	212
594.2	23.9	1500	593.2	6.30	391.2
893.1	15.9	1500	892.1	5.77	593.04
1193.7	11.9	1500	1192.3	4.68	584.33
1491.5	9.55	1500	1490.8	4.33	675.19
1790.3	7.96	1500	1787.1	4.04	756

**Table # 4.2.1 (h): Input and Outpower of Cone Clutch after increased Spring force**

Clutch Power at Different Angular Speeds (40 mm Spring Deflection)					
Input Shaft			Output Shaft		
Angular Speed (rpm)	Torque (N.m)	Power (W)	Angular Speed (rpm)	Torque (N.m)	Power (W)
295.4	47.7	1500	295.1	7.40	228
594.2	23.9	1500	593.2	6.80	422.41
893.1	15.9	1500	892.1	6.00	560.52
1193.7	11.9	1500	1192.3	5.45	680.47
1491.5	9.55	1500	1490.8	5.14	802.81
1790.3	7.96	1500	1787.1	5.09	952.57

**Table # 4.2.1 (i): Input and Outpower of Cone Clutch after increased Spring force**



**Figure # 4.2.1 (f): Power Transmission Efficiency Graph**

Graph # 4.2.1 (e) above shows the different powers being produced when the spring was in normal engagement length along with several other efficiencies. Noticeably the blue line indicates a very low efficiency of the cone clutch when we use it on a normal engagement length. As we move further up the graph, we can see the efficiency to increase considerably as we increase the normal force which overcomes the frictional losses, increasing the force of friction and eventually raising the power that the cone clutch can transfer.

**4.2.2 Cone Clutch (12.5°):**

<b>Clutch Power at Different Angular Speeds</b>					
<b>Input Shaft</b>			<b>Output Shaft</b>		
<b>Angular Speed (rpm)</b>	<b>Torque (N.m)</b>	<b>Power (W)</b>	<b>Angular Speed (rpm)</b>	<b>Torque (Nm)</b>	<b>Power (W)</b>
295.3	48.5	1500	296	5.96	184.74
594	24.1	1500	593.2	5.6	347.87
893	16	1500	892.8	3.97	371.17
1195	12	1500	1193.8	3.72	464.47
1494.5	9.58	1500	1494.5	3.36	525.85
1793.5	7.99	1500	1789.8	2.10	393.6

**Table # 4.2.2: Input and Outpower of Cone Clutch**

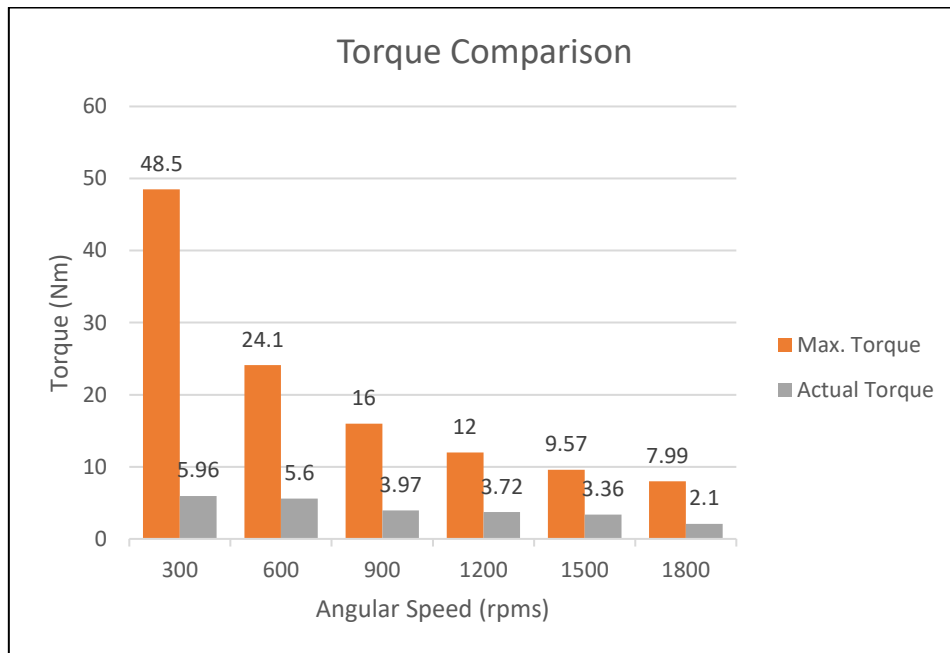
Following table illustrates us the torque difference or comparison of what our clutch is able to achieve as compared to prescribed motor specifications.

<b>Angular Speeds (rpm)</b>	<b>Comparison</b>	<b>Torque (Nm)</b>
<b>300</b>	<b>Max. Possible</b>	48.5
	<b>Actual</b>	5.96
<b>600</b>	<b>Max. Possible</b>	24.1
	<b>Actual</b>	5.60
<b>900</b>	<b>Max. Possible</b>	16
	<b>Actual</b>	3.97
<b>1200</b>	<b>Max. Possible</b>	12
	<b>Actual</b>	3.72
<b>1500</b>	<b>Max. Possible</b>	9.58
	<b>Actual</b>	3.36
<b>1800</b>	<b>Max. Possible</b>	7.99
	<b>Actual</b>	2.10

**Table # 4.2.2 (a): Torque Difference between theoretical and experimental**

Table # 4.2(a), it is very prominent that there is a huge difference between actual and maximum possible torque and the reason is due to immense amount of frictional losses, the clutch is not able to withstand high torque and slips. In order to compensate frictional losses, the maximum

deflection was maintained at a maximum of 40 mm with intervals of 10 mm and this was primarily done to avoid the spring from compressing into its solid length.



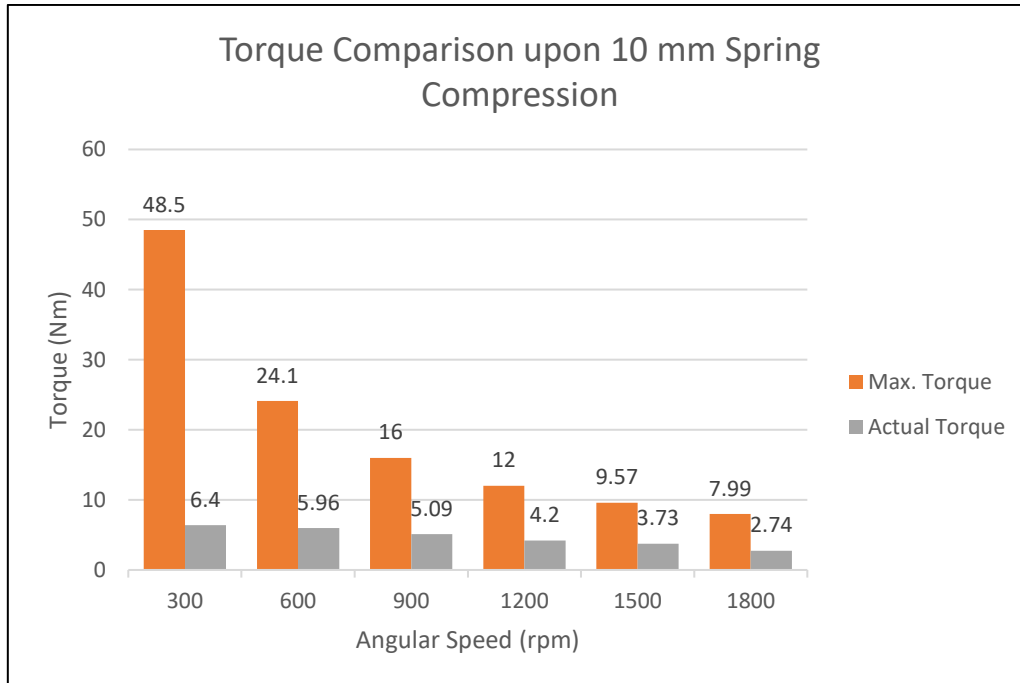
**Graph # 4.2.2 (a): Torque Comparison**

**Spring Deflection 10 mm:**

Angular Speeds (rpm)	Comparison	Torque (Nm)
300	Max. Possible	48.5
	Actual	6.40
600	Max. Possible	24.1
	Actual	5.96
900	Max. Possible	16
	Actual	5.09
1200	Max. Possible	12
	Actual	4.20
1500	Max. Possible	9.58
	Actual	3.73
1800	Max. Possible	7.99
	Actual	2.74

**Table # 4.2.2 (b): Torque Difference between theoretical and experimental (10 mm Spring Deflection)**

If we take notice of table # 4.2 (b), it is very obvious that the deflection in the spring increases the normal force which directly increases the frictional force on the engagement peripheral. It shows our theory and objective is being successful. However, the increment is very minimal but to improve it more, following deflections were studied.



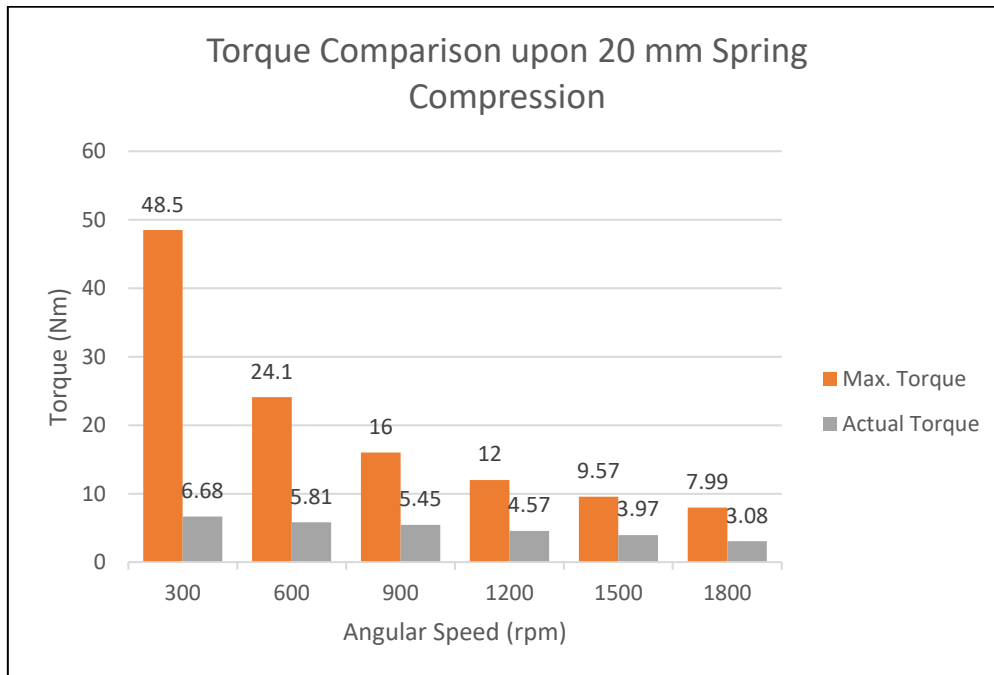
**Graph # 4.2.2 (b): Torque Comparison upon 10 mm Spring Comparison**

**Spring Deflection 20 mm:**

Angular Speeds (rpm)	Comparison	Torque (Nm)
300	Max. Possible	48.5
	Actual	6.68
600	Max. Possible	24.1
	Actual	5.81
900	Max. Possible	16
	Actual	5.45
1200	Max. Possible	12
	Actual	4.57
1500	Max. Possible	9.58
	Actual	3.97
1800	Max. Possible	7.99
	Actual	3.08

**Table # 4.2.2 (c): Torque Difference between theoretical and experimental (20 mm Spring Deflection)**

From table # 4.2 (c), further deflection in the spring further increases the frictional force. However, we still were getting clutch to slip at higher speeds but an improvement in the overall torque withstanding abilities.

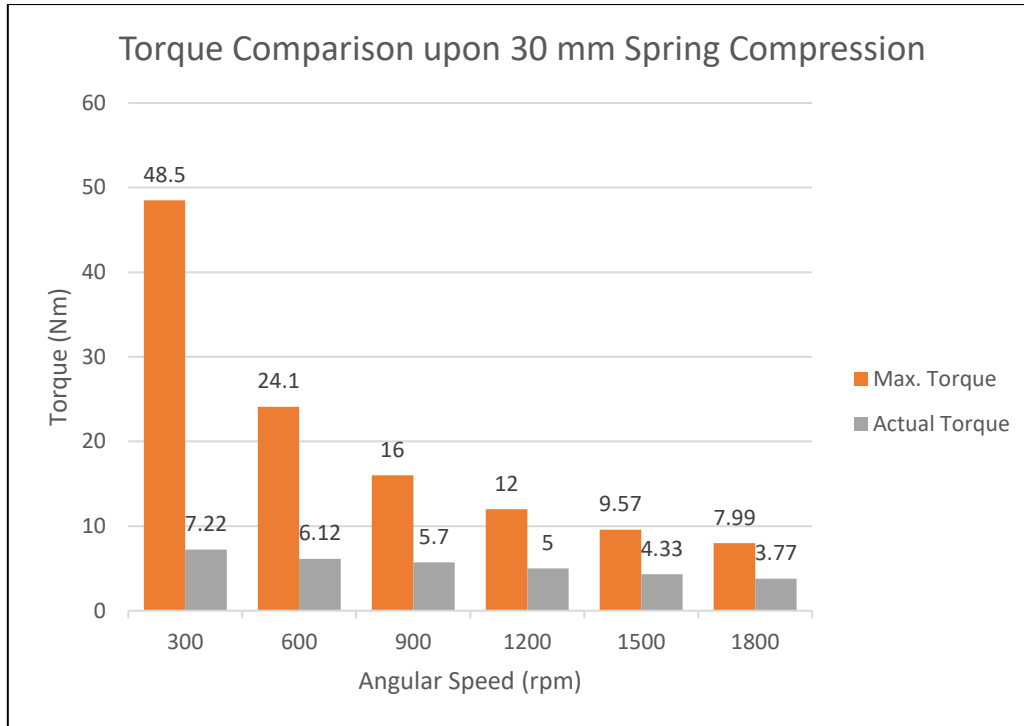


**Graph # 4.2.2 (c): Torque Comparison upon 10 mm Spring Comparison**

**Spring Deflection 30 mm:**

Angular Speeds (rpm)	Comparison	Torque (Nm)
300	Max. Possible	48.5
	Actual	7.22
600	Max. Possible	24.1
	Actual	6.12
900	Max. Possible	16
	Actual	5.70
1200	Max. Possible	12
	Actual	5.00
1500	Max. Possible	9.58
	Actual	4.33
1800	Max. Possible	7.99
	Actual	3.77

**Table # 4.2.2 (d): Torque Difference between theoretical and experimental (30 mm Spring Deflection)**

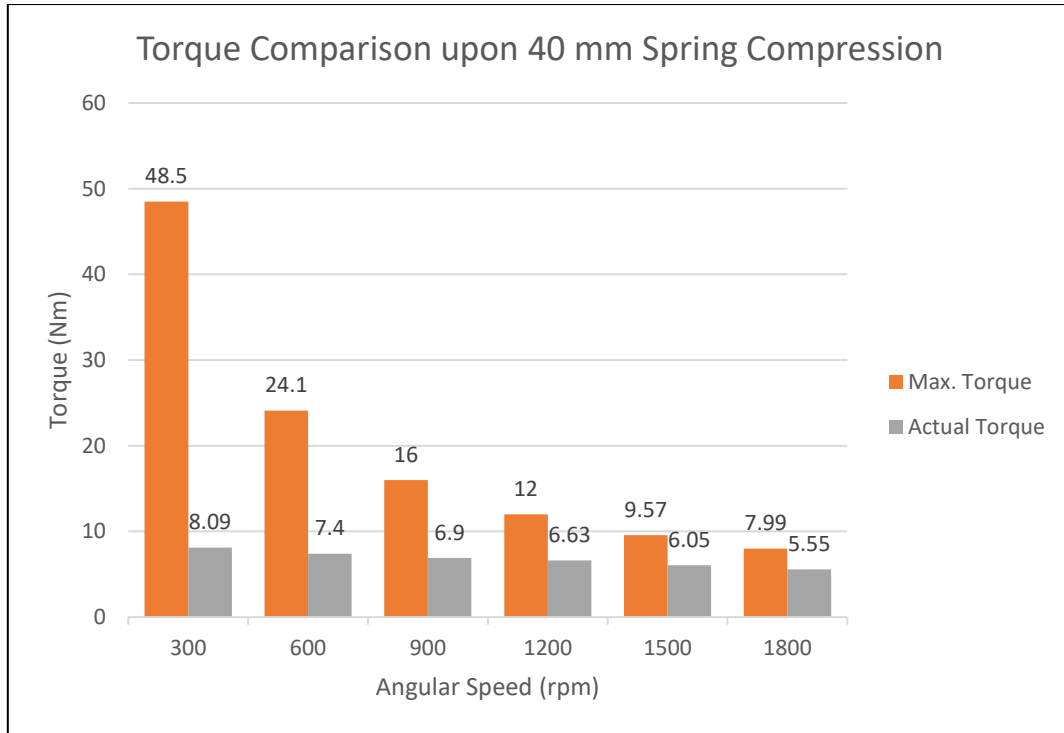


**Graph # 4.2.2 (d): Torque Comparison upon 10 mm Spring Comparison**

**Spring Deflection 40 mm:**

Angular Speeds (rpm)	Comparison	Torque (Nm)
300	Max. Possible	48.5
	Actual	8.09
600	Max. Possible	24.1
	Actual	7.40
900	Max. Possible	16
	Actual	6.90
1200	Max. Possible	12
	Actual	6.63
1500	Max. Possible	9.58
	Actual	6.05
1800	Max. Possible	7.99
	Actual	5.55

**Table # 4.2.2 (e): Torque Difference between theoretical and experimental (40 mm Spring Deflection)**



**Graph # 4.2.2 (e): Torque Comparison upon 10 mm Spring Comparison**

<b>Clutch Power at Different Angular Speeds (10 mm Spring Deflection)</b>					
<b>Input Shaft</b>			<b>Output Shaft</b>		
<b>Angular Speed (rpm)</b>	<b>Torque (N.m)</b>	<b>Power (W)</b>	<b>Angular Speed (rpm)</b>	<b>Torque (N.m)</b>	<b>Power (W)</b>
295.4	48.5	1500	296	6.40	198
594.2	24.1	1500	593.2	5.96	345
893.1	16	1500	892.8	5.09	476
1193.7	12	1500	1193.8	4.20	525
1491.5	9.57	1500	1494.5	3.73	584
1790.3	7.99	1500	1789.8	2.74s	514

**Table # 4.2.2 (f): Input and Outpower of Cone Clutch after increased Spring force**

Clutch Power at Different Angular Speeds (20 mm Spring Deflection)					
Input Shaft			Output Shaft		
Angular Speed (rpm)	Torque (N.m)	Power (W)	Angular Speed (rpm)	Torque (N.m)	Power (W)
295.4	48.5	1500	296	6.68	207
594.2	24.1	1500	593.2	5.81	361
893.1	16	1500	892.8	5.45	510
1193.7	12	1500	1193.8	4.57	571
1491.5	9.57	1500	1494.5	3.97	621
1790.3	7.99	1500	1789.8	3.08	577

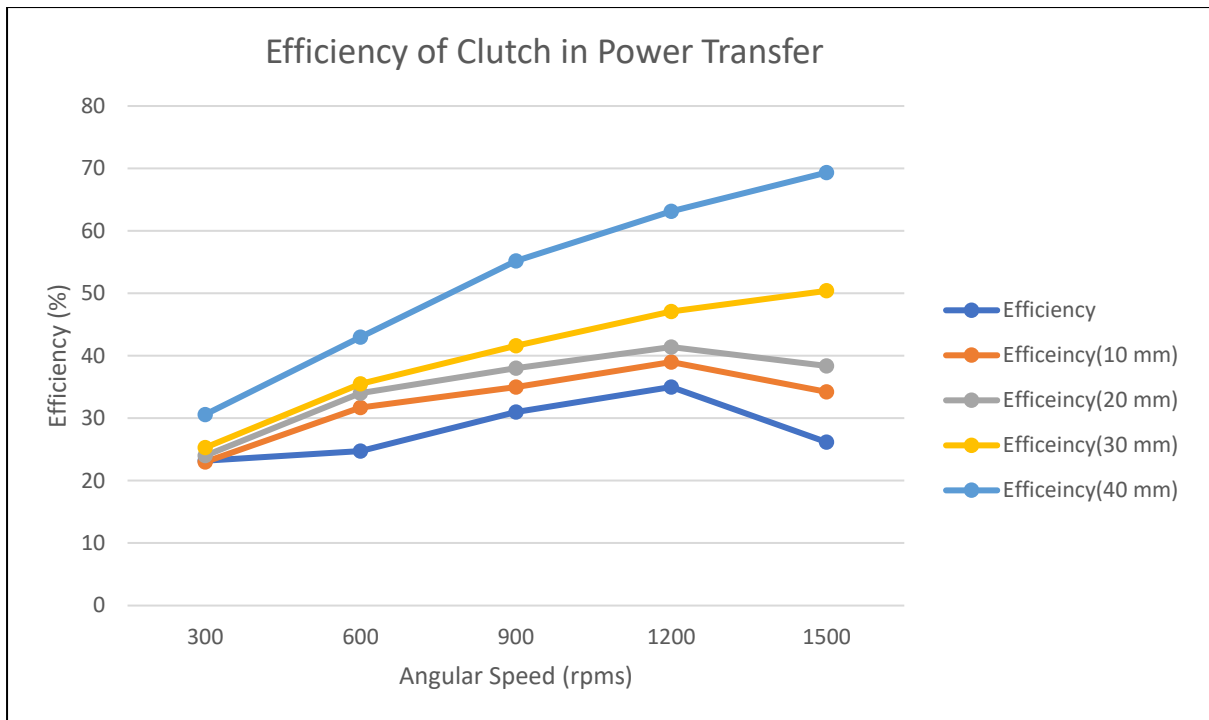
**Table # 4.2.2 (g): Input and Outpower of Cone Clutch after increased Spring force**

Clutch Power at Different Angular Speeds (30 mm Spring Deflection)					
Input Shaft			Output Shaft		
Angular Speed (rpm)	Torque (N.m)	Power (W)	Angular Speed (rpm)	Torque (N.m)	Power (W)
295.4	48.5	1500	296	7.22	223
594.2	24.1	1500	593.2	6.12	380
893.1	16	1500	892.8	5.70	533
1193.7	12	1500	1193.8	5.00	625
1491.5	9.57	1500	1494.5	4.33	678
1790.3	7.99	1500	1789.8	3.77	707

**Table # 4.2.2 (h): Input and Outpower of Cone Clutch after increased Spring force**

Clutch Power at Different Angular Speeds (40 mm Spring Deflection)					
Input Shaft			Output Shaft		
Angular Speed (rpm)	Torque (N.m)	Power (W)	Angular Speed (rpm)	Torque (N.m)	Power (W)
295.4	48.5	1500	296	8.09	250.77
594.2	24.1	1500	593.2	7.40	460
893.1	16	1500	892.8	6.90	645.11
1193.7	12	1500	1193.8	6.63	828.85
1491.5	9.57	1500	1494.5	6.05	946.85
1790.3	7.99	1500	1789.8	5.55	1040.22

**Table # 4.2.2 (i): Input and Outpower of Cone Clutch after increased Spring force**



**Graph # 4.2.2 (f): Power Transmission Efficiency Graph**

Data elaborated in all the graphs above illustrates a very prominent improvement through the torque increment against the maximum theoretical benchmark as it shows and provides the evidence of how effectively the spring is able to exert a normal force to directly overcome frictional losses to some extent in order to increase the overall efficiency in transferring power. Moreover, the results also depict information that efficiency increment also has a part to play in avoiding the slippage of clutch which clearly improves the overall efficiency of our cone clutch mechanism even at higher speed applications. s

## Chapter 5: Project Management

### 5.1 Project Plan

The project comprises of various tasks that are assigned to each group member in an equal manner, to ensure fairness between the members. Each member was given a specific task that needed to be completed within a certain amount of time.

The times and dates listed in the Gantt Chart were followed to ensure consistency and quality of the work done by the group members.

Table 5.0 displays the number of tasks done alongside with the number of days it took for that specific task to be completed.

S. No.	Tasks	Start	End	Duration	
1	Ch. 1: Introduction	23.01.2019	27.01.2019	4 days	
2	Ch. 2: Literature Review	30.01.209	03.02.2019	4 days	
					Project Background
					Previous Work
	Comparative Study				
3	Ch. 3: System Design	08.02.2019	19.02.2019	9 days	
					Design Constraints & Methodology
					Engineering Design Standards
					Theory & Theoretical Calculations
					Product Subsystems & Component Selection
Manufacturing & Assembly					

4	Ch. 4: System Testing & Analysis	Experimental Setup, Sensors & Data	10.03.2019	29.03.2019	19 days
		Results, Analysis & Discussion			
5	Ch. 5: Project Management	Contribution of Team Members	06.04.2019	09.04.2019	3 days
		Project Execution Monitoring			
		Challenges & Decision Making			
		Project Bill of Materials & Budget			
6	Ch. 6: Project Analysis	Impact of Engineering Solution	05.04.2019	08.04.2019	3 days
		Contemporary Issues Addressed			
7	Ch. 7: Conclusion & Recommendation	Conclusion	07.04.2019	09.04.2014	2 days
		Future Recommendation			
8	Design of Prototype		08.02.2019	11.02.2019	3 days
9	Parts Purchased		11.02.2019	27.03.2019	46 days
10	Manufacturing		20.03.2019	27.03.2019	7 days
11	Testing		28.03.2019	04.04.2019	7 days

**Table 5.1.0 Tasks and their Duration**

Table 5.1 identifies the team members responsible for their respected tasks.

S. No.	Task	Assigned Members
1	Introduction	All members

2	Literature Review	Majid and Anas
3	System Design	Asim and Omar
4	Testing and Analysis	Asim
5	Project Management	Omar
6	Project Analysis	Majid
7	Conclusion and Recommendation	Anas
8	Design	Asim
9	Parts Purchased	Everyone
10	Manufacturing	Asim and Anas
11	Testing	All members

**Table 5.1.1 Assigned Members for Each Task**

## 5.2 Contribution of Team Members

Each member's contribution and their willingness to work was discussed in our first meeting as a team, and the tasks were divided and agreed upon by each member.

Table 5.2.1 shows how much work each group member contributed, as a rough percentage.

S. No.	Tasks	Assigned Member	Contribution	
1	Ch. 1: Introduction	All members	100%	
2	Ch. 2: Literature Review	Project Background	Asim	33%
		Previous Work	Majid	33%
		Comparative Study	Omar & Anas	34%
3	Ch. 3: System Design	Design Constraints & Methodology	Majid	20%
		Engineering Design Standards	Omar	20%

		Theory & Theoretical Calculations	Asim	20%
		Product Subsystems & Component Selection	Omar	20%
		Manufacturing & Assembly	Asim & Anas	20%
4	Ch. 4: System Testing & Analysis	Experimental Setup, Sensors & Data	All members	40%
		Results, Analysis & Discussion	Asim	60%
5	Ch. 5: Project Management	Contribution of Team Members	All members	100%
		Project Execution Monitoring		
		Challenges & Decision Making		
		Project Bill of Materials & Budget		
6	Ch. 6: Project Analysis	Impact of Engineering Solution	All members	100%
		Contemporary Issues Addressed		
7	Ch. 7: Conclusion & Recommendation	Conclusion	All members	100%
		Future Recommendation		
8	Design of Prototype		Asim	50%

		Anas	50%
9	Parts Purchased	Omar	20%
		Asim	30%
		Anas	30%
		Majid	20%
10	Manufacturing	Asim	60%
		Anas	40%
11	Testing	All members	100%

**Table 5.2.1 Contribution of Tasks**

### 5.3 Project Execution Monitoring

To ensure the continuous progress of the project, regular meetings between the group members, to discuss the next step, and between the group members and the advisor, to take approval for said step, needed to be done on a regular basis. In addition to these meeting, we were asked to hand in progress reports and perform a presentation to explain what we have done in the project till the date of the presentation. All the dates are listed in table 5.3.1 below

Activities and/or Events	Time and Date
Assessment Class	Once a week
Meeting with the group members	Weekly
Meeting with the Advisor	Bi-Weekly
First Finished Prototype	27.03.2019
Midterm Presentation	21.03.2019
First Test of System	28.03.2019
Finishing Final Prototype	04.04.2019
Test of the System	06.04.2019
Final Submission of Report	17.04.2019
Final Presentation	18.04.2019

**Table 5.3.1 Dates of Activities and Events**

## **5.4 Challenges and Decision Making**

Every task has its challenges. We faced a great deal of challenges and setbacks while our project was in its developing stages. From designing, up to assembling and testing, the issues we faced were a great setback to the progress of the project, but in spite of these obstacles, with proper guidance from the advisor and regular group meeting these setbacks were resolved and dealt with. These setbacks are listed below.

### **5.4.1: Equipment and Device Problems**

- **Cup and Cone Material**

We needed to change the material of the cup and cone as they were made of a very heavy steel. Due to the heavy material of the previous cup and cone, the motor was not working properly. So, what we did was we manufactured new cup and cone made with a lighter material which Aluminum steel.

- **Dynamometer Rope**

Another issue was selecting a proper material for the dynamometer rope that can

- 1- withstand the high amounts of torque the driven shaft exerted
- 2- has a high coefficient of friction to ensure the stopping of the shaft

We couldn't find a rope with the material we needed, so we made our own dynamometer rope by stitching a high friction material with a material that is high in strength, to get the benefit of both the material in one rope.

- **Weight Scale**

This was a relatively easy setback as the weight scale we needed was not available in the local market, so we had to resort to an international market that can provide us with a weight scale that can handle the high amounts of force that it'll experience.

### **5.4.2: Testing & Safety Issues**

Due to our project's heavy weight and big size, we were asked to get it off the university campus and relocate it somewhere else. Luckily, one of our group members has a big empty space in his home so we moved the prototype there for testing. Safety was only an issue when the motor was operated at high rotations per minute, so we took proper precautions when we operated the motor at high frequencies.

### 5.4.3: Design Problems

Upon finishing the design for our improved clutch, we noticed that we did one simple mistake, which is we arranged the parts in such a way that it was difficult for us to assemble and disassemble the clutch. Another issue we faced but could not control is the heavy weight of the clutch as the motor itself weighs approximately 20 kg. It also involves little trouble if we are to transport it since it covers a lot of surface area, it requires considerably wider spaces such as a pickup truck or an SUV to accommodate. Similarly, the weight also affects the portability in case of movement, in which case, the whole mechanism needs to be dismantled and disassembled.

## 5.5 Project Bill of Materials & Budget

The table below illustrates the parts we purchased and the amount given to the third party for manufacturing some of the intricate parts for us. It includes the total amount spent in our project in Saudi Riyals (SAR).

Table 5.5.0 shows the amount of money paid for each part in Saudi Riyals (SAR).

Material	Cost /SAR
Manufacturing Cup and Cone (12.5° & 14.5°)	1890
Weight Scale	200
Actuators	400
Friction Lining	65
Dynamometer Support	100
Friction Damping Material	40
Spring	45
Fabrication and Welding	740
12 V, 3 A Battery for Actuators	60
Rope Brake for Dynamometer	80
Bearings (NSK-6207ZZ)	90
Protective Paint	50
<b>Total Sum</b>	<b>3760</b>

**Table 5.5.0 Bill of Materials**

## **Chapter 6: Project Analysis**

### **6.1 Life-Long Learning**

We had a soul purpose that was completely firm in our minds while occupied on our project, and that was to accomplish all the targets we had set in the beginning of the semester. Of course, in order to complete that, we were inclined to utilize software and hardware by consuming our time in a very competent manner. Furthermore, to achieve all of these things, we had to arrange and impose a preordained schedule which really provided us an enhancement in every aspect we worked on and we would like to share some of that experience.

#### **6.1.1: Software Skills:**

When designing our prototype, we first referred to some websites online and then test out the constraints on Solid-Works Simulation. We designed and simulated the necessary components for our project to guarantee suitable procedure concurring to our needs of materials that are sufficient enough to withstand our system so that it can run efficiently. It all went extremely well by the group's contribution and support since each member was able to solve an obstacle more rapidly depending on the way they thought. Correspondingly, we utilized Microsoft Excel to exhibit the charts and graphs displaying our experimentation data.

#### **6.1.2: Hardware Skills:**

To conduct a performance test of our system, we utilized a weight Scale to measure the force applied and a Tachometer to measure the rotational velocity of the shaft. Having sufficient background knowledge about forces and rotational speed. The Dynamometer we installed gave us the values of torque with the help of the industrial rubber rope break wrapped around the end of shaft. The actuators installed were tasked with engaging and disengaging the cone and the other was installed linearly to the shaft to apply an axial force via the spring. Both actuators were operational with the use of the 12-volt (3-amps) battery we purchased for the project.

#### **6.1.3: Time Management:**

We had about three months of total time to complete the project, we really needed to manage our time in an efficient manner in order to be ahead of time for unpredicted difficulties and obstacles we might face. Thankfully, all group members were in close contact and everyone

was on the same page when making decisions, which really helped with cutting time and utilizing it effectively.

#### **6.1.4: Project Management:**

We needed a very intricate plan to follow step by step, to carry out the whole schedule of developing our project. Tasks were assigned based on each group members most convenient time schedule where each colleague was available; this was achieved through weekly meetings with all group members. Thankfully, to our very humble group leader, he kept us alert at all times and this mutual communication and understanding led to a suitably accomplished progress flow related to our project which we are very proud of.

## **6.2 Impact of Engineering Solutions**

### **6.2.1: Society:**

We started our project on the basis of shedding more light on cone clutches and how it would serve the society and the advantages cone clutches offer. Especially where there are high torque requirements like tow trucks and combustion engine transmissions. Cone clutches require much less capital to manufacture and are cheaper to preserve. They transmit greater magnitudes of torque than plate or disk clutches of equivalent proportions due to the wedging action and enlarged surface area. We hope for them to be used in more than just synchronizers in manual gearboxes.

### **6.2.2: Economy:**

Economically, each part used in the assembly of our prototype was found locally, except for the weight scale which was ordered and brought from abroad. Subsequently, most of the parts were affordable excluding the cup and cones which were machined. The cup and cones machined were more expensive due to them being made of aluminum instead of mild steel. This shows that this project can be utilized in the domestic industry and easily manufactured. Moreover, there is no complexity when it comes to operating this mechanism, it is very easily operated and gives immediate results.

### **6.2.3: Environment:**

Since our project is a mechanism that utilizes a motor and electrically based, it is completely environmentally friendly and has no pollutants to be produced. Moreover, the industrial rubber rope will undergo high temperatures due to its friction with the shaft. This will result in the wear of the rope and will have to be exchanged. The rope will not be disposed of, but instead be taken to be recycled and reused for other purposes. This is also true for all materials used in the project, each part can be recycled and reused in the industry.

## **6.3 Contemporary Issues Addressed**

There is a comprehensive course in the route of going green in terms of consuming resources and diminishing pollutants which would help in saving the earth's atmosphere. Influencing the economy towards being environmentally friendly and decreasing the risks of pollution. Due to cone clutches having less wear and tear when put side by side with positive displacement clutches. Furthermore, relatively greater torque is transmitted with cone clutches than similar size plate clutches. It is one of the oldest types of clutches used in automobile industries. This clutch is easy to engage and disengage contrasted to positive displacement clutches which were used before invention of friction clutches. Moreover, all materials and parts applied in the machining and manufacturing of cone clutches are recyclable and reusable. Additionally, it is powered with electrical inputs, means clean energy and no pollutants arise over time. All things considered, such kinds of projects should be explored into at a much broader scale especially when it comes down to safeguarding the earth and its inhabitants.

# **Chapter 7: Conclusion & Future Recommendations**

## **7.1 Conclusion**

All things considered, we altogether fulfilled the objectives most importantly the losses at two different angles (12.5 & 14.5) it was also able to withstand much higher torques at high speed application and the slippage was reduced by a very big margin. This helped in achieving maximum power transmission when slippage was taken care of by the help of varying or increasing spring deflection assisted by an actuator. Overall our theory and objectives were successfully accomplished which, in the beginning, seemed a very distant achievement bound to be hurdled with failures and mishaps.

However, by a proper committed and responsible teamwork between our group. We were able to achieve what we had set as a goal in the beginning of the semester. We learned how to properly use our engineering knowledge and apply them to successfully complete our prototype and above all that we learned that always be hopeful because what may seem unachievable is just an illusion to find an excuse to let down of ourselves.

## **7.2 Future Recommendations**

Our project was completed in a timely fashion by the help of a well-organized plan and team mates. However, there are still few things we can recommend in future which is modern clutch lining material so that it can maintain better coefficient of friction as these friction materials are rough and provides added friction and increased efficiency. The second important thing to recommend will be control systems to detect slippage so the spring can increase normal force to compensate for the loss of friction. And the last one is to keep on trying to reduce the final weight.

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