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Senior Design Project Report

Design and Development of a Modified Flexure Bearing for Complaint Mechanisms Applications

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

Team 19

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Abstract

To design and develop a modified Flexure bearing forcompliant mechanism applications. Flexure Bearingsare designed to eliminate the use of lubrication but are constrained to a certain angle of rotation. These are used in compliant mechanisms. Our design aimsto solve the problem of fatigue that is likely to occur in some applications by using springs instead of the flexures inside the bearing pivot. Springs will assist for use in high-speed applications and have the ability to absorb vibrations. The angle of rotation achieved is 45 degrees (±22 degrees) which is higher than a conventional Flexure bearing. Moreover, springs can be easily replaced after their service life.

Acknowledgments

Our team has worked in collaboration with faculty in the engineering department. We have a special gratitude for our mentor Dr. Muhammed Asad for his guidance. Also Mr. Taha Waqar for his instructions and assistance during our work on the CAD software to build the design. The prototyping was done using a 3D printing which Mr. Christopher helped out the team. The team used electrical parts in the design for the actuation system, which Mr. Stephen offered unstoppable help as well as providing support during the testing phase. Lastly, we would like to extend our thanks and appreciate to Dr. Mohamed Elmahdi and Dr. Nassim Khalid for their guidance and encouragement.

List of Acronyms (Symbols) used in the report

Symbol	Definition
y_{cr}	Critical Deflection
λ_{eff}	Effectiveness Slenderness Ratio
C_1' C_2'	Dimensionless Constants
S_{sy}	Torsional Yield Strength for a Spring
F	Load Corresponding to Yield strength for One Spring
K_B	*Bergsträsser factor*
C	Spring Index
L_0	Length of Spring
k	Spring Rate
D	Mean Coil Diameter

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Chapter 1: Introduction

1.1 Project Definition

The goal of this project is to design and manufacture a modified Flexure bearing using modern technological tools like the SOLIDWORKS design software and 3D printing. Mechanical bearings are made to take radial or thrust loads, constrain a particular movement and allow a specific desired motion. Bearings are often used to facilitate rotational or linear movement between two pieces. Bearings are prone to friction since they are frequently positioned in contact with other parts as a joint. As a result, the necessity for frequent lubrication and maintenance is uneconomical. The goal of this project is to develop and produce a Flexure Bearing that has no friction and so does not require lubrication. Flexure bearings are likely to undergo fatigue in high-speed rotation applications due to the cyclic stress of the inner flexures. The flexures will be replaced by springs to overcome this problem, allowing the component to oscillate without fear of fatigue or friction. As a result, this product was created to broaden the range of operating uses for mechanical bearings.

1.2 Project Objectives

The main goals of this project are as follows:

1. Design a modified Flexure Bearing to suit a variety of applications
2. Replacement of flexure plates with springs Exclude the need of lubrication to maintain functionality
3. Extend the angle of rotation to be higher than a normal Flexure
4. Economical manufacturing and testing

1.3 Project Specifications

1. Designed specifically as a joint for a robotic arm
2. Outer Diameter: 11cm
3. Length of the joint: 11cm
4. Total rotation: 45° degrees (±22.5°)
5. Mounted from its outside surface tothe robotic arm with two sleeves

1.4 Applications

The main applications for the project are:

- To be used for robotic arm as a joint
- To be used in the neck of a robot as a joint. The angle of rotation is needed to not obstruct with the wires that is mounted in the back of a robot.
- To be used in the stand of a solar panel

Chapter 2: Literature Review

2.1 Project background

Bearings are among the most commonly utilized machine parts. They are basic machine components that are vital for movement applications. The primary function of a bearing is to reduce frictional forces between moving parts by giving a surface on which to roll as opposed to slide over. The secondary function of a bearing is to transmit loads. Consequently, bearings have two types of loads which are radial and axial loads. The radial loads are perpendicular to the shaft (see figure 2.1, [1]), while the axial loads are parallel to the shaft (see figure 2.2, [1]). Although, some bearings experience combined loads (see figure 2.3, [1]). which are both loads; the radial and axial loads, simultaneously contingent upon the application [1].

Figure 2.1: Radial loads [1].

Figure 2.2: Axial loads [1].

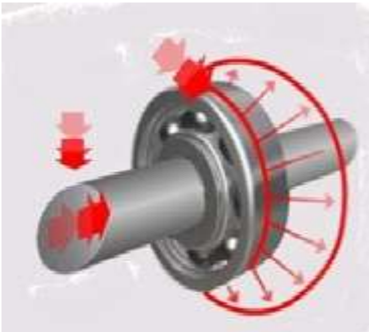


Figure 2.3: Combined loads [1].

There are various sorts of bearings, each utilized for explicit purposes and intended to help particular kinds of loads, such as radial or axial loads. There are, however, six common types of bearings which are widely used, and they are as follows [2]:

1) Plain bearing (see figure 2.4, [2]). which comprises of a shaft that rotates in an opening. They have a high load conveying limit, are by and large the most economical, and, contingent upon the materials, have any longer lives than different types.

Figure 2.4: Plain bearing [2].

2) Rolling-element bearing, in which is to avoid sliding friction, it is positioned between the spinning and stationary races. There are also two main types of rolling-element bearing. Ball bearings are the most well-known from of rolling-element bearing (see figure 2.5, [2]). These bearings can handle both radial and axial loads, but they're most commonly used when the load isn't too heavy. The inner and outer rings have little contact with the balls due to their structure. The balls would distort and damage the bearing if the bearing was overloaded. Roller bearings are the other type (see figure 2.6, [2]). Because they don't employ balls, they can handle much larger overhung loads, similar to transportation lines. They have chambers that allow more contact between the rings, dispersing the load across a broader zone, all things considered. In any event, this bearing is not designed to withstand heavy axial loads [2].

Figure 2.5: Ball bearing [2].

Figure 2.6: Roller bearing [2].

3) Jewel bearings (see figure 2.7, [2]). Plain bearings with a metal spindle revolve in a jewel-lined pivot hole are used. They are most often seen in mechanical timepieces and sustain loads by rolling the axle slightly off-center. This is due to its low and predictable friction, which increases the watch's accuracy [2].

Figure 2.7: Jewel bearing [2].

4) Fluid bearings (see figure 2.8, [2]), which uphold their load by a slight layer of gas or liquid and can be divided into two kinds: Fluid-dynamic bearings and hydrostatic bearings are two types of bearings. The fluid in a fluid dynamic bearing is rotated into a lubricating wedge against the inner surface. An external pump pumps the fluid, which is usually oil, water, or air, in hydrostatic bearings [2].

Figure 2.8: Fluid bearing [2].

5) Magnetic bearings (see figure 2.9, [2]), which sustain moving components without relying on real contact, instead relying on magnetic fields to transport loads [2]. They require a persistent power supply to keep the load stable, so a reinforcement bearing is needed if there should be an occurrence of force or control system failure.

Figure 2.9: Magnetic bearing [2].

6) Flexure bearing (see figure 2.10, [2]). A typical flexure bearing is a section that interfaces two others, similar to a hinge, where the movement is upheld by a load component that flexes. These bearing require continued bending, so the material choice is highly significant. A few materials fall flat after continued bending, even at low loads, yet with the proper materials and bearing design, the flexure bearing can have an indefinite life.

Figure 2.10: Flexure bearing [2].

Derivable from the increase of automation in companies, especially in the mechanical production systems, in order to diminish the labor force. The interest for automated arms has substantially expanded, which has likewise expanded the interest for the orientation that structures the joints of such robotic arms. In some of these robotic arm joints, Flexure bearings get selected since they exhibit very low or no friction and require no lubrication. However, there are some disadvantages over choosing Flexure bearings, in which they are constrained to a certain angle of rotation, and they are also subjected to fatigue especially if they undergo high-speed applications for a long period of time.

The proposed solution which is spring that will replace the flexure inside the bearing pivot, will be exposed to some challenges and barriers. Our primary aim as a senior project group is to identify challenges and obstacles and most importantly how tackle them to obtain excel results. The major challenge was the type of the spring which will be assembled inside the bearing pivot. It was decided to choose a compression spring. However, there might be some types of contacts between the spring and the casing of the bearing itself which will lead to friction. Therefore, the size of the spring will play a major factor in this matter. We have to pick a proper compression spring's size if we intend to prevent the spring's friction.

2.2 Previous Work

A Flexure bearing simplifies the design of an assembly by taking place of multiple components in an assembly like bearings, shafts and retaining components, this also can reduce the assembly time and cost [5]. These flexure bearings are manufactured with different sizes and specifications. There are two types of flexure bearings, single-ended and double-ended (figure 2.11, [6]). The single-ended flexure bearings have two sleeves. One sleeve is fixed, while the other is mounted to the rotating component. Double-ended flexure bearings have three sleeves and they are mounted at both ends allowing the center portion to rotate, or it can be central mounted with both ends free to rotate.

Figure 2.11: Double-ended, and single-ended flexure bearings [6].

The sleeves do not affect the performance of the springs, so they can be altered to any size to provide the proper fit of an application. Adjusting length and outer diameters are the common alterations (figure 12, [7]).

Figure 2.12: Different length and diameter bearing sleeves [7].

The flexure bearings are typically limited to an angular travel of up to 60° (+/- 30°) rotation [6]. Life expectancy of the flexure bearings depends only on fatigue of the flexing material resulting from repeated applied load and rotation, since friction between parts is not present [7].

A simplified design of flexural pivots is proposed for lower cost manufacturing and mass production, called the Advanced Flexural (AF) pivot [8]. Conventional flexural pivots involve complicated assembly techniques with tight tolerances and their sleeves are complicated components that need precision machining and finishing operations (figure 2.13, [8]).

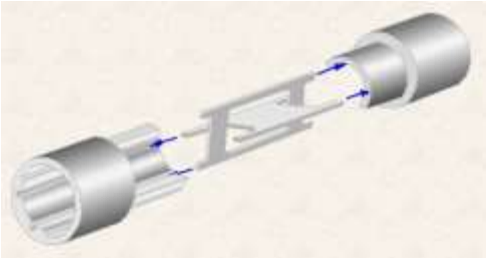


Figure 2.13: Conventional flexural pivot [8].

The proposed AF pivot eliminates these complex machining operations by using simple cylindrical end housings and sheet metal stampings. A stamping combines the flexure support, flexure beam, and the beam support all in a single piece (figure 2.14, [8]). Two tubes as sleeves with two identical stampings comprise one flexure pivot. The detailed manufacturing process of the stampings and assembly are mentioned in the referenced article [8].

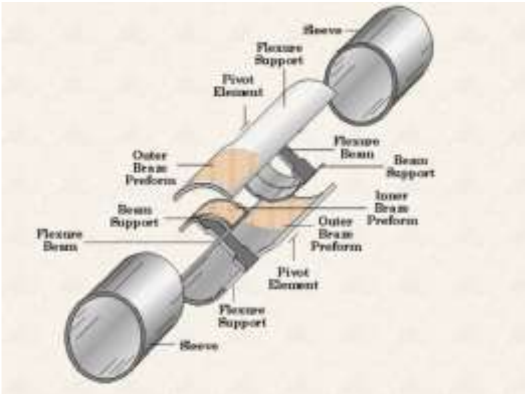


Figure 2.14: Advanced Flexural pivot assembly [8].

Moving onto the use of springs in joints. Robotic actuation devises widely use springs to provide tolerance to impact loads, and to provide safety and reliability especially in non-industrial applications where robots interact with humans [9]. These actuation devises are called series elastic actuators, where an elastic element or spring is attached between the mechanical energy source and the load. Springs also are used for energy storage, for example torsion springs in robotic finger joints to allow the finger to return to its initial state after closing it with motors [10]. A compact rotary series elastic actuator design was presented in [9]. The design consists of six linear springs that are pre-contracted, a three spoke output component that rotates on bearings, and a circular input pulley (figure 2.15, [9]).

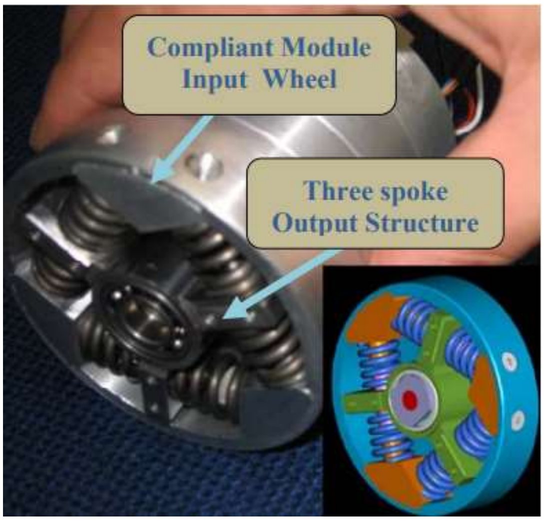


Figure 2.15: Compact rotary SEA [9].

Another proposed design of a compliant joint actuator used dual spiral springs to provide high compliance and deformation values [11]. It uses two preloaded spiral springs in opposite directions, as one spiral spring produces torque only in one direction (figure 2.16, [11]). They are preloaded to avoid unwinding that exceeds the initial configuration. The centers of the springs are fixed to a shaft, while the other ends of the springs are attached to the outer case. The spiral spring outer diameter is 90mm and has a maximum deformation of 8 rad. In terms of size, torque and stiffness specifications, it was noted that a spiral spring has more freedom [11].

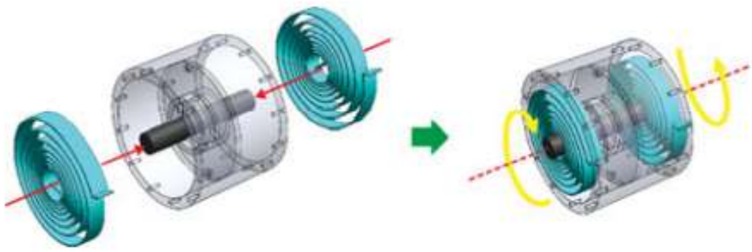


Figure 2.16: Installation of two spiral springs with preloading in opposite directions [11].

Although spiral torsion springs are generally made of carbon steel alloys, an optimal design of 3D printed spiral torsion springs (STS) using plastic materials is proposed in [12]. The optimization approach is used to provide spring geometric parameters for given material characteristics. Poor fatigue life and low yield strength are limitations of plastic materials, but the main advantages of 3D printing are the design flexibility and the ability to integrate elastic components in a joint into a single part. The study showed that a reliable and low-cost alternative to steel springs can be achieved where the application loads are limited to a certain threshold [12].

Figure 2.17: STS 3D model and 3D printed sample [12].

2.3 Comparative Study

A lot of work has been done on designing rotary flexure bearings, the aim of this study is to find the already designed rotary flexure bearings, we study them carefully, find the weakness and strength of each design made. As a result, this will enable us to design a better rotary flexure bearing which will contribute to the present technology and could be used as well in real applications. The study will also develop a better understanding on what factors must be kept under serious consideration while designing the rotary flexure bearing and it will also increase our knowledge on the working of bearings.

We went through some similar projects that may enhance our idea and improve our knowledge. A similar project has been done by students at Bilkent University, Department of Mechanical Engineering in Turkey. Their project title is “Design, Position, Control and Realization of Robot Arm with Flexure Bearing” [13]. They designed a robotic arm with a flexure bearing as it joint, and the arm is controlled with a microprocessor. Their project consisted of several steps. They followed the design process from the start to the end. The procedure included engineering analysis of the bearings and arms using simulations and calculations. Based on their project they have succeeded in designing an arm that rotates (±20°), and position control of the robotic arm. This is the only undergraduate project we found that is similar to our project. But we found patents that deal with the same topic of flexure bearings.

Figure 2.18. Robot Arm Assembly [13].

Figure 2.19. The robot arm Flexure Bearing [13].

A rotary flexure bearing is designed by Michael Valois. It has inner and outer hubs and both of the hubs are concentric. The inner and outer hubs are connected through compound flexure stages. Compound flexures are of great use as they provide compliance for rotation of bearing and also provide compliance for foreshortening of flexure, during this whole process they have a constant axis of rotation. The proposed design in this study is suitable for large angular displacement, low operational stress and torque and high stiffness in five degrees of freedom. This bearing can be used particularly in opto-mechanics. [14]

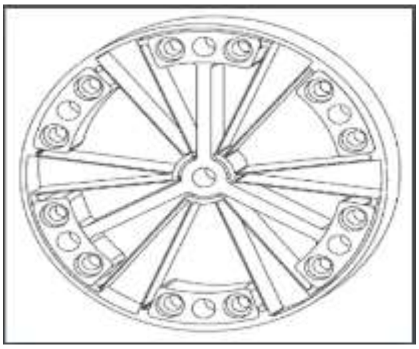


Figure 2.20. Front view of the rotary flexure bearing [14]

Robert John Calved of California Institute of technology presented a better design of rotary flexure bearing. The purpose of design was to show great radial and axial stiffness, moreover there should not be any kind of movement in center of rotation of the flexure bearing. This idea came, because already existing flexure bearings somehow showed lateral movement in the end which was not required. The center of rotation of already existing rotary flexure bearings shifted virtually. This design consists of a flexure made of a single billet of material. Three flexure blades extend from the outer ring which is included in the design. These blades form a centerpiece as they extend towards the center. In each pair of blades exist a lobe. There are three lobes in total. These lobes are extended towards the outer ring. While rotating no visual movement is exhibited by the pivot axis. The following figures further explain the design. [15]

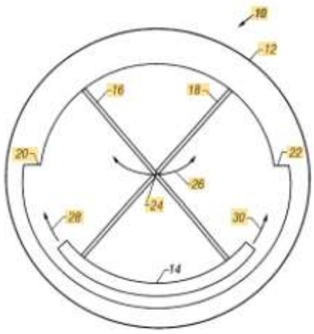


Figure 2.21. Cross-sectional view of a conventional Bendix flexure [15].

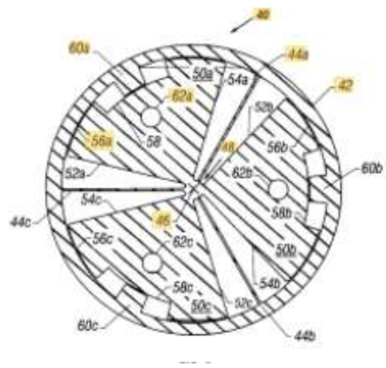


Figure 2.22. cross-sectional view of a rotary flexure embodying the invention [15].

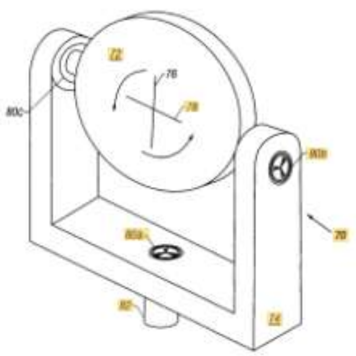


Figure 2.23. perspective view of a dual axis gimbal containing several rotary flexures like that shown in Fig. 22 [15].

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1: Geometrical Constraints

The design of this system required specific geometrical measurements to be followed in order to work in accordance with the constraints to achieve the final design. The spring bearing is designed to have an outer diameter of 80 mm to be able to fit it in the lathe machine. The inner diameter is designed to be 40 mm to ease up the process of assembling the spring. Moreover, the weight of the bearing will not be heavy since the dimensions of the prototype are not too big.

3.1.2: Sustainability

When designing this product, sustainability was one of our priorities. As we know that customers of mechanical parts expect a long lasting product that would serve them for a substantial period of time. Therefore, the materials picked for the bearing and spring were pricked by taking into account the importance of sustainability to our future customers.

3.1.3: Environmental

During the manufacturing phase of this system, our top priority was taking into consideration the environmental aspects. For instance, any residual material remaining as a result of using the lathe machine will be either disposed or recycled at the specified place. Being environmentally friendly is one of the most important aspects that goes into designing any system, especially at the current time to protect our environment.

3.1.4: Social

Our system can be used for a variety of jobs to make people's repetitious activities easier. It can be utilized in a robotic system as an arm joint. For instance, it can be used to mix dough for mothers so they don’t get affected by exhaustion while preparing the dough for baking.

3.1.5: Economic

Including the spring in our design will contribute massively in the economic aspect of this design as a whole. The spring will contribute in the prevention of having any friction or corrosion and therefore the need for lubrication or any wear prevention technique.

3.1.6: Safety

The nature of using bearings requires taking into consideration all the safety precautions to avoid any harmful incidents. Therefore, careful handlings when using the bearing is a must. Also, when using the lathe machine, the team carefully followed the instructions as serious injuries could easily occur as a result of any misuse of the machine. Therefore, using the proper tools when using the machine like wearing gloves is highly important for the safety of the team members.

3.1.7: Ethical

In the design phase of this project, ethics were involved in every single aspect of the design. Making sure originality is maintained while following the international standards of measurements and safety.

3.1.8: Risk Analysis

Risk and hazards are common in such a prototype due to the nature of its applications. The system was designed by taking into consideration the preferred and common sizes. Certain sizes are not easily obtainable, due to its rare use. Therefore, in the case of an order of one of the parts such as the spring, its availability was one of our commitments in the design phase. Since the bearing is designed for fast applications, the inner blades were replaced by a spring to minimize the risk of any damage to occur in the inner side of the bearing.

3.2 Engineering Design Standards

In the compression springs bearing we are following standards for designing parts wherever possible. It is important to follow standard sizes and us standard materials to be efficient, when there is a need to replace a part for maintenance the standard size can be found in the market easily. Also, the use of standard sizes is important for cost reduction, since standard or stock sizes are readily available without the need to make a special order from a manufacturer. The design consists of: two outer case parts or sleeves and identical or same size compression springs. The outer case parts sizing or inner diameter and outer diameter is specified following the ISO standards for ball bearings, while the springs are selected according to the Associated Spring RAYMOND selection of standard compression springs. See table 3.1

Table 3.1: Engineering Standards

Component	**Engineering Standard**	**Details**
Springs	Associated Spring Raymond	C0235-029-1000-S
Bearing (OD & ID Sizing)	ISO	Ball Bearing ISO 15 - 4240
Spring Material	American Society for Testing and Materials (ASTM)	ASTM-A313 Stainless Steel
Bearing Material	The Aluminum Association	Aluminum 2030 (or A92030 according to UNS)

3.2.1: Bearing Sleeve (Outer Case)

The sizing of outer and inner diameters of the bearing is done following the ISO 15 - 4240 standard.

- Outer Diameter: 80 mm
- Inner Diameter (or bore): 40 mm
- Material: 2030 (AlCu4PbMg, A92030) Aluminum

3.2.2: Compression Springs

It is a round wire compression spring selected form Associated Spring RAYMOND.

- Outer Diameter: 5.97 mm
- Wire Diameter: 0.74 mm
- Free Length: 25.4 mm
- Solid Length: 10.9 mm
- Spring Rate: 1.476 N/mm
- Material: Stainless Steel ASTM-A313

3.3 Theory and Theoretical Calculations

The designed system consists of multiple springs that undergoes compression as the assembly rotates clockwise and counterclockwise. Stiffness of the compression springs in this case is an important factor that should be looked into in details. Also, stability of the springs against buckling needs attention, because compression springs may buckle when the deflection becomes too large [16]. Angle of rotation calculation is shown as well.

3.3.1: Stability:

The critical deflection is calculated using the following equation [16]:

$$y_{cr} = L_0 C_1' \left[1 - \left(1 - \frac{C_2'}{\lambda_{eff}^2}\right)^{\frac{1}{2}}\right] \qquad (3.1)$$

Where y_{cr} is the deflection corresponding to the onset of instability. λ_{eff} is the effectiveness slenderness ratio and it is given by:

$$\lambda_{eff} = \frac{\alpha L_0}{D} \qquad (3.2)$$

C_1' and C_2' are dimensionless constants defined by:

$$C_1' = \frac{E}{2(E-G)},\ C_2' = \frac{2\pi^2(E-G)}{2G+E} \qquad (3.3)$$

$L_0 = 25.4mm$ for the used spring. The mean coil diameter $D = D_0 - d = 5.97mm - 0.74mm = 5.23mm$, which equals to the outer diameter minus the wire diameter. α is *end-condition constant* and it depends on how the spring ends are supported for our case $\alpha = 0.5$. For the 302 Stainless Steel alloy (30200), $E = 193 \times 10^3\ MPa$ and $G = 78 \times 10^3\ MPa$.

$$C_1' = \frac{193 \times 10^3}{2(193 \times 10^3 - 78 \times 10^3)} = 0.839$$

$$C_2' = \frac{2\pi^2(193 \times 10^3 - 78 \times 10^3)}{2(78 \times 10^3) + (193 \times 10^3)} = 4.892$$

$$\lambda_{eff} = \frac{\alpha L_0}{D} = \frac{0.5 \times 25.4}{5.23} = 2.428$$

$$y_{cr} = (25.4 \times 0.839)\left[1 - \left(1 - \frac{4.892}{2.428^2}\right)^{\frac{1}{2}}\right] = 12.52mm$$

The condition for absolute stability for Steels [16], turns out to be

$$L_0 < 2.36\frac{D}{\alpha} \qquad (3.4)$$

$L_0 = 25.4mm$, and $2.36\frac{D}{\alpha} = 2.63 \times \frac{5.23}{0.5} = 27.5$. So actually, the free length L_0 is less than 27.5mm and buckling is unlikely.

3.3.2: Yield Strength and Load:

The torsional yield strength of the spring wire is estimated by [16],

$$S_{sy} = 0.35 S_{ut} \qquad (3.5)$$

$$\text{where } S_{ut} = \frac{A}{d^m} \qquad (3.6)$$

$A = 1867\ MPa.mm^m$ and $m = 0.146$, getting these values from Table10-4 [16]. Therefore,

$$S_{sy} = 0.35 \times \frac{1867}{0.74^{0.149}} = 682.8\ MPa$$

To find the load corresponding to the yield strength for one spring, we use

$$F = \frac{\pi d^3 S_{sy}}{8 K_B D} \qquad (3.7)$$

Where $K_B = \frac{4C + 2}{4C - 3}$ and it is called *Bergsträsser factor* [16]. The spring index $C = \frac{5.23}{0.74} = 7.1$. Hence, $K_B = 1.197$ and

$$F = \frac{\pi (0.74)^3 682.8}{8(1.197)5.23} = 17.36\ N$$

3.3.2: Spring Length and Equivalent Spring:

Now the deflection caused by this load given that our standard spring has a spring rate k = 1.476 N/mm, is

$$y = \frac{F}{k} \qquad (3.8)$$

$$= \frac{17.36}{1.476} = 11.76\ mm.$$

To prevent permanent change in free length of the spring when it is compressed solid and released, the length of the spring should be estimated by

$$L_0 = y + L_s \qquad (3.9)$$

Therefore, $L_0 = 11.76 + 10.9 = 22.66\ mm$ [16]. This is the minimum length and our standard spring length is 25.4 mm.

Since the bearing design consists of two springs on each side, this means they are connected in parallel and their k values (spring constant) are should be added to get the equivalent k_{eq}. Also, the force F doubles with two springs [17].

$$k_{eq} = k_1 + k_2 \qquad (3.10)$$

$$F_{eq} = F_1 + F_2 \qquad (3.11)$$

For a single spring compressed from initial position of 25.4 mm to 11 mm, that is a deflection of $y = 14.4\ mm$, and using Eq. (3.8) $F = 14.4 \times 1.476 = 21.25\ N$. Therefore,

$$k_{eq} = 1.476 + 1.476 = 2.952\ N/mm$$

$$F_{eq} = 21.25 + 21.25 = 42.5\ N$$

3.3.2 Rotation Angle:

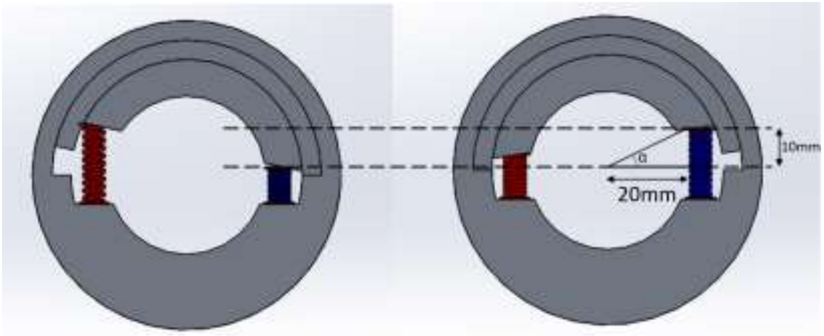


Figure 3.1: Initial and final position of bearing.

The distance between the bearing center to the spring or inner radius R is 20 mm. While the distance covered by one spring as it compresses and opens is 10 mm as shown in figure. From the shown triangle we can calculate the total angle of rotation from the minimum compressed position to the maximum open position of the spring. We calculate the angle knowing the opposite side and adjacent side by

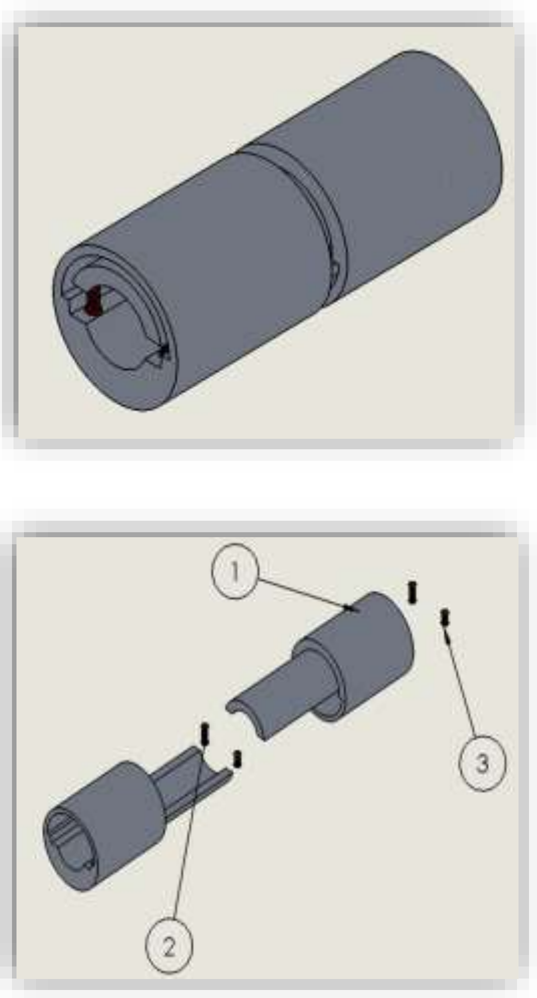
$$\tan\alpha = \frac{Opposite}{Adjacent} \qquad (3.12)\ [18]$$

Hence, $\alpha = \tan^{-1}\frac{Opposite}{Adjacent} = \tan^{-1}\frac{10}{20} = 26.56°$.

In this case the bearing is able to rotate approximately $\pm13.3°$ from its equilibrium centered position.

3.4 Product subsystems and selection of components for compression parts

The figure 3.2 below shows the compression assembly of the project. We can see various parts of the project including outer case or sleeve, compression spring, and spring base. The final shape of the assembly is showed at the left side of the figure while the right side showed the compression parts and the dotted which explain how each part is fixed to each. The base is the main part which is carrying all. The outer case/sleeve is the head cover for the compression as a save guard to make this area for compression. The compression spring is making flexibility to make motion for the compression. The last one is spring base to make balancing between the compression and foundation of the head during the compression.



Item NO.	PART NUMBER	QTY.
1	Outer case/sleeve	2
2	Compression spring	4
3	Spring base	8

Figure 3.2: Exploded assembly of the system.

3.5 Manufacturing and assembly (Implementation)

In terms of selection materials, the outer cases/sleeves and the spring bases are made from plastic (303 PLA) due to its ease of machinability through the 3D printer. However, the springs that are selected to be installed are made from stainless steel (302 Stainless Steel) due to its high strength and ductility. However, the outer cases/sleeves and the spring bases are manufactured by using the CNC lathe machine which is a machine tool that uses Computer Numerical Control (CNC), where the material or part is clamped and rotated by the main spindle, while the cutting tool that works on the material, is mounted and moved in various axis. The spring bases will be set to the outer cases/sleeves by using the tapping operation where internal threads can be made.

3.6 Economic Evaluation

The economic evaluation for any project is crucial for attaining expectations and avoid obstacles. For our senior design project, the Modified Flexure Bearing, there would be some equipment costs. The table 3.6 below shows the expected expense of the material "aluminum alloy 2030 rod" that is needed in order to make out the bearing in the CNC lathe machine is (SR208.35). Whereas, the cost required for the four stainless steel compression springs that will be installed inside the bearing is (SR166.25). However, the labor expense to execute the manufacturing of the bearing by using the CNC lathe machine is (SR517.5). Note that, the tax (VAT) rate in Saudi Arabia is considered to be 15% of any purchased products or any offered services, therefore, the prices discussed above are including the tax cost.

	Spring Semester 2021
Capital Cost	
Equipment	SR374.6
Construction	Not Applicable
Total	SR374.6
Operating Cost	
Energy	Not Applicable
Electricity	Not Applicable
Labor	SR450
Insurances	Not Applicable
Taxes	15%
Total	SR517.5
Revenue	
Product 1	Not Applicable
Product 2	Not Applicable
Product 3	Not Applicable
Total	Not Applicable
Profits	Not Applicable

Table 3.6: The simple cost template.

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, and Data Acquisition System:

4.1.1 System Base

The system base, as shown in Figure 4.1, is made of stainless steel and will help keep the bearing stationary as well as hold the hydraulic to aid in the system's motion.

Figure 4.1: System Base.

4.1.2 Push/ Pull Rod Motor

The push/pull rod motor will assist in supplying a linear motion to the arm. As illustrated in Figure 4.2, the motor has a power range of 10 to 12 watts.

Figure 4.2: Push/ Pull Rod Motor.

4.1.3 3D Printed Bearing

The 3D Printed Bearing in Figure 4.3 is constructed of PLA 303. Between the base and the arm, the bearing will serve as a joint. The arm will be able to travel vertically due to the bearing's rotation. This bearing is intended to flex at a 15-20 degree angle.

Figure 4.3: 3D Printed Bearing.

4.1.4 System Arm

The arm in Figure 4.4 is composed of stainless steel. The arm may be employed in a variety of sectors, including medicine and industrial technology.

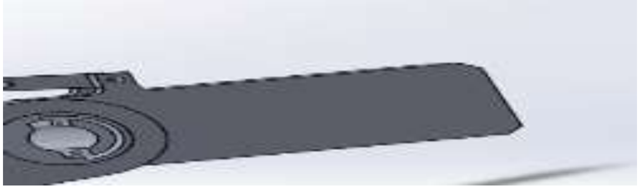


Figure 4.4: System Arm.

4.1.5 Compression Springs

Stainless steel ASTM-A313 compression springs are used. The inner flexural beams will be replaced with springs, which will aid by increasing the angle of rotation, allowing the bearing to be utilized for quick applications, reducing fatigue, and absorbing any kinetic energy that causes vibration (see Figure 4.5).

Figure 4.5: Compression Springs.

4.1.6 Battery

The hydraulic rod will be powered by the battery, allowing the hydraulic system to function as an actuator. The system requires a battery with a capacity of 12 volts and 10 amps. Figure 4.6 shows the hour.

Figure 4.6: Battery.

4.1.7 Toggle Switch

In Figure 4.7, the type of toggle switch used is a double pole single throw (DPST) switch, which performs similarly to two SPST switches.

Figure 4.7: Toggle Switch.

4.2 Results, Analysis, and Discussion

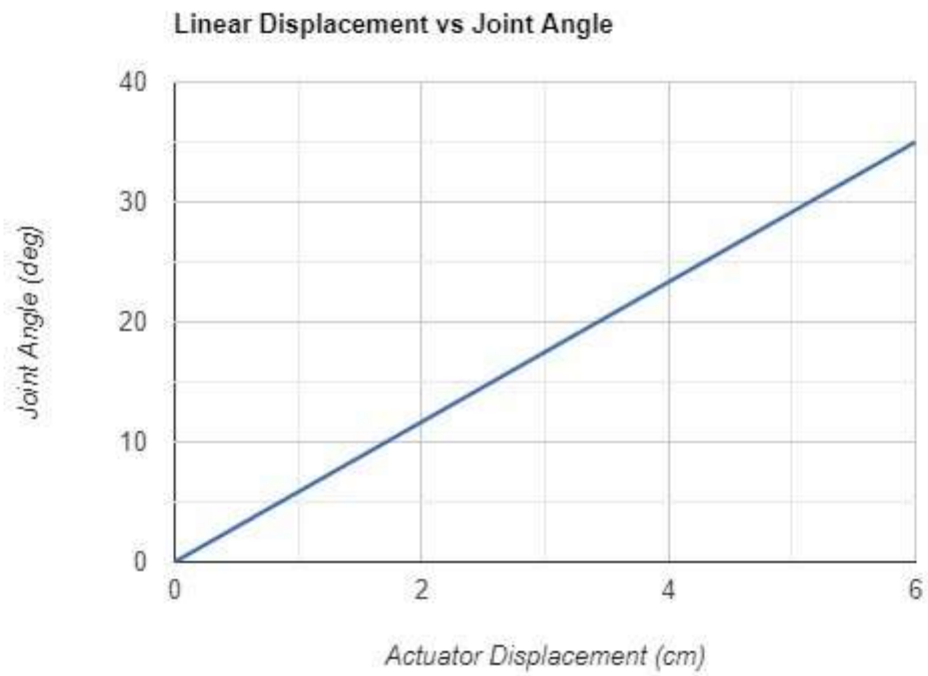


Figure 4.2: Graph of actuator displacement verses joint angle.

In this section as shown in the above Figure 4.2, the actuator displacement of the push/pull rod motor can go for six centimeters therefore the accomplished rotation of angle is made on the bearing is 35 degrees which causes the arm to rise.

Chapter 5: Project Management

5.1 Project Plan

There are several duties in our project. One or more individuals are allocated to each job. Here you'll find all of the details regarding the tasks, team members, and the time it will take to finish each one. Tasks and durations are listed in table 5.1, and assigned members are shown in table 5.2.

Table 5.1: Tasks and their durations

#	Tasks		Start	End	Duration
1	Chapter 1: Introduction		27/1/2021	31/1/2021	4
2	Chapter 2: Literature Review	Project Background	1/2/2021	7/2/2021	6
		Previous Work			
		Comparative Study			
3	Chapter 3: System Design	Design Constraints and Design Methodology	8/2/2021	14/3/2021	34
		Engineering Design standards			
		Theory and Theoretical Calculations			
		Product Subsystems and selection of Components			
		Manufacturing and assembly			
4	Chapter 4: System Testing & Analysis	Experimental Setup, and data	15/3/2021	23/3/2021	8
		Results, Analysis and Discussion			
5	Chapter 5: Project Management	Project Plan	23/3/2021	31/3/2021	8
		Contribution of Team members			
		Project Execution Monitoring			
		Challenges & Decision			

		Making			
		Project Bill of Material & Budget			
6	Chapter 6: Project Analysis	Life Long Learning	1/4/2021	7/4/2021	6
		Impact of Engineering Solution			
		Contemporary Issues Addressed			
7	Chapter 7: Conclusion & Recommendation	Conclusion	8/4/2021	11/4/2021	4
		Future Recommendation			
8	Design of Prototype	Bearing Shape	16/2/2021	22/2/2021	6
		Springs Bases			
		Adjustment & Location			
9	Parts Purchase	Battery	22/2/2021	29/2/2021	7
		Push/ Pull Rod Motor			
		Toggle Switch			
		Compression Springs			
		3D Printer's PLA Material			
10	Manufacturing	Structure Welding	1/3/2021	14/3/2021	13
		Grinding			
		Bearing 3D Printing			
11	Testing	Changing Bearing's Design	15/3/2021	18/3/2021	3
		Changing Springs's Bases to Holes	18/3/2021	20/3/2021	2
		Changing Bearing Gap's Dimensions	21/3/2021	23/3/2021	2
		Retesting	23/3/2021	26/3/2021	3

Table 5.2: Tasks and assigned members

#	Tasks	Assigned Members
1	Chapter 1: Introduction	All
2	Chapter 2: Literature Review	Majed Inkis
		Mohammed Alhuliami
		Abdullah Almoosa
3	Chapter 3: System Design	All
4	Chapter 4: System Testing & Analysis	All
5	Chapter 5: Project Management	Majed Inkis
		Abdullah Almoosa
		Mohammed Alhuliami
6	Chapter 6: Project Analysis	Majid Alrashidi
		Mohammed Alsubai
		Majed Inkis
7	Chapter 7: Conclusion &Recommendation	Mohammed Alsubai
		Majid Alrashidi
		Abdullah Almoosa
8	Design of Prototype	Mohammed Alhulaimi
		Majed Inkis
9	Parts Purchase	All
10	Manufacturing	Majed Inkis
		Mohammed Alhulaimi
11	Testing	Majed Inkis

5.2 Contribution of Team Members

One or more participants were allocated to the responsibilities in this project. It is dependent on the task's competence and the time necessary to do it. Table 5.3 lists the duties and members, as well as the percentages of each member's contribution.

Table 5.3: Tasks the contribution of the members

<table>
<tr><th>#</th><th>Tasks</th><th colspan="2">Assigned</th><th>Cont. %</th></tr>
<tr><td>1</td><td>Chapter 1: Introduction</td><td colspan="2">All</td><td>100%</td></tr>
<tr><td rowspan="9">2</td><td rowspan="9">Chapter 2: LiteratureReview</td><td rowspan="3">Project Background</td><td>Inkis</td><td>33%</td></tr>
<tr><td>Alhulaimi</td><td>33%</td></tr>
<tr><td>Almoosa</td><td>34%</td></tr>
<tr><td rowspan="3">Previous Work</td><td>Alhulaimi</td><td>34%</td></tr>
<tr><td>Inkis</td><td>33%</td></tr>
<tr><td>Alsubai</td><td>33%</td></tr>
<tr><td rowspan="3">Comparative Study</td><td>Almoosa</td><td>33%</td></tr>
<tr><td>Inkis</td><td>34%</td></tr>
<tr><td>Alrashidi</td><td>33%</td></tr>
<tr><td rowspan="14">3</td><td rowspan="14">Chapter 3: System Design</td><td rowspan="4">Design Constraints andDesign Methodology</td><td>Almoosa</td><td>30%</td></tr>
<tr><td>Alhulaimi</td><td>30%</td></tr>
<tr><td>Alrashidi</td><td>30%</td></tr>
<tr><td>Alsubai</td><td>10%</td></tr>
<tr><td rowspan="2">Engineering Design standards</td><td>Inkis</td><td>50%</td></tr>
<tr><td>Alhulaimi</td><td>50%</td></tr>
<tr><td rowspan="3">Theory and Theoretical Calculations</td><td>Inkis</td><td>39%</td></tr>
<tr><td>Alhulaimi</td><td>39%</td></tr>
<tr><td>Alsubai</td><td>22%</td></tr>
<tr><td rowspan="3">Product Subsystems andselection of Components</td><td>Alhulaimi</td><td>40%</td></tr>
<tr><td>Inkis</td><td>40%</td></tr>
<tr><td>Almoosa</td><td>20%</td></tr>
<tr><td rowspan="2">Manufacturing and assembly</td><td>Inkis</td><td>50%</td></tr>
<tr><td>Alhulaimi</td><td>50%</td></tr>
</table>

4	Chapter 4: System Testing& Analysis	Experimental Setup, &data	All	100%
		Results, Analysis and Discussion	All	100%
5	Chapter 5: Project Management	Project Plan	All	100%
		Contribution of Team members		
		Project Execution Monitoring		
		Challenges & Decision Making		
		Project Bill of Material & Budget		
6	Chapter 6: Project Analysis	Life Long Learning	Inkis Alrashidi Alsubai	100%
		Impact of Engineering Solution		
		Contemporary Issues Addressed		
7	Chapter 7: Conclusion &Recommendation	Conclusion	Alrashidi Alsubai Alhulaimi	100%
		Future Recommendation		
8	Design of Prototype	Bearing Shape	Alhulaimi Inkis	100%
		Springs Bases		
		Adjustment & Location		
9	Parts Purchase	Battery	All	100%
		Push/ Pull Rod Motor		
		Toggle Switch		
		Compression Springs		
		3D Printer's PLA Material		

10	Manufacturing	Structure Welding	Inkis	100%
		Grinding		
		Bearing 3D Printing		
11	Testing	Changing Bearing's Design	Inkis Alhulaimi	100%
		Changing Springs's Bases to Holes		
		Changing Bearing Gap's Dimensions	Alhulaimi	100%
		Retesting	All	100%

5.3 Project Execution Monitoring

We had various actions related to improving our project through the course of our project. The crucial meeting and events relating to our senior project are among these activities. The list of meetings and other activities for our project for the spring semester of 2021 is shown in table 5.4.

Table 5.4: Dates of the activates and events

Time/Date	**Activities/Events**
One time a week	Assessment class
Weekly	Meeting with group members
weekly	Meeting with the advisor and co-advisor
15, March, 2021	Finishing first prototype
17, April, 2021	Midterm presentation
19, April, 2021	First test of the system
29, April, 2021	Finishing final prototype
8, May, 2021	Test the system
15, May, 2021	Final Submission of the report
20, May, 2021	Final presentation

5.4 Challenges and Decision Making

During the phases of planning the design, and the manufacturing of the prototype and the final product, the team encountered several challenges that required critical thinking, teamwork and decision making skills to overcome. The first challenge that the team faced was choosing between two ideas to incorporate in the design of the spring bearing. The initial idea was designing and manufacturing a spiral spring bearing. However, designing and manufacturing a compression spring bearing is more efficient and practical since it requires less parts, the manufacturing process is less complex and the obtainment of parts is easier. Also, to illustrate the use and functionality of the product, it was decided to install the bearing in a robotic arm with a motor as an actuator to make sure the product is functioning properly. Moreover, using the lathe machine provided by the university to manufacture the bearing was a challenge. Therefore, carefully reading the manual for instructions on how to use the machine as well as communicating with the manufacturer of the lathe machine to fully understand the method of using the machine were the decisions that the team took to assure a successful manufacturing process and to minimize any risks or hazards in the process.

5.5 Project Bill of Materials and Budget

Materials: 1- Springs: ASTM-A313 Stainless Steel

2- Bearing: PLA 303

Budget: 1- Aluminum Alloy: 208.35 SAR   2- Stainless Steel: 166.25 SAR

3- Labor: 450 SAR   4- Lathe Machine training/labor: 517 SAR

5- Banner: 500 SAR   6- Brochure: 300 SAR

Chapter 6: Project Analysis

6.1 Life-long Learning

The crew obtained diversified expertise about several topics while working on the project, including software skills, hardware skills, time management skills, and project management abilities. We learned how to handle tasks by guaranteeing time management and effective communication skills with team members by working as a team. In this section, we'll go through the many talents we've acquired as a result of working on this project.

6.1.1 Software Skills

We acquired hands-on experience dealing with applications such as MS Word, MS PowerPoint, and Solidworks as part of this assignment. We utilized Solidworks software to create the improved flexure bearing, which helped us hone our abilities in this design program. In addition, we learned how to use Word and PowerPoint to write reports and give presentations.

6.1.2 Hardware Skills

We practiced assembling the designed elements to manufacture the flexure bearing during our project. We've also got some hands-on experience with 3D printing. Furthermore, before going on to the fabrication phase of the project, make thorough calculations and revise them because a slight discrepancy in calculations might result in a significant difference in the finished product.

6.1.3 Management Skills

One of the most significant skills we learned while working on this project was time management, which focused on how deadlines should be fulfilled efficiently during the project's execution. Furthermore, we learnt various skills such as job distribution, teamwork, and guiding the team in the appropriate path during the project's completion.

6.2 Impact of Engineering Solutions

The following are the project's social, economic, and environmental impacts:

6.2.1 Social Impacts of project

Our project may be utilized for a variety of jobs to make people's repetitious activities easier. It's also utilized in robotic systems as an arm joint.

6.2.2 Economic Impacts of project

The modified flexure bearing we devised have a long service life. Maintenance-free functioning that helps to avoid wear and tear.

6.2.3 Environmental Impacts of project

In today's world, when pollution is a major concern for all stakeholders, we made certain that any waste generated during lathe operations will be disposed of or recycled through the production cycle of our project.

6.3 Contemporary Issues Addressed

- The following are some of the current challenges that our redesigned flexure bearing addresses: The most pressing issue we faced was excessive pollution. The initial technique was to dispose of or recycle any trash generated during lathe operations.
- We put springs in these bearings to address the second problem of fatigue, which is likely to develop if bearings are subjected to high-speed applications for an extended length of time. Springs have the capacity to absorb vibrations. Spring-loaded devices can also be used in high-speed applications.

Chapter 7: Conclusions and Future Recommendations

7.1 Conclusion

The purpose of this research was to address the issue of bearing fatigue, which is common when bearings are subjected to high-speed applications over extended periods of time. Springs are recommended to be utilized instead of flexure beams inside the bearing pivot in this case. Springs have the capacity to absorb vibrations and can be used in high-speed applications. Furthermore, the rotational angle may be increased beyond that of a standard Flexure bearing. Springs may also be simply replaced when they reach the end of their useful life. Solidworks will be used for modeling and design, followed by the creation of a prototype to test the concept. Bearings are often used to facilitate rotational or linear movement between two pieces. Bearings are prone to friction since they are frequently positioned in contact with other parts as a joint. As a result, the necessity for frequent lubrication and maintenance is uneconomical. The goal of this project is to create a Flexure Bearing that does not have any friction, therefore removing the need for lubrication. Flexure bearings are likely to undergo fatigue in high-speed rotation applications due to the cyclic stress of the inner flexures. The flexures will be replaced by springs to overcome this problem, allowing the component to oscillate without fear of fatigue or friction. As a result, this product is being developed to broaden the scope of mechanical bearings' operating uses.

7.2 Future Recommendations

There is a suggestion to test the discussed other design using spiral springs and compare results with the presented compression springs, see figure 7.2.

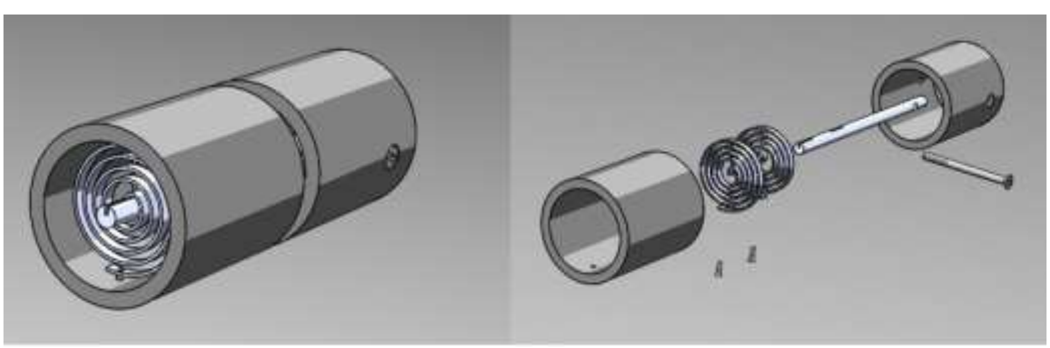


Figure 7.2: Spiral springs.

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Appendix A: Progress Reports

	SDP – Monthly MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Spring**	**ACADEMIC YEAR:**	**2020/2021**
PROJECT TITLE	**Design and Development of a Modified Flexure Bearing for Complaint Mechanisms Applications**		
SUPERVISORS	**Dr. Muhammad Asad, Taha Waqar**		

Month 2: March

#	Member Name	ID Number
1	Mohammed Alhulaimi	201500183
2	Majed Inkis	201801850
3	Abdullah Almoosa	201902235
4	Majid Alrashidi	201502154
5	Mohammed Alsubaie	201500684

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Chapter 3: Design Constraints and Methodology	3	100%	
2	CAD Model	1, 2	100%	
3	Chapter 3: Engineering Standards and Calculations	1	100%	
4	Chapter 3: Product Subsystems and selection of Components	4	100%	
5	Chapter 3: Manufacturing and assembly	2	100%	
6	Chapter 3: Economic Evaluation	5	100%	

List the tasks planned for the month of April and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Preparing Midterm Presentation	All
2	Prototype Manufacturing	1,2
3	Chapter 4: Prototype Testing and Analysis	All
4	Chapter 5: Project Management	All
5	Chapter 6: Project Analysis	3,4,5
6	Chapter 7: Conclusion and Recommendation	1,2

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate	Properly and efficiently makes team work plans and allocate resources and tasks

			resources and tasks	
MEEN5B: Ability to participate and function effectively in team work projects to meet objectives	Fails to participate and function effectively in team work projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in team work projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in team work projects to meet objectives	Function effectively in team work projects to meet objectives
MEEN5C: Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	Communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	Mohammed Alhulaimi	4	4	4	4
2	Majed Inkis	4	4	4	4
3	Abdullah Almoosa	3	3	3	4
4	Majid Alrashidi	3	3	2	2
5	Mohammed Alsubaie	3	3	2	2

Comments on individual members

Name	Comments
Mohammed Alhulaimi	Excellent
Majed Inkis	Excellent
Abdullah Almoosa	Very good
Majid Alrashidi	Good
Mohammed Alsubaie	Good

	SDP – Monthly MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Spring**	**ACADEMIC YEAR:**	**2020/2021**
PROJECT TITLE	**Design and Development of a Modified Flexure Bearing for Complaint Mechanisms Applications**		
SUPERVISORS	**Dr. Muhammad Asad, Taha Waqar**		

Month 3: April

#	Member Name	ID Number
1	Mohammed Alhulaimi	201500183
2	Majed Inkis	201801850
3	Abdullah Almoosa	201902235
4	Majid Alrashidi	201502154
5	Mohammed Alsubaie	201500684

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Preparing Midterm Presentation	All	100%	
2	1st Prototype testing	1, 2	100%	
3	Chapter 4: Prototype Testing and Analysis	2,3	25%	
4	Chapter 5: Project Management	2,3	50%	
5	Chapter 6: Project Analysis	4,5	50%	
6	Chapter 7: Conclusion and Recommendation	4,5	50%	

List the tasks planned for the month of May and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Try new solutions and design modifications	1
2	Prototype testing and manufacturing	1,2
3	Prototype video recording	1,2
4	Chapter 4 & 5	2,3
5	Chapter 6 & 7	4,5
6	Banner & Brochure	2
6	Final Presentation preparation	All

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: Ability to develop team work plans and	Fails to develop team work plans and allocate	Shows limited and less than adequate ability to develop	Demonstrates satisfactory ability to	Properly and efficently makes team work plans

allocate resources and tasks	resources and tasks	team work plans and allocate resources and tasks	develop team work plans and allocate resources and tasks	and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in team work projects to meet objectives	Fails to participate and function effectively in team work projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in team work projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in team work projects to meet objectives	Function effectively in team work projects to meet objectives
MEEN5C: Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	Communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	Mohammed Alhulaimi	4	4	4	4
2	Majed Inkis	4	4	4	4
3	Abdullah Almoosa	3	3	3	4
4	Majid Alrashidi	3	3	2	2
5	Mohammed Alsubaie	3	3	2	2

Comments on individual members

Name	Comments
Mohammed Alhulaimi	Excellent
Majed Inkis	Excellent
Abdullah Almoosa	Very good
Majid Alrashidi	Good
Mohammed Alsubaie	Good

	SDP – Monthly MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Spring**	**ACADEMIC YEAR:**	**2020/2021**
PROJECT TITLE	**Design and Development of a Modified Flexure Bearing for Complaint Mechanisms Applications**		
SUPERVISORS	**Dr. Muhammad Asad, Taha Waqar**		

Month 4: May

#	Member Name	ID Number
1	Mohammed Alhulaimi	201500183
2	Majed Inkis	201801850
3	Abdullah Almoosa	201902235
4	Majid Alrashidi	201502154
5	Mohammed Alsubaie	201500684

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Redesign and prototypes testing	1,2	100%	Presented
2	Buying needed electronic parts	2	100%	
2	Final prototype manufacturing	2	100%	Presented
3	Finalizing the report	2,3,4,5	100%	
4	Preparing Final Presentation	All	100%	

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Properly and efficently makes team work plans and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in team work projects to meet objectives	Fails to participate and function effectively in team work projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in team work projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in team work projects to meet objectives	Function effectively in team work projects to meet objectives

MEEN5C: Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	Communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	Mohammed Alhulaimi	4	4	4	4
2	Majed Inkis	4	4	4	4
3	Abdullah Almoosa	3	3	3	4
4	Majid Alrashidi	3	3	2	3
5	Mohammed Alsubaie	3	3	2	3

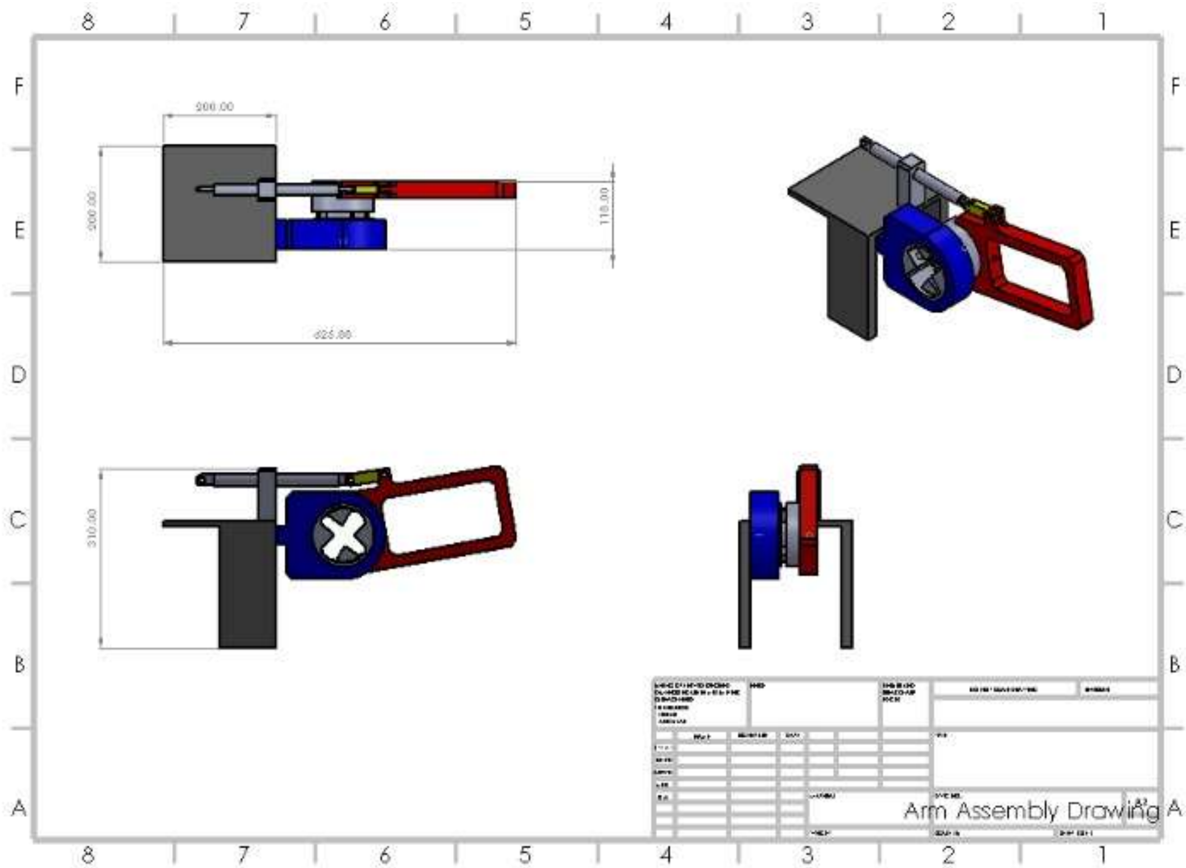
Comments on individual members

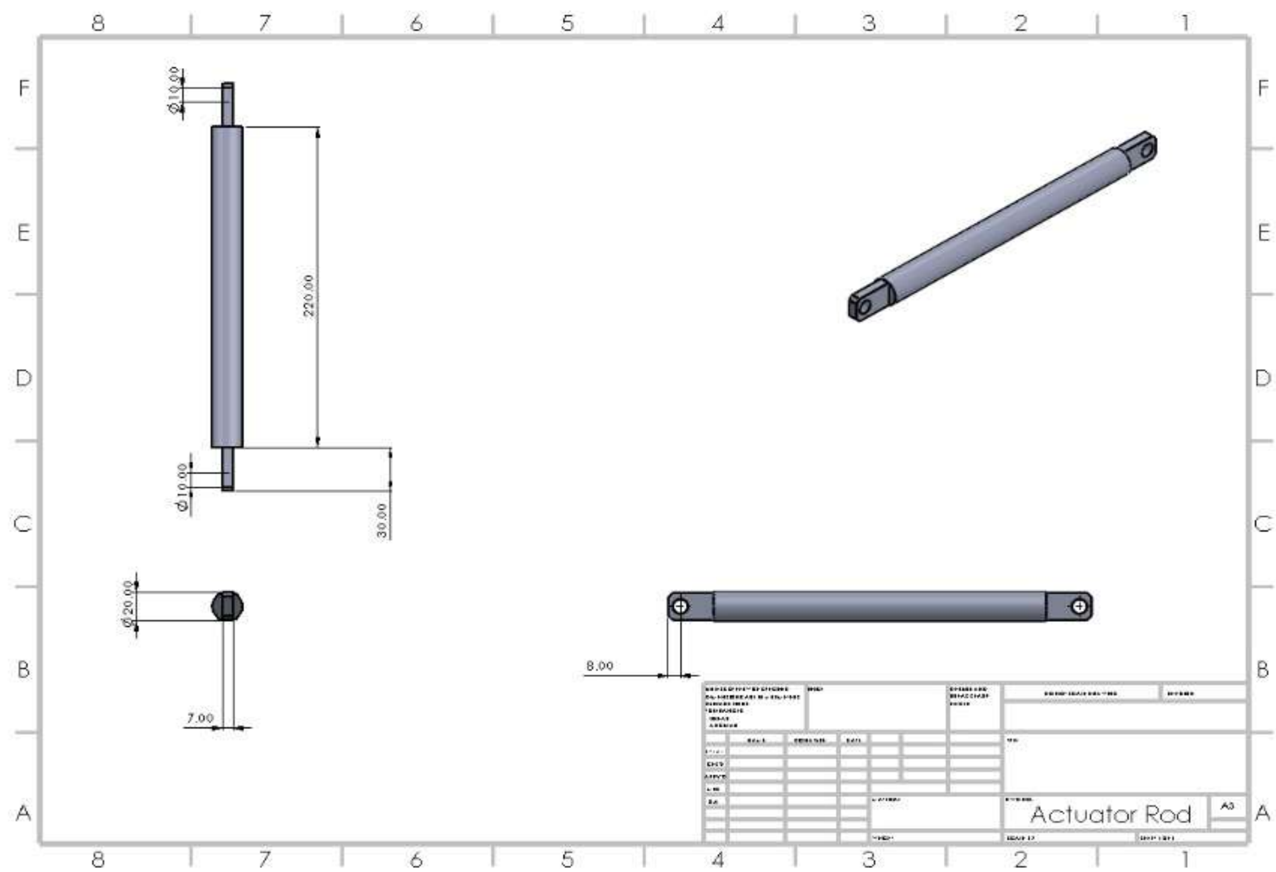
Name	Comments
Mohammed Alhulaimi	Excellent
Majed Inkis	Excellent
Abdullah Almoosa	Excellent
Majid Alrashidi	Good
Mohammed Alsubaie	Good

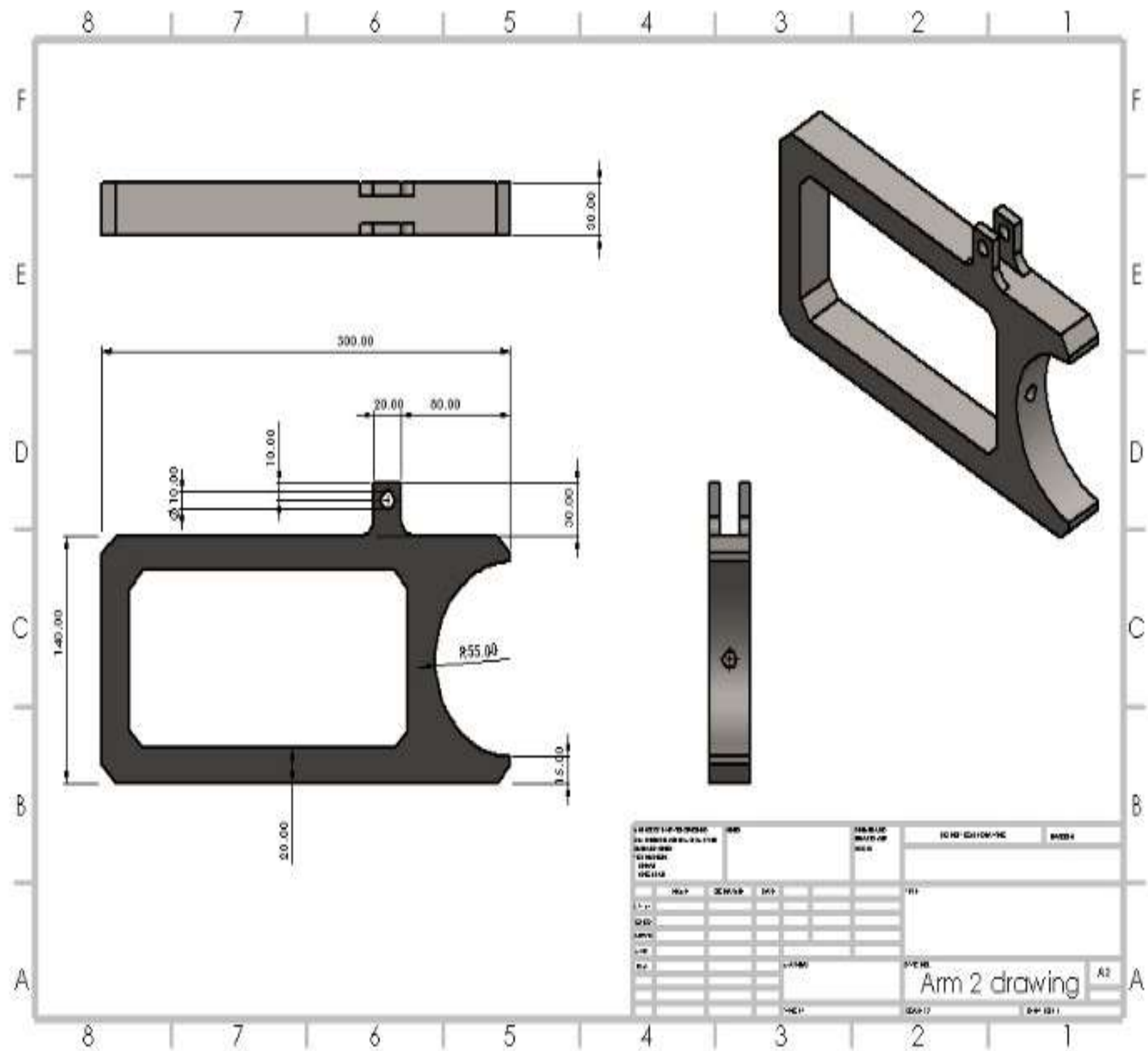
Appendix B: Engineering standards (Local and International)

Component	Engineering Standard	Details
Springs	Associated Spring Raymond	C0235-029-1000-S
Bearing (OD & ID Sizing)	ISO	Ball Bearing ISO 15 - 4240
Spring Material	American Society for Testing and Materials (ASTM)	ASTM-A313 Stainless Steel
Bearing Material	The Aluminum Association	Aluminum 2030 (or A92030 according to UNS)

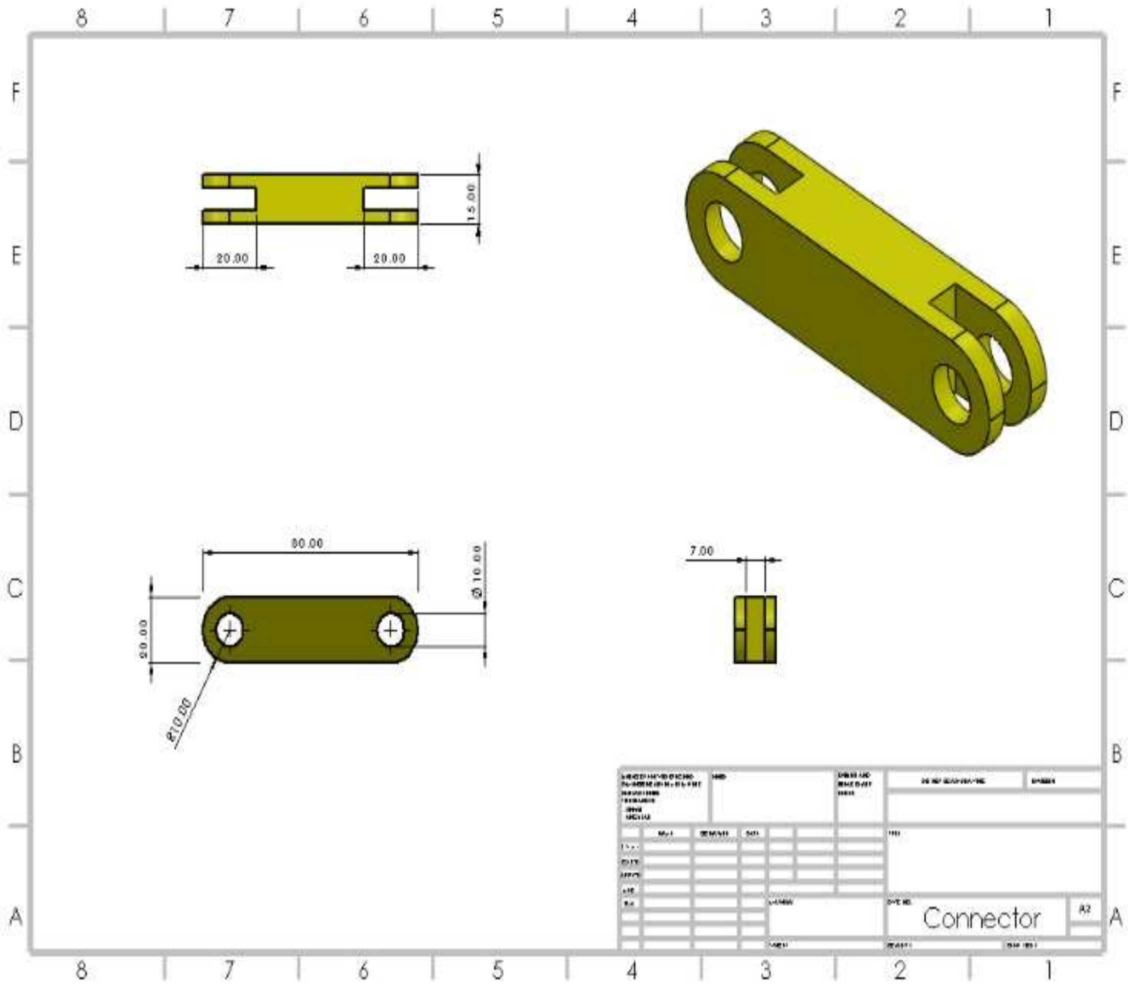
Appendix C: CAD drawings and Bill of Materials

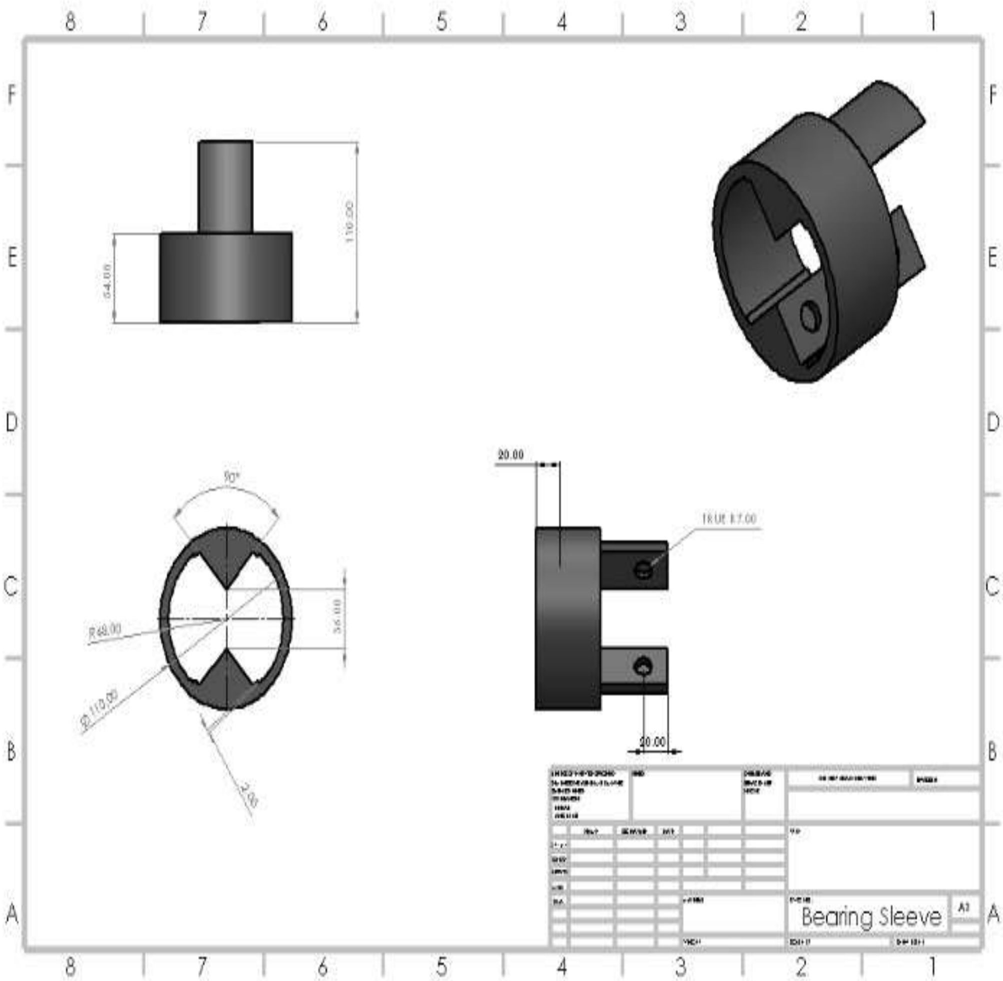


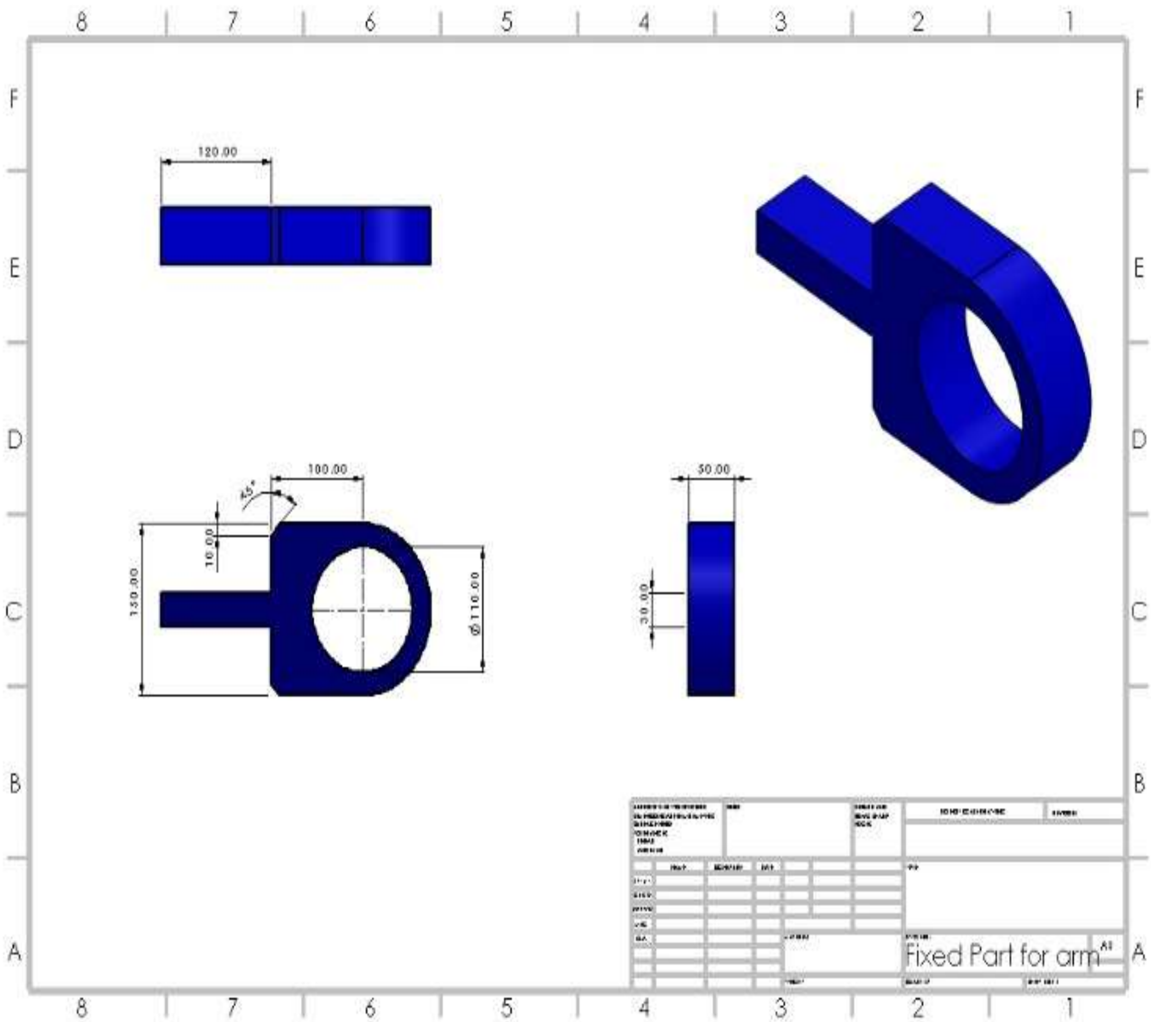

Ø10,00
220,00
Ø10,00
30,00
Ø20,00
7,00
8,00
Actuator Rod
A3



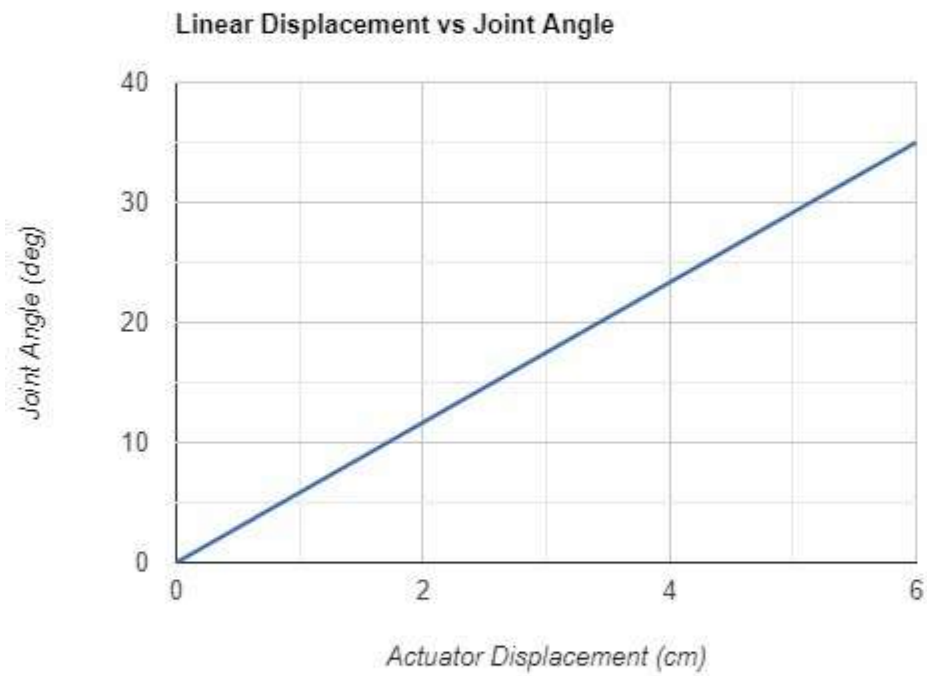
300.00
20.00
80.00
10.00
Ø10.00
30.00
30.00
140.00
R55.00
15.00
20.00
Arm 2 drawing
A4


20.00
20.00
15.00
80.00
Ø10.00
20.00
R10.00
7.00
Connector
A2


110.00
64.00
90°
R48.00
36.00
Ø110.00
2.00
20.00
THRU 17.00
20.00
Bearing Sleeve
A3


120.00
100.00
45°
10.00
150.00
⌀110.00
50.00
30.00
Fixed Part for arm
A4

Appendix D: Datasheets



Appendix E: Operation Manual

Please follow these procedures to run the prototype.

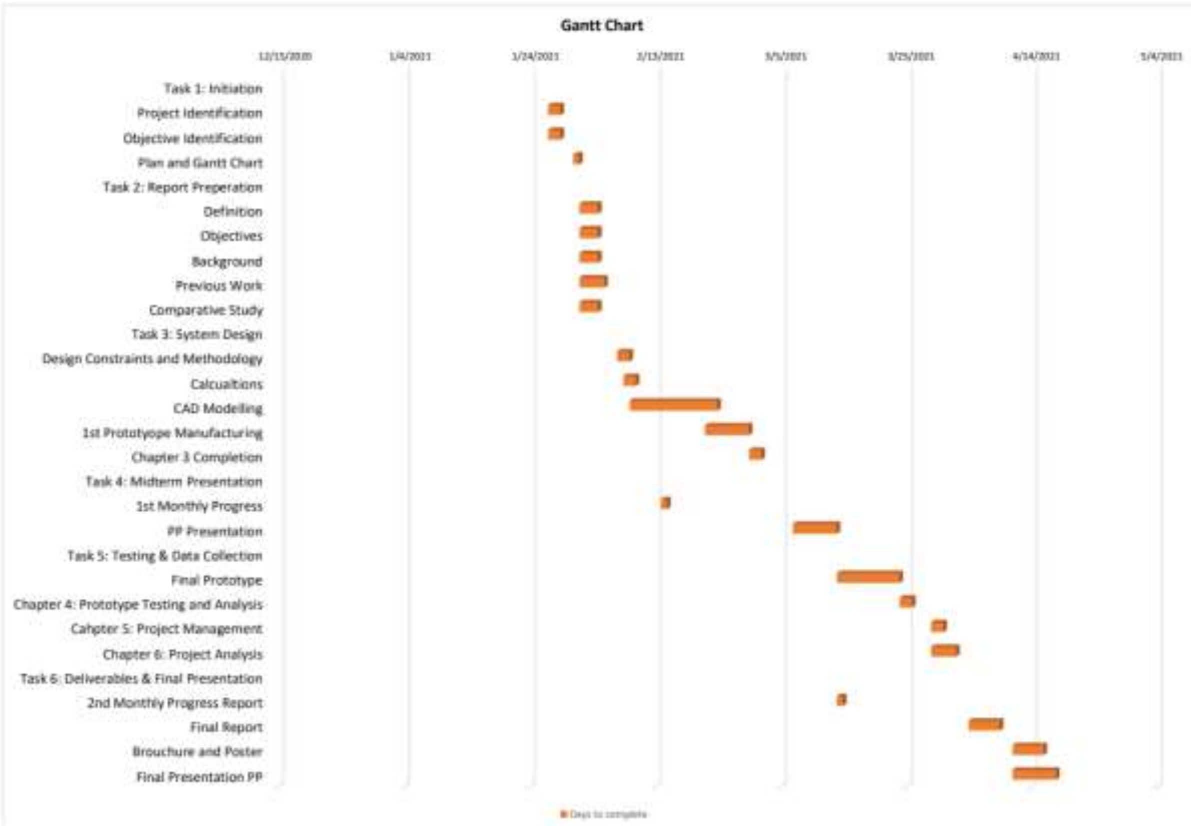
- Adjust the system above a table and double-check that the wires are linked to the battery poles
- To make the arm go up, turn on the mechanism using the toggle switch
- To make the arm stop at the desired angle, use the toggle switch to turn off the system
- To make the arm go down, turn on the system using the toggle switch

The following are the predicted outcomes of this operation:

- The arm would be bent at an angle
- The push/pull rod (actuator) has a maximum displacement of 6 cm.

Appendix F: Gantt Chart

Task	Start Date	Days to Complete
Task 1: Initiation		
Project Identification	25/1/2021	2
Objective Identification	25/1/2021	2
Plan and Gantt Chart	26/1/2021	1
Task 2: Report Preparation		
Introduction - Definition	27/1/2021	4
Introduction - Objectives	27/1/2021	4
Literature Review - Background	1/2/2021	6
Literature Review - Previous Work	1/2/2021	6
Literature Review - Comparative Study	1/2/2021	6
Task 3: System Design		
Design Constraints and Methodology	8/2/2021	4
Calculations	11/2/2021	3
CAD Modelling	12/2/2021	14
1st Prototype Manufacturing	26/2/2021	7
Completion	5/3/2021	2
Task 4: Midterm Presentation		
1st Monthly Progress	7/3/2021	1
PP Presentation	8/3/2021	4
Task 5: Testing & Data Collection		
Final Prototype	13/3/2021	2
Chapter 4: Prototype Testing and Analysis	15/3/2021	8
Chapter 5: Project Management	23/3/2021	8
Chapter 6: Project Analysis	31/3/2021	4
Task 6: Deliverables & Final Presentation		
2nd Monthly Progress Report	3/4/2021	1
Final Report	4/4/2021	5
Brochure and Poster	4/11/2021	5
Final Presentation PP	4/11/2021	7



Gantt Chart
12/15/2020
1/4/2021
1/24/2021
2/13/2021
3/5/2021
3/25/2021
4/14/2021
5/4/2021
Task 1: Initiation
Project Identification
Objective Identification
Plan and Gantt Chart
Task 2: Report Preperation
Definition
Objectives
Background
Previous Work
Comparative Study
Task 3: System Design
Design Constraints and Methodology
Calcualtions
CAD Modelling
1st Prototyope Manufacturing
Chapter 3 Completion
Task 4: Midterm Presentation
1st Monthly Progress
PP Presentation
Task 5: Testing & Data Collection
Final Prototype
Chapter 4: Prototype Testing and Analysis
Cahpter 5: Project Management
Chapter 6: Project Analysis
Task 6: Deliverables & Final Presentation
2nd Monthly Progress Report
Final Report
Brouchure and Poster
Final Presentation PP