Liverpool John Moores University

Adjustable Mechanical Prosthetic Foot

5500ICBTEL

Dynamic Designers | 2/25/25 | Design Project

ACKOWLEDGEMENT

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Finally, we acknowledge the unwavering support of our families and friends, whose motivation and belief in our abilities have been a driving force behind our efforts.

Thank you all for being part of this journey with us.

-Dynamic Designers-

Dynamic Designers

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ABSTRACT

The **Adjustable Mechanical Prosthetic Foot** is designed to provide enhanced adaptability, comfort, and functionality for individuals with lower limb amputations. The primary objective of this project is to develop a prosthetic foot mechanism that allows **adjustments in multiple angles**, ensuring better mobility and improved user experience. Unlike conventional prosthetic feet, our design integrates **a universal joint mechanism**, enabling controlled movement in four directions to mimic natural ankle motion.

The project incorporates **lightweight materials** to maintain durability while reducing overall weight, ensuring ease of use. Additionally, **springs and bumper mounts** are implemented to enhance shock absorption, improving comfort and energy return during walking. A key aspect of our design is the **mechanical energy conservation system**, which optimizes energy efficiency, making it suitable for users with varying activity levels.

Through extensive research on **biomechanics, prosthetic foot mechanisms, and material selection**, the project aims to bridge the gap between **functionality and affordability** in prosthetic design. Ethical considerations, including user safety, accessibility, and sustainability, have also been thoroughly evaluated.

The outcome of this project demonstrates a **cost-effective and mechanically efficient prosthetic foot**, capable of providing **greater adaptability and comfort** compared to traditional prosthetic solutions. This innovation has the potential to enhance mobility and improve the quality of life for amputees worldwide.

Contents of Headings

CHAPTER 01 – Introduction

1.1 Rational of the Topic

Regarding amputees in the world, the type of amputation and study can be divided into several parts. For example, 83.9% of lower limb amputees use a prosthetic leg, and 56.1% of upper limb amputees use a prosthetic leg.

In the analysis of the above data, it appears that most users of artificial legs have lost their lower legs. But overall, it seems that most disabled people are motivated to use artificial legs. As a result, they have been able to normalize their lives.

Different types of technologies are used to make artificial feet. There are two main types of artificial limbs. They are permanent prosthetic legs and functional prosthetic legs. The main difference between fixed prostheses and functional prostheses is that while a functional prosthesis has the same mobility and capabilities as a normal living limb, fixed prostheses have none of these capabilities. The main moving part of a functional prosthetic foot is the ankle and the foot below it. The part above the ankle varies depending on the location of the amputation and its function varies accordingly.

This project aims to produce the ankle and the foot, the main component of functional prosthetic feet, in an efficient, durable, comfortable, and low-cost way that can make everyday tasks easier for people who need to use prosthetic feet. The goal is to produce a functional prosthetic limb that is approximately equivalent to the value of a permanent prosthetic limb.

1.2 Problem Identification

In developing countries like Sri Lanka, the economic levels of the people are very low. Therefore, people with various disabilities in such countries often live in helpless conditions, unable to carry out their daily activities, and some of them are even tempted to beg. Among them, there are a significant number of people who have had their legs amputated. They often must use a permanent artificial leg that is available at a low price. With it, they cannot carry out their daily activities like a healthy person. There are functional artificial legs that can facilitate such daily activities, but they are very expensive.

1.3 Aim

- The goal is to create a low-cost artificial ankle and foot that functions similarly to a real ankle and a foot.

1.4 Objectives

- Conduct a critical exploration of prosthetic legs and their function and technology.
- Creating three hypothetical designs using knowledge gained from critical exploration.
- Selecting the most appropriate hypothetical design from among the three hypothetical designs created.
- Creation of a prototype of the chosen hypothetical design.
- Creating the actual final product using the prototype.
- Conducting tests using the final product created.
- Analyzing the test data obtained and reaching a final conclusion.

1.5 Scope

- The goal is to enable disabled people without legs to perform their daily tasks like a normal healthy person at a low cost.

1.6 Limitations

- This prosthetic leg can only occur day today basic movements such as walking.
- Can't using while bathing.

CHAPTER 02 – Literature Review

2.1 Literature Mapping

2.2 Literature Review

2.2.1Biomechanics

2.2.1.1 Autonomy of a foot

<u>Biological Context (Humen or Animal Foot)</u>

If referring to a biological limb, "autonomy" refers to the limb's ability to act independently or adapt to its environment without direct control from the brain or central nervous system.

- Reflexes: The foot may respond to stimulation without conscious awareness (pulling away from a sharp object).
- Biomechanics: The complex structure (bones, muscles, tendons, and nerves) of the foot allows it to adapt to unusual surfaces, absorb shock, and maintain auto balance.

<u>Robotics or Prosthetics Context</u>

In Robotics or Prosthetics, an “autonomous limb” often uses sensors and an algorithm to function. This allows it to perform the functions of a normal foot and leads to a prosthetic foot.

It can adjust its position, balance, or gait in real time based on sensor feedback (pressure, terrain, or movement).

Also, autonomous features could adapt to different walking speeds, slopes, or surfaces without manual input.

<u>Philosophical or Metaphorical Context</u>

In a metaphorical sense, the "autonomy of a leg" can signify independence or self-sufficiency, even if it is a small or insignificant part of a larger system.

2.2.1.2 Bio Mechanism of a Foot

According to Liu et al. (2021), the study of the biomechanics of the foot considers walking, running, and jumping and how they distribute force. A foot has 26 bones, 33 joints, and over 100 muscles to function as a support and a flexible structure.

New research has focused on walking, using motion capture technology and force plate systems to study pressure distribution in the foot. This allows biomechanically optimized footwear to increase prosthetic stability and reduce stress on joints. Computational techniques such as finite element analysis (FEA) have also been used to create new energy-efficient prosthetic feet, including shock absorbers and insoles.

2.2.1.3 Skeleton of a foot

According to Miller et al. (2020), the skeletal structure of the foot plays a fundamental role in its movement and is composed of three main parts. These are the forefoot, the midfoot, and the hind foot. The arch structure of the foot helps in shock absorption and energy conservation during its movement.

3D imaging and x-rays are used to more accurately study foot bone deformities and stress fractures. Studying the location of natural bones when designing prosthetic feet can help distribute the weight of the prosthetic feet better and provide a more effective and comfortable design for the amputee.

2.2.2 Prosthetic Foots

According to park et al. (2018), a variety of prosthetic foot mechanisms can be created by designing artificial feet based on the movement and function of a natural foot, and several main types are as follows.

- Passive prosthetic feet - These absorb the impact and release the energy back through a carbon fiber spring.
- Dynamic-Response feet - Designed for users who perform relatively strenuous activities, they efficiently store and release mechanical energy.
- Microprocessor-controlled feet - These are adjusted based on ground conditions and walking patterns and include sensors and actuators.
- Hydraulic and pneumatic feet - These use fluid or air pressure to provide a smooth transition between different walking surfaces.

Currently, the use of AI-based gait prediction models for stability and energy conservation has been growing recently.

2.2.2.2 Different materials used in prosthetic foots

According to Johnson et al. (2019), the choice of materials is very important when making artificial feet, and attention should be paid to their durability, flexibility, and weight. Some of the most used materials are as follows.

- Carbon Fiber- It is very strong and lightweight, making it an ideal material for creating prosthetic feet.
- Titanium and aluminum alloys-They have high strength and low weight, which is why they are used for structural components.
- Polyurethane and silicone- Used to improve foot covers.
- 3D printed Composites- Modern technology allows for customized prosthetic designs to balance mechanical properties.

Recent research has focused on using eco-friendly materials to create artificial devices that minimize their impact on the environment.

2.2.3 Applied Mechanisms

2.2.3.1 Universal Joints

According to Smith et al. (2020), with the development of universal joints, attention has been paid to improving their efficiency, load-carrying capacity, and flexibility in motion transmission. U-joints are mechanical components that enable actuation between rods that are not in direct alignment. Due to uneven torque transmission, U-joints are subjected to high loads, which can lead to permanent failure.

Recent advances in U-joints include the use of high-strength alloys and composite materials to increase durability and reduce weight. There are also hybrid lubrication techniques to extend service life and reduce friction. A major development in the four-angle adjustable U-joints is the integration of a ball bearing system, which distributes the load evenly and reduces backlash, increasing performance in dynamic applications. Further refining the above parts by running CAD simulations increases material distribution and minimizes stress concentration zones.

2.2.3.2 Spring

According to Kumar et al. (2018), spring technology is primarily focused on storing a high amount of energy in a low mass. They are widely used in mechanical and automotive applications for functions such as shock absorption, force balancing, and load distribution. According to the latest findings, composites and shape memory alloys (SMA) can be used to manufacture springs, increasing their performance and durability.

Nano-structured materials in springs increase their fatigue resistance and increase their operational durability. This is a crucial milestone in the development of springs, and a notable innovative feature is the progressive-rate spring design. It varies its stiffness according to load requirements, improving shock absorption and adaptability. And lightweight carbon fiber-reinforced polymer (CFRP) springs have reduced weight by 30% while maintaining the same strength and durability compared to steel springs.

2.2.3.3 Bumper Mounts

According to Lee et al. (2019), Bumper mounts play a major role in reducing the impact of a crash and help reduce the weight of vehicles. While traditional bumper mounts are primarily made of mild steel, modern technology can use high-strength aluminum alloys and polymer compounds to increase energy absorption and reduce impact forces.

Combining the structure of honeycomb and foam materials, the bumper mount structure is modified to absorb and dissipate impacts more efficiently. Sensors and actuators have been used to develop bumper mount systems based on crash severity. Researchers have found that optimizing the geometry of bumper mounts through finite element and crash simulations minimizes the impact on the vehicle and passengers.

2.2.3.4 Light weight wood materials

According to Johnson et.al. (2021), the advancement in the use of lightweight wood materials is driven by the desire to increase strength while maintaining sustainability. Wood-based materials are widely used in the automotive, construction, and aerospace industries due to their favorable strength-to-weight ratio and environmental benefits.

Current innovations include densified and cross-laminated wood (CLT), which offers higher strength than traditional wood at a lower weight. Researchers are also investigating Nano-cellulose reinforced wood composites, which can improve mechanical properties without compromising flexibility. Applying thermal and chemical treatments to wood increases its resistance to moisture and decay and increases the durability of structural applications in which the wood is used.

Another breakthrough in lightweight wood materials is the use of aerogel-infused wood, which is significantly lighter than the excellent thermal insulation properties of traditional plywood or MDF. Thus, wood-based materials are ideal for high-performance engineering applications, including environmentally friendly vehicle interior parts and lightweight furniture.

2.2.4 Applied Power Source

2.2.4.1 Mechanical energy conservations

According to Wang et al. (2022), Conservation of energy in mechanical systems is a fundamental principle of engineering, focusing on minimizing energy losses and improving their efficiency. Energy-storing and energy-returning (ESAR) mechanisms play a significant role in biomechanical applications.

Modern efficient prosthetic limbs and exoskeletons use spring-loaded and elastomeric materials to capture and release energy during walking. In robotics, reciprocating brake systems and piezoelectric materials are combined to convert stored mechanical energy into electrical energy. Lightweight high-strength alloys can also be used to minimize energy loss in moving mechanical parts and increase overall efficiency.

2.2.5 Ethical Guidelines

2.2.5.1 Ethical guidelines for projects

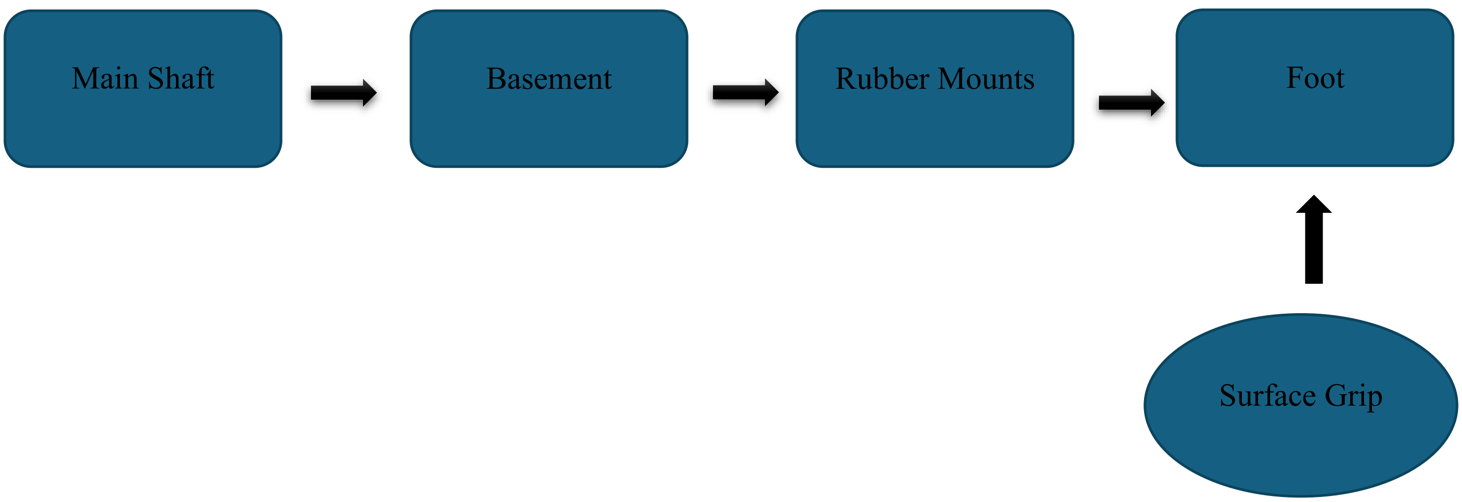
Ethical guidelines for projects ensure responsible innovation by prioritizing **safety, transparency, and fairness**. In prosthetic development, ethics focus on **user well-being, accessibility, and affordability**, ensuring solutions benefit diverse populations (WHO, 2022). The **Belmont Report (1979)** and **Helsinki Declaration (2013)** establish principles of **autonomy, beneficence, and justice** in human subject research (World Medical Association, 2013). The **IEEE Code of Ethics (2020)** and **ISO 13485** highlight the importance of **quality, safety, and regulatory compliance** in medical devices (IEEE, 2020). Sustainability is also a concern, urging the use of **eco-friendly materials** (UNESCO, 2021). Ethical AI in prosthetics emphasizes **privacy, fairness, and non-discrimination** (Floridi et al., 2018). Challenges such as **intellectual property rights and commercialization ethics** require careful consideration (Stahl, 2012). Regular ethical assessments and adherence to regulations ensure credibility, making **technological advancements both responsible and equitable** (Macrina, 2021).

CHAPTER 03 – Methodology

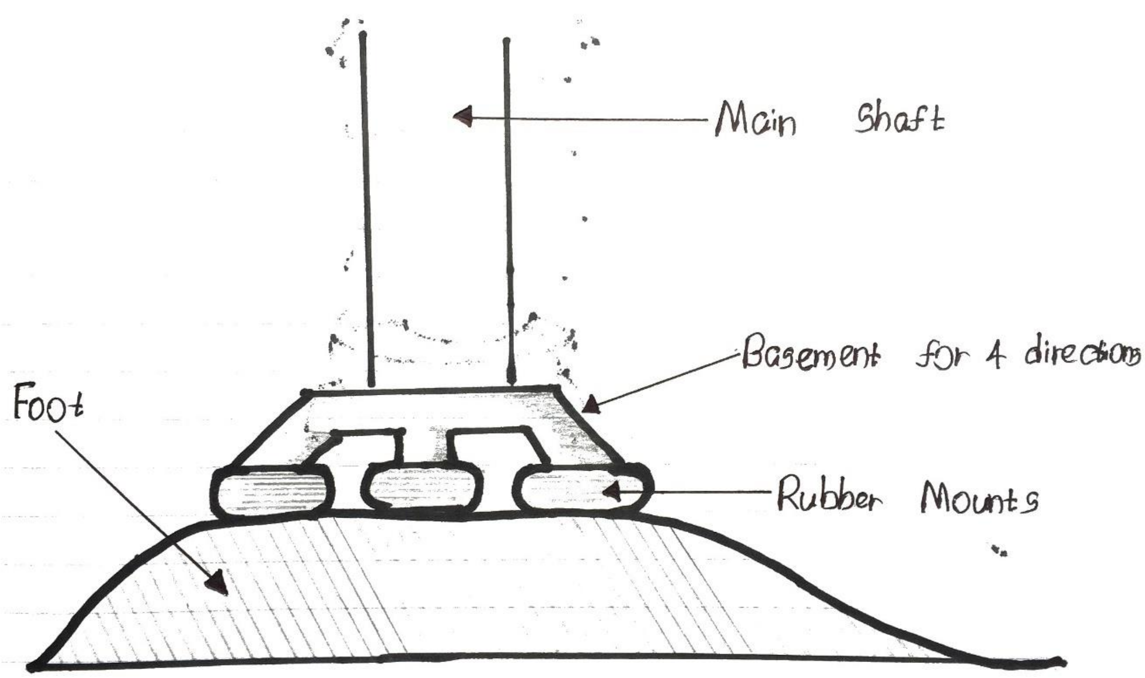
3.1 Conceptual Designs

- For this project we have designed several design concepts. Among them most suitable and most advanced top 3 concepts are stated below.

3.1.1 Design Concept 01 – "Rubber Mounted Foot"

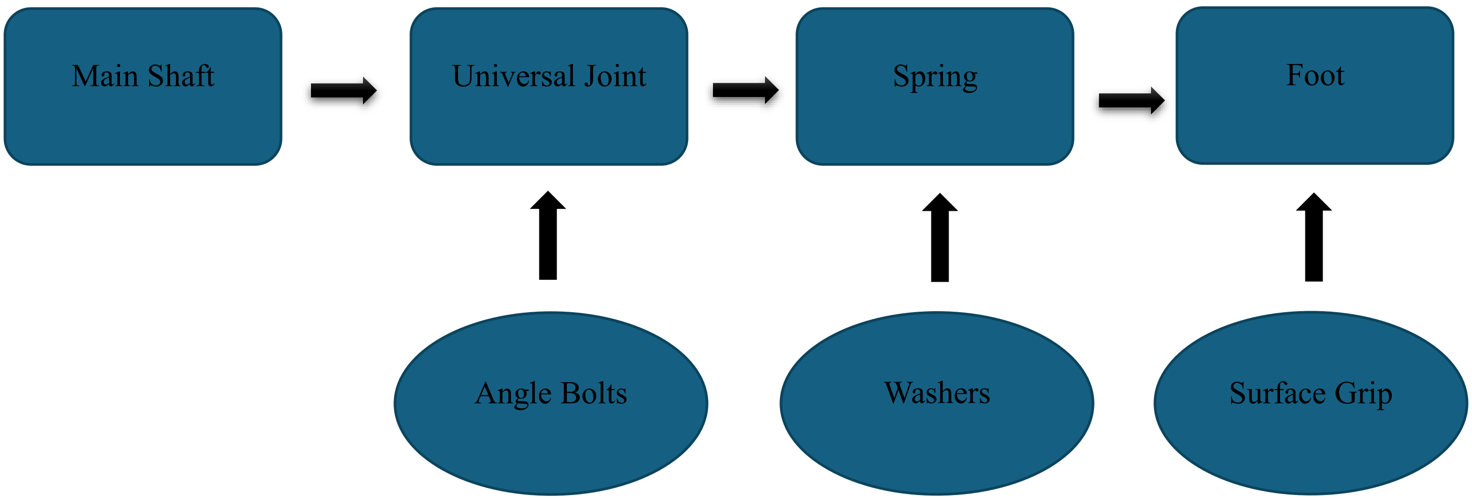


✓ In this model, the model maintains balance by using rubber mounts to absorb shocks to the sole of the foot and to build the mechanism of the heel. The use of four rubber mounts reduces the weight and makes it very comfortable for the user to use. Compared to other designs, this product is very cost-effective. Also, maintenance can be done only by replacing the four rubber mounts used.



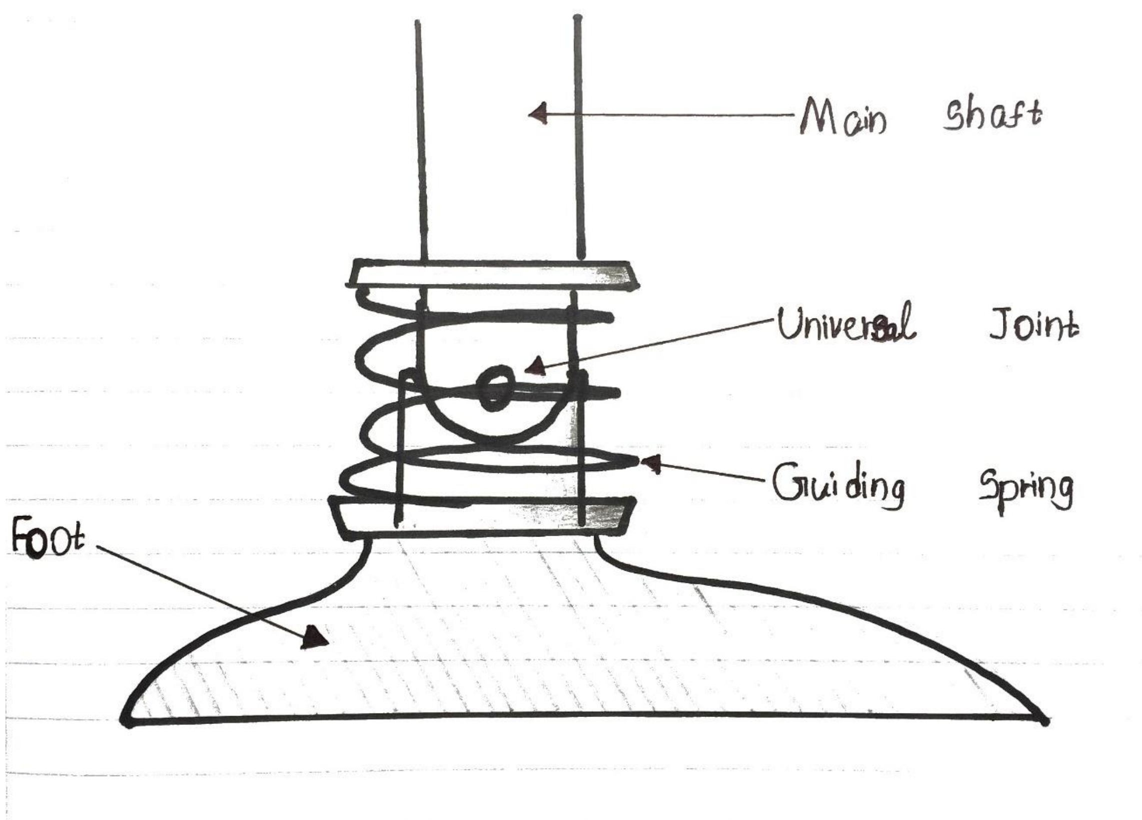
Main Shaft
Basement for 4 directions
Foot
Rubber Mounts

3.1.2 Design Concept 02 – "Universal Jointed Foot"

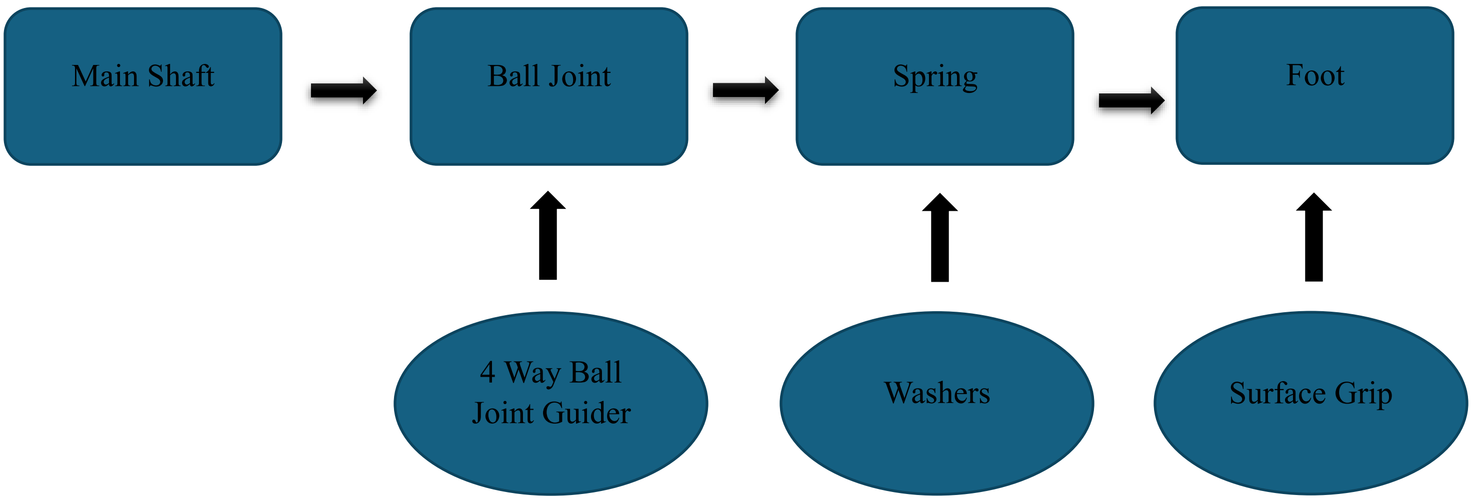


- ✓ By using a universal joint in this model, the ball-and-socket mechanism is built, and the required angles of motion can be created in the four required directions of motion compared to the first model. The spring used to center the U-joint allows for smoother reaction movements in all four directions. The weight of this design is higher than that of other designs. The only maintenance that can be done here is to replace the springs used to center the U-joint due to the loss of tension.


ROME-VA


Main shaft
Universal Joint
Guiding Spring
Foot

3.1.3 Design Concept 03 – “Ball Jointed Foot”



- ✓ By using a universal joint in this model, the ball-and-socket mechanism is built, and the required angles of motion can be created in the four required directions of motion compared to the first model. The spring used to center the U-joint allows for smoother reaction movements in all four directions. The weight of this design is higher than that of other designs. The only maintenance that can be done here is to replace the springs used to center the U-joint due to the loss of tension.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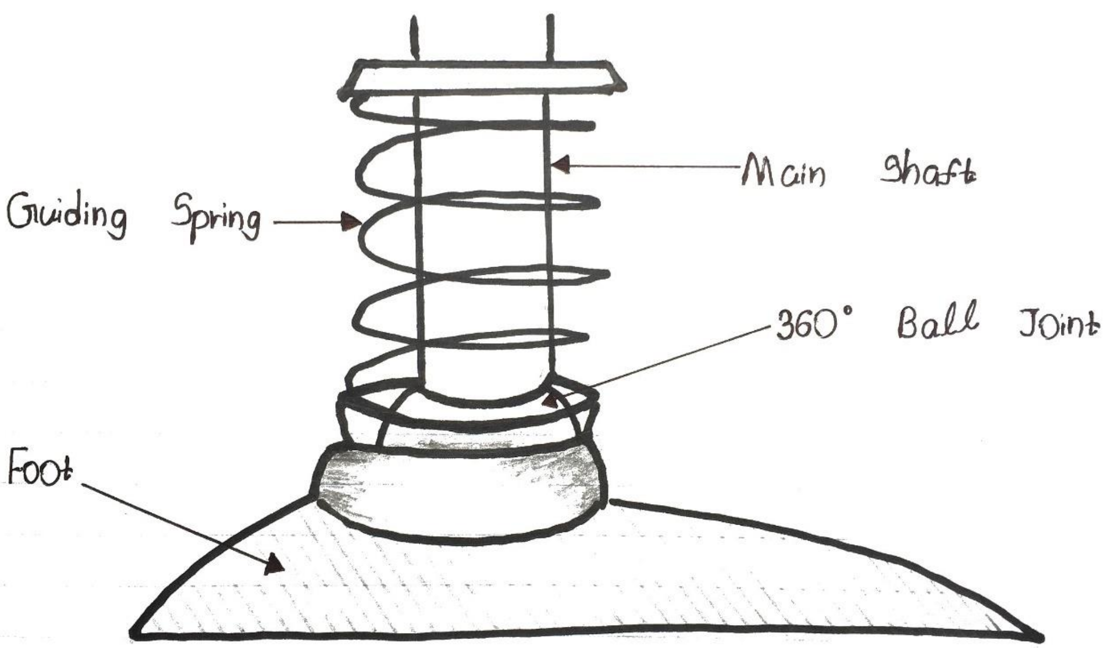

Main Shaft
Guiding Spring
360° Ball Joint
Foot

3.2 Optimum Design Selection and Justification

When selecting the **optimum design** for the prosthetic foot and ankle mechanism, several critical factors were considered, including **multi-directional movement, smoothness of motion, shock absorption, and control over unnecessary movements**. Three primary design concepts were evaluated based on their capabilities, limitations, cost-effectiveness, and overall feasibility for practical implementation.

Concept 01: Basic Multi-Directional Movement with Shock Absorption

This design features **4-directional movability** (dorsiflexion, plantarflexion, inversion, and eversion) and **integrated shock absorption**, ensuring improved comfort and durability. However, one major drawback is that the movement is **not entirely smooth**, which could affect the user's walking experience, especially on uneven terrain. Despite this limitation, this concept remains a **low-cost** option, making it a viable solution for affordability-focused designs. The total evaluation score for this design is **7/10**, primarily due to its **cost-effectiveness and basic functional reliability**, though its lack of smooth motion reduces its overall effectiveness.

Concept 02: Enhanced Multi-Directional Movement with Improved Smoothness

This concept retains the **4-directional movability** seen in Concept 01 but introduces **greater flexibility and a smoother range of motion**, significantly enhancing the walking experience. However, it **lacks an integrated shock absorption method**, requiring additional components to address impact forces. This increases the design complexity but allows for customization based on user preferences and terrain conditions. The cost remains **moderate**, striking a balance between affordability and functionality. With **a total evaluation score of 9/10**, this design is an **excellent choice for users prioritizing smooth movement and comfort** but requires the addition of a separate shock absorption mechanism.

Concept 03: 360° Multi-Directional Movement with Full Adaptability

This design expands upon the **4-directional movement capability** by introducing a **360-degree range of motion**, offering the most natural and adaptable foot movement among all concepts. While this provides an unparalleled level of flexibility, it also presents **challenges in controlling unnecessary movements**, which could lead to instability or unwanted motion. Therefore, a **guiding mechanism** must be integrated to restrict excessive movement in undesired directions. Additionally, **a separate shock absorption system** is needed to enhance user comfort and reduce stress on the prosthetic components. The cost is **moderate**, like Concept 02, due to the additional complexity in controlling movement. With **a total evaluation score of 8/10**, this design offers the highest flexibility but requires precise motion regulation to prevent instability.

Final Design Justification

Among the three concepts, **Concept 02** emerges as the **most optimal choice** due to its **balanced combination of smooth movement, controlled multi-directional flexibility, and cost-effectiveness**. While it requires an added **shock absorption method**, this can be addressed through **rubber mounts** or other damping mechanisms without significantly increasing cost or complexity. Concept 03, while offering the most flexibility, introduces challenges in **motion control**, making it less practical without additional guiding mechanisms. Concept 01, though cost-effective, falls short in **motion smoothness**, which is crucial for a **comfortable and natural walking experience**.

By selecting **Concept 02**, the final design ensures that the prosthetic **provides natural movement, stability, and comfort while remaining within a reasonable cost range**.

CHAPTER 04 - Design and Implementation

4.1 Main Project Concept

By using a universal joint make the moving ability of a prosthetic foot is the main concept of this project. And need to add a shock absorption method for this foot.

Main parts of the foot,

4.1.1 Universal Joint – To Create 4 Directions

A universal joint is a mechanical component capable of movement in multiple directions. These joints are necessary when creating this artificial limb because they allow controlled movement in four directions and provide flexible functionality like a natural ankle.

- ✓ Dorsiflexion (foot moves upward).
- ✓ Plantarflexion (foot moves downward).
- ✓ Inversion (foot tilts inward).
- ✓ Eversion (foot tilts outward).

This design can mimic the natural movement of the ankle and is more comfortable and stable for walking on different surfaces. Unlike a straight prosthetic leg, the use of a U-joint allows for adaptation to uneven terrain and different walking styles. Moreover, since the U-joint has a free axis of rotation, it can control and limit unwanted movement. Otherwise, it can cause instability or discomfort for the user.

4.1.2 Guided Spring – To Control Movements in Directions

The compression spring combines with the U-joint to control movement and direction, providing stability and comfort. The heel controls the necessary movements by providing resistance. It returns to its original position after the movement is completed and does not allow the user to feel discomfort. It absorbs some of the necessary energy during walking, making the movement smoother and more natural. It can be adjusted, allowing the stiffness of the foot to be fine-tuned.

- ✓ The user's weight (in case, 80 kg).
- ✓ The user's walking style (some people may prefer a firmer or softer response).
- ✓ The terrain the user frequently walks on (a person walking on rough terrain might need more resistance).

Springs are installed inside or outside the U-joint to stabilize it. The foot can move in different directions during operation. Therefore, it is essential to see that equal support is provided in all directions. The compression should also be uniform.

4.1.3 Rubber Mount – To Absorb Linear Shocks

Walking involves a variety of impact forces that occur when the ankle hits the ground. Rubber is used as a shock absorber to reduce excessive stress on prosthetic components and increase comfort. Therefore,

- ✓ Reduces stress on joints and other artificial parts.
- ✓ Smooths out vibrations and increases user comfort by relieving sudden shocks.
- ✓ It increases the lifespan of the prosthetic leg by minimizing wear on mechanical parts.
- ✓ Improves balance by preventing excessive bouncing or uncontrolled movements.

Rubber mounts are typically manufactured from compounds containing silicone, polyurethane, or rubber, which can handle compression and expansion.

4.1.4 Foot – To Fill the Actual Foot Space and Contact the Floor

The outer foot shell is a very important component of prosthetic design, providing both aesthetic and functional services. That is,

- ✓ By providing the correct shape and size of a human foot, the artificial foot can be made to look like a natural foot. This allows for proper weight distribution during natural walking and standing.
- ✓ Helps create proper contact with the ground, thereby distributing movement and pressure naturally.
- ✓ Made from foam, thermoplastic or carbon fiber composites for comfort and durability.

Some designs can be made with a slightly flexible foot shell to absorb shock and increase walking efficiency.

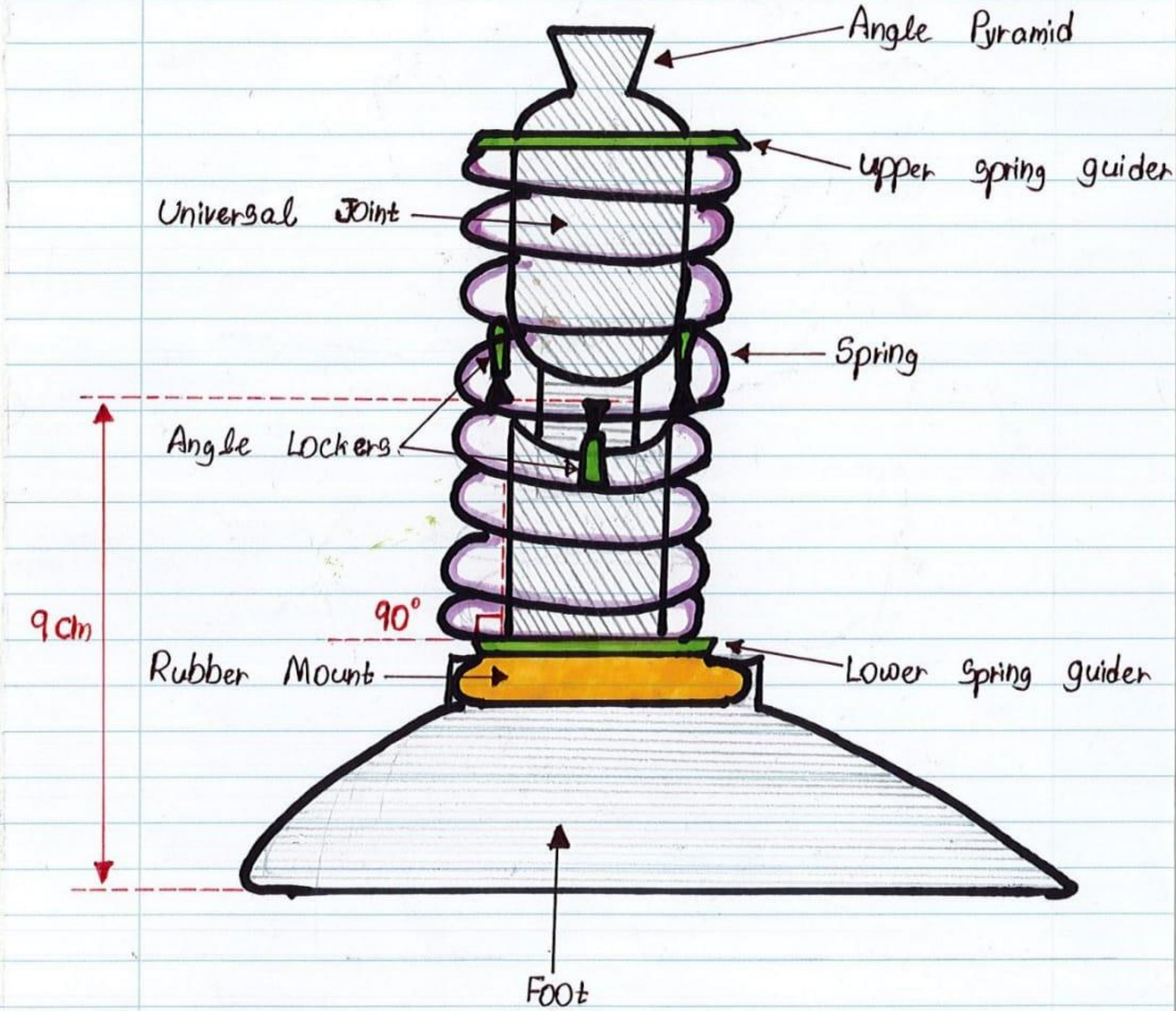
4.1.5 How These Components Work Together

All these elements together provide the prosthetic leg with the necessary movements. The u joint moves in different directions and the ligaments maintain flexibility. This controls and limits the movements to the required extent. It also ensures balance. The rubber mount absorbs shocks while walking and controls the tension between the foot and the user. The foot shell provides the necessary shape, contact, and weight distribution to provide comfort and natural movement. All these units work together to provide the most comfortable and adaptable functionality, allowing for better mobility and minimizing user stress.

No :

Date: 06/02/2025

Adjustable Mechanical Foot Design

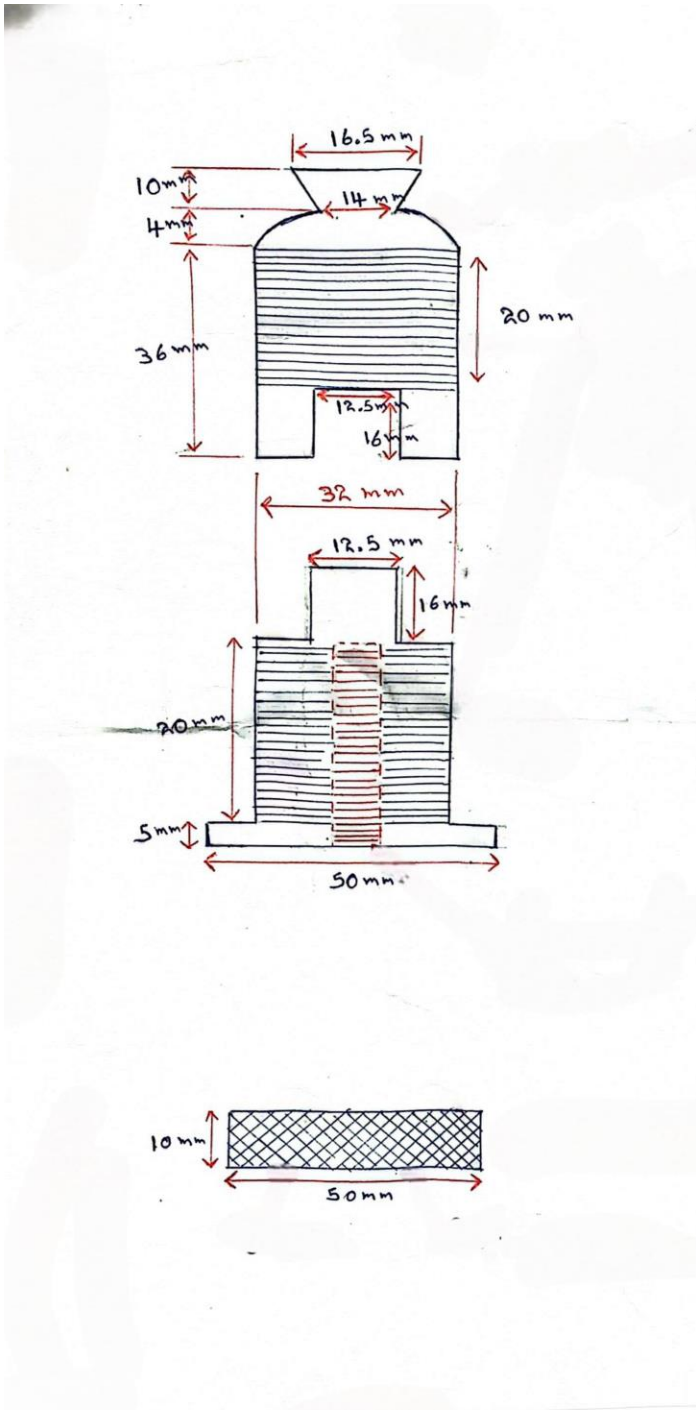


- Guiders
- Angular Suspension
- Linear Suspension

4.2 Material Selection

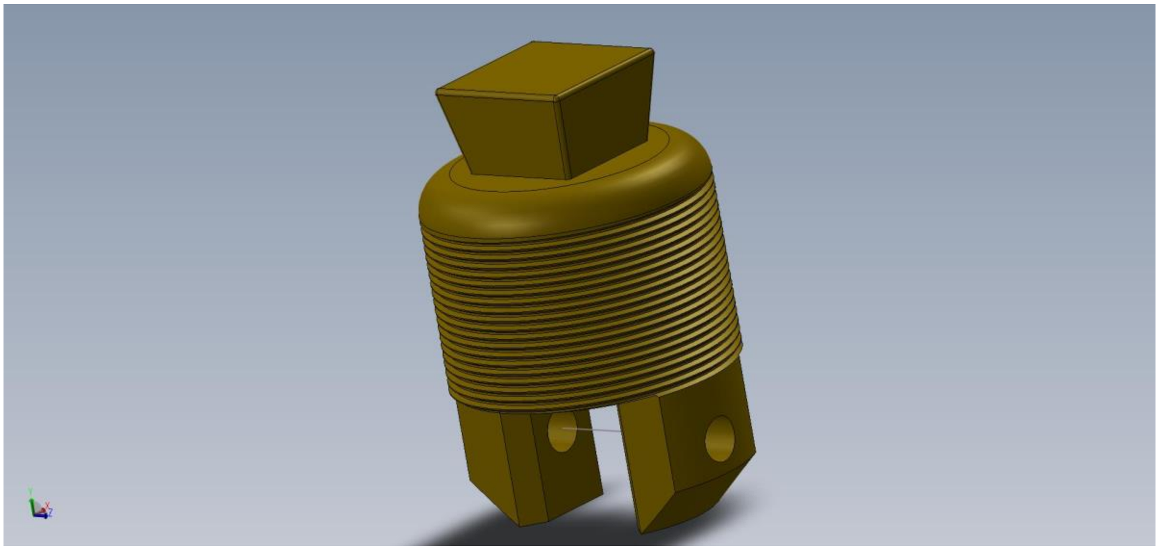
Parts	Simulated Material	Uased Material	Reason
Complete Universal Joint	Titanium	Carbon Steel	**High wear resistance**, ensuring longevity. **Superior hardness**, preventing deformation under load. More cost-effective than titanium while maintaining strength.
Universal Joint Connecting Pin	Stainless Steel	Stainless Steel	**Corrosion resistance**, preventing rust over time. **High toughness**, reducing the risk of fracture. Sufficient hardness to withstand mechanical stress.
Spring	Titanium	Stainless Steel	**Lightweight**, reducing overall prosthetic weight. **High elasticity**, ensuring consistent performance. Durable and cost-effective compared to titanium.
Rubber Mount	Rubber	Rubber	**Superior shock absorption**, reducing impact forces. **High durability**, capable of withstanding repeated compression. Provides comfort and stability for the user.
Foot	Teak	Teak	**Natural aesthetic**, resembling a human foot. **High durability and impact resistance**. Can be shaped and customized easily.

4.3 Software Implementation



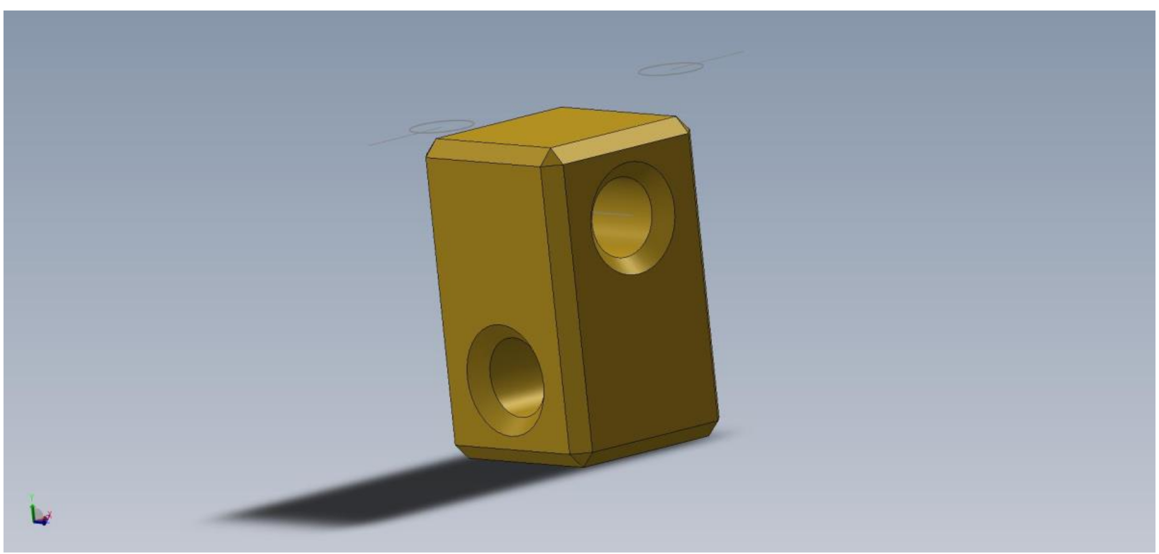
❖ For design and simulation this prosthetic foot functionality we used the software 'SOLIDWORKS'.

4.3.1 Universal Joint (Upper)



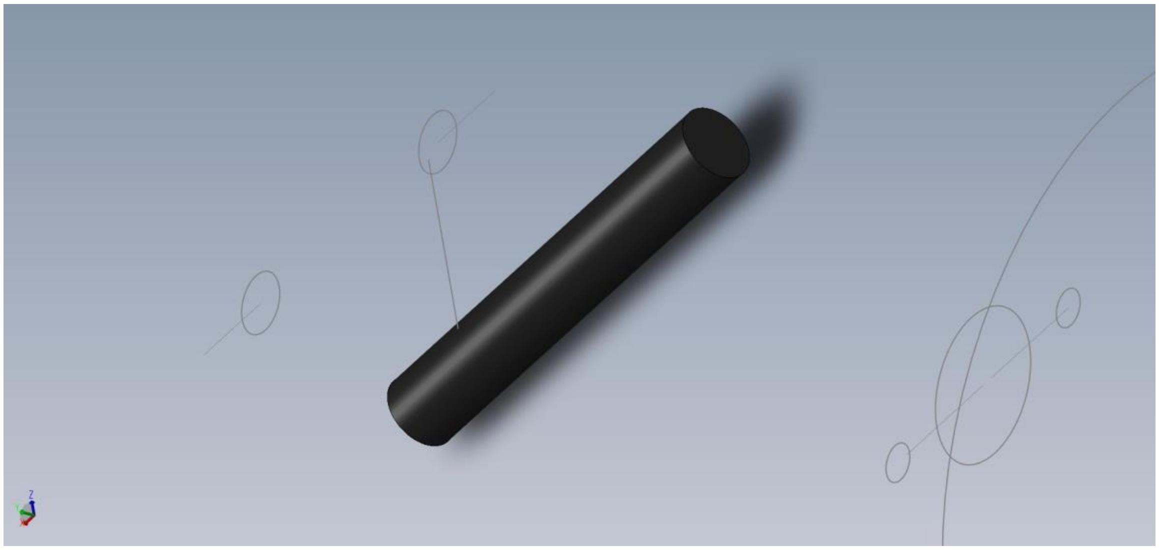
- ✓ This is the upper part of the universal joint and helps to set the fixed adjustment of the ankle.

4.3.2 Center Joint (Cube)



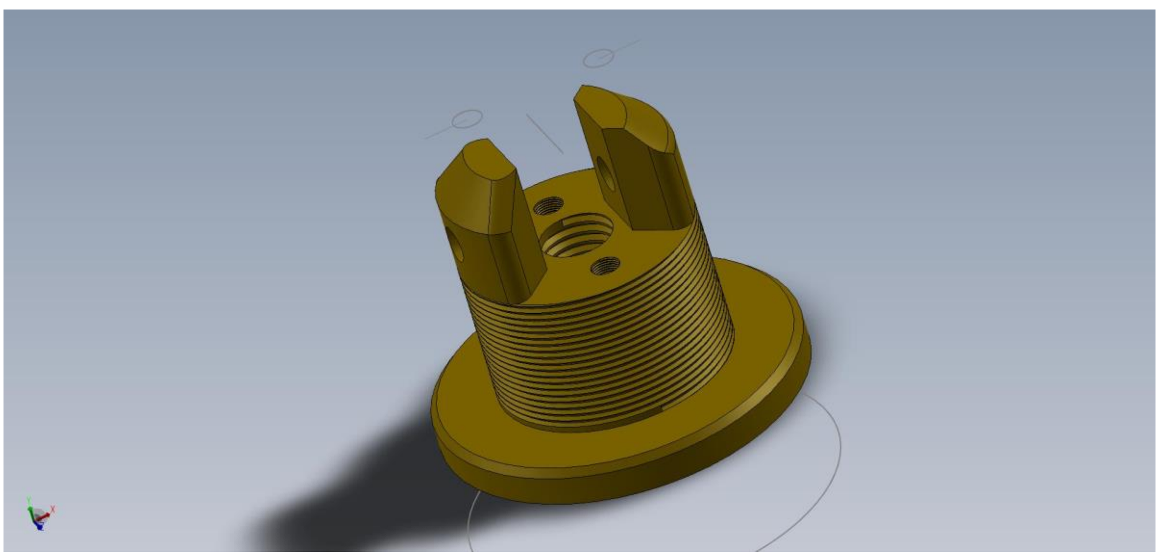
- ✓ Using this part, the upper and lower parts of the universal joint are assembled using two pins.

4.3.3 Pins (Cube)



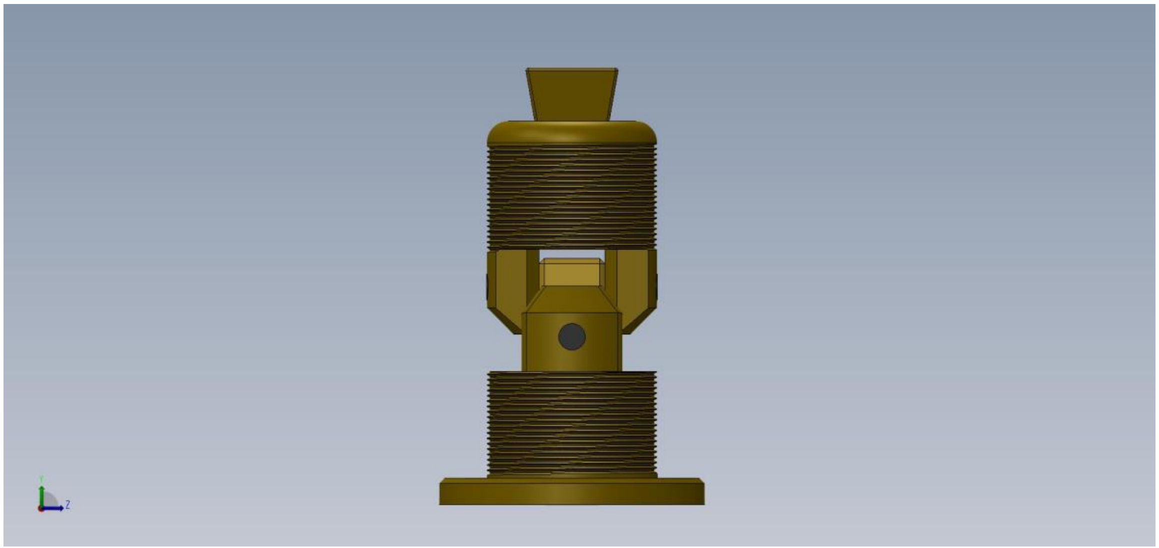
- ✓ This is the pin that connects the center joint to the upper and lower parts of the universal joint. There are two such pins.

4.3.4 Universal Joint (Lower)



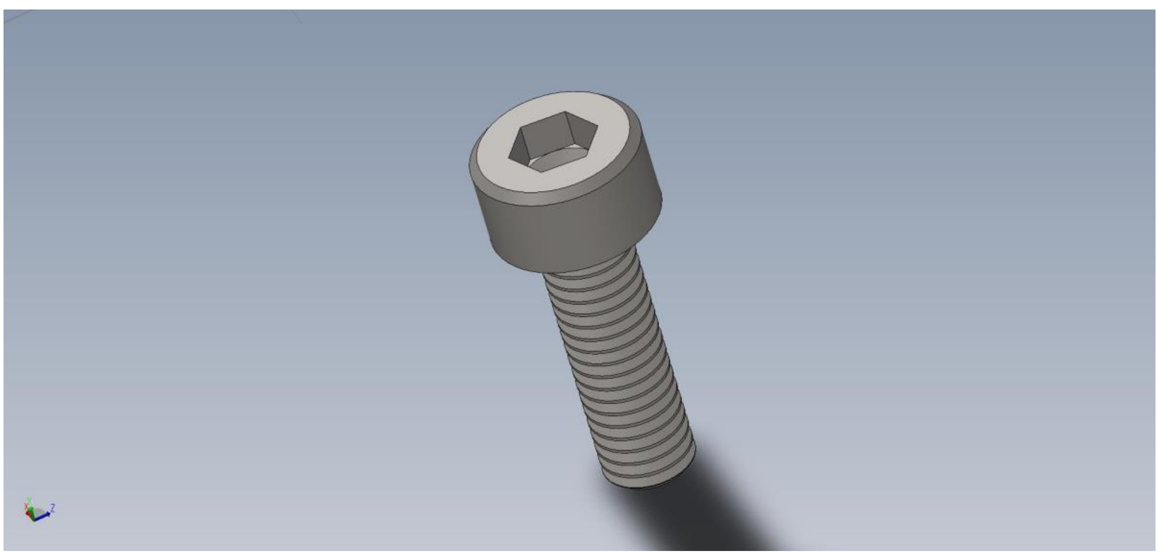
- ✓ This is the bottom part of the U-joint and is also the foundation of the U-joint. It connects to the foot via a rubber mount.

4.3.5 Universal Joint (Assembled)



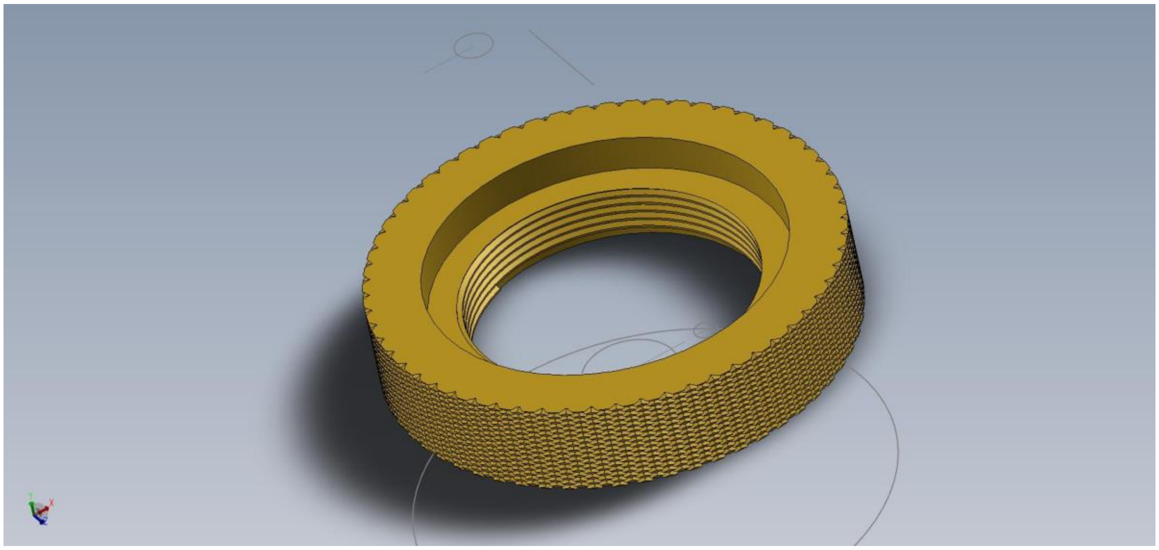
- ✓ This assembly is obtained when the two pins, the center joint, the upper part of the U-joint, and the lower part of the U-joint are assembled.

4.3.6 Socket Head cap Screw (Angle Adjustments/Lockers)



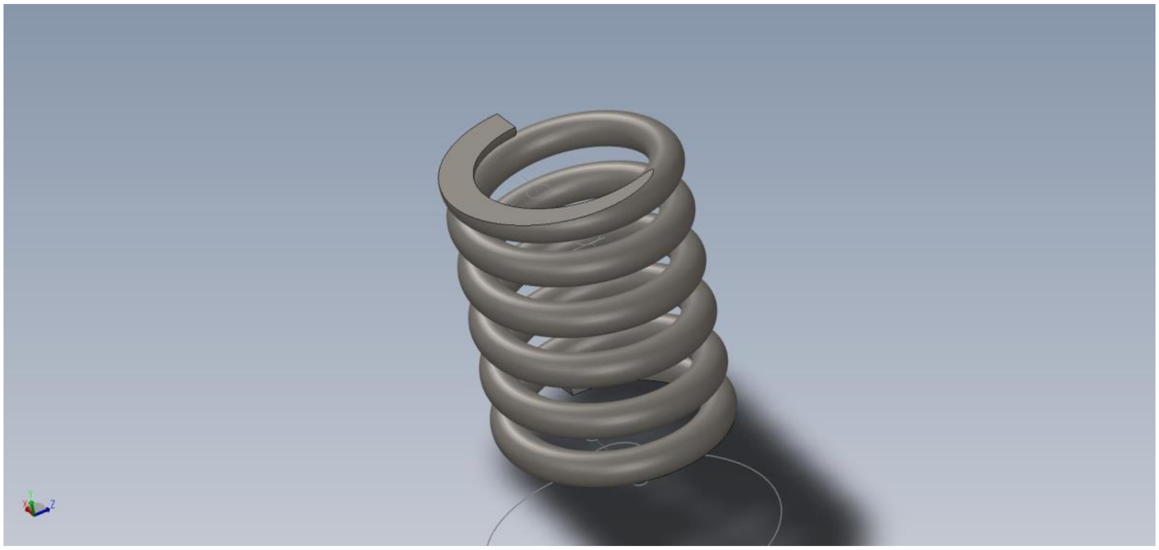
- ✓ This adjusts the angles for dorsiflexion, plantarflexion, inversion, and eversion.

4.3.7 Washers / Spring Guiders



- ✓ This part is used to connect and tension the spring used in the U-joint.

4.3.8 Spring



- ✓ The spring guides the U-joint and provides a corresponding reaction to every motion the foot make.

4.3.8.1 Spring Calculations

Spring Constant formula,

$$F = Kx$$

$$K = \frac{F}{x}$$

$$= \frac{80 \times 9.81}{2} \div 0.01$$

$$= 39\,200\ Nm^{-1}$$

$$F = \frac{80 \times 9.81}{2} \approx 392\ N$$

(80 kg = weight of the Person)

Spring design formula

$$K = \frac{Gd^4}{8D_m^3 N}$$

- Spring stiffness (K) = 39 200 Nm^{-1} (for one leg)
- Shear modulas (G) = 77 GPa = 77×10^9 Pa (for SS)
- Inner diameter (D_i) = 35 mm (According to the diameter of universal joint)
- Total height (H) = 57 mm (According to the height of universal joint)
- Pitch gap = 10 mm

$$\text{Active Coils (N)} = \frac{H}{\text{Pitch gap}} = \frac{57}{10} = 5.7 \approx 5$$

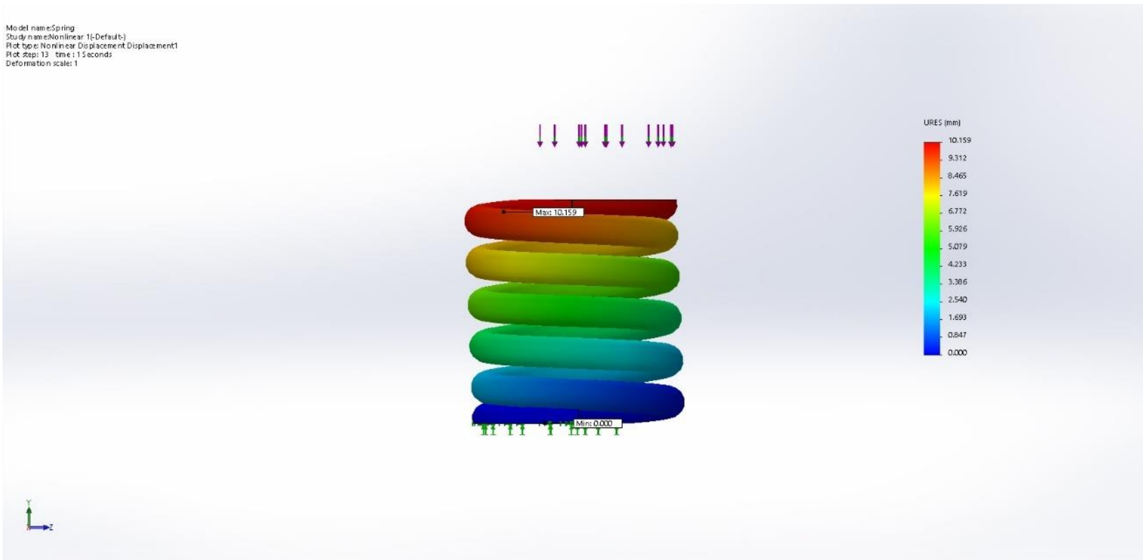
Mean coil diameter (D_m) = $D_i + d$ (Numerical calculation)

$$= 35 + d$$

$$d^4 = \frac{8K\,D_m^3\,N}{G}$$

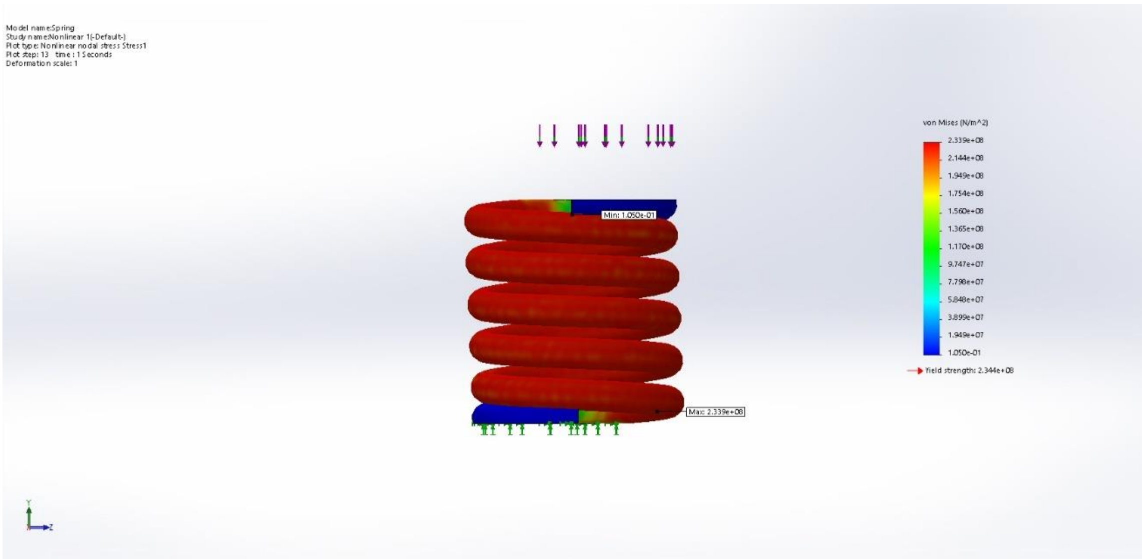
$$d = 6.37\ mm$$

4.3.8.2 Displacement Simulation of the Spring

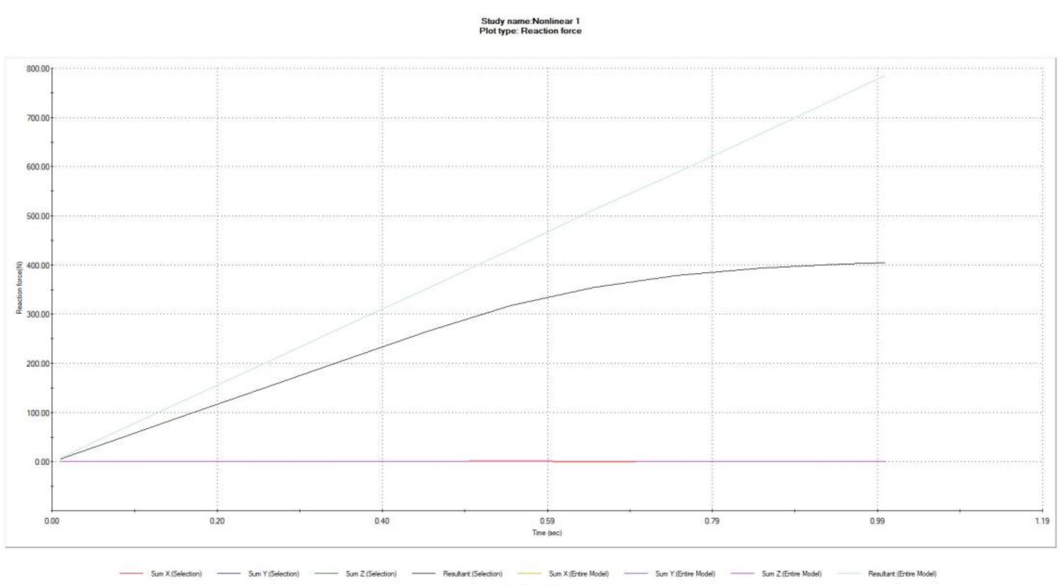


4.3.8.3 Strain Simulation of the Spring

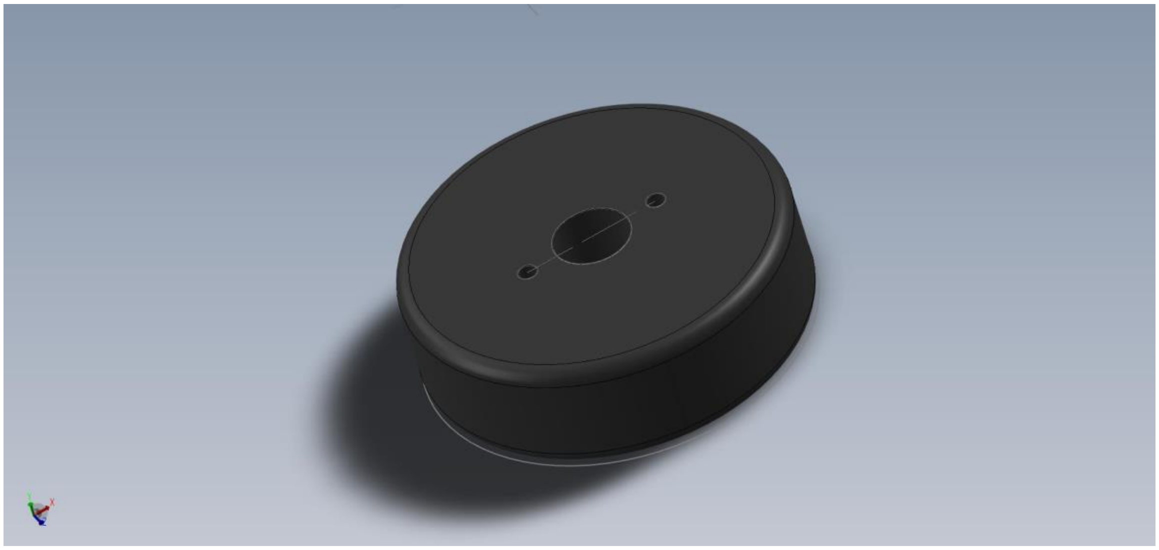
4.3.8.4 Stress Simulation of the Spring



4.3.8.5 Reaction Force Vs Time of the Spring



4.3.9 Rubber Mount

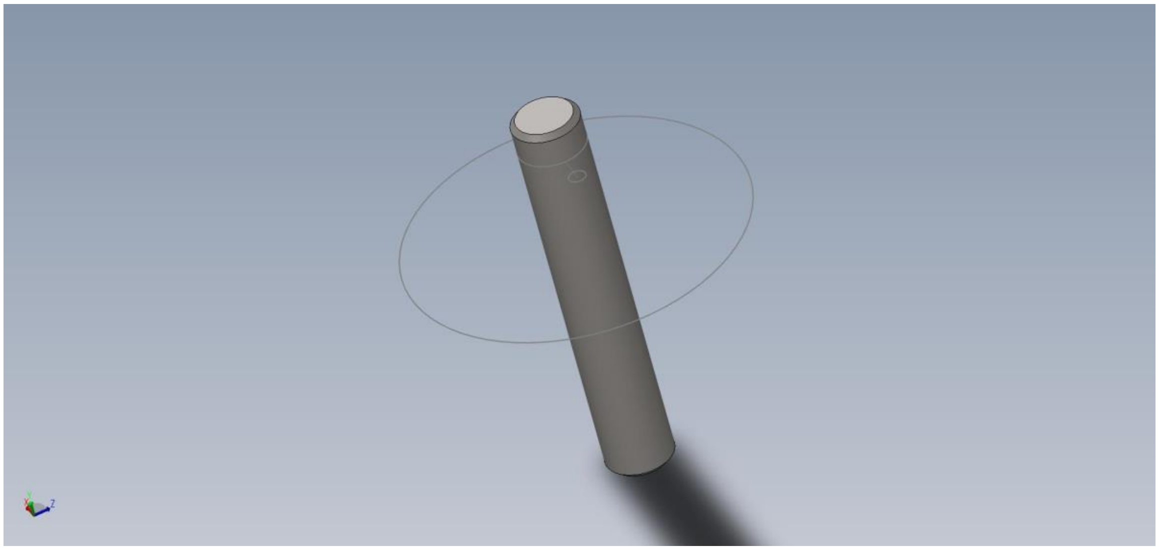


- ✓ This absorbs the linear shocks that occur during walking. It is located between the bottom of the U-joint and the foot.

4.3.10 Foot

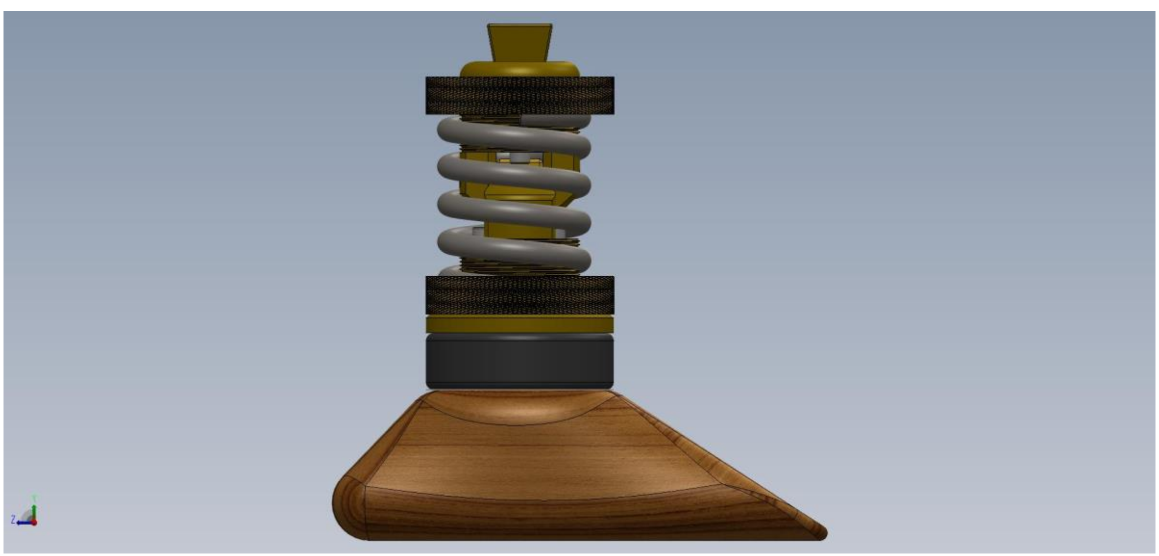
- ✓ This part provides the fill that matches the shape of the actual foot and helps the assembled foot contact with the ground.

4.3.11 Main Pin (Foot)

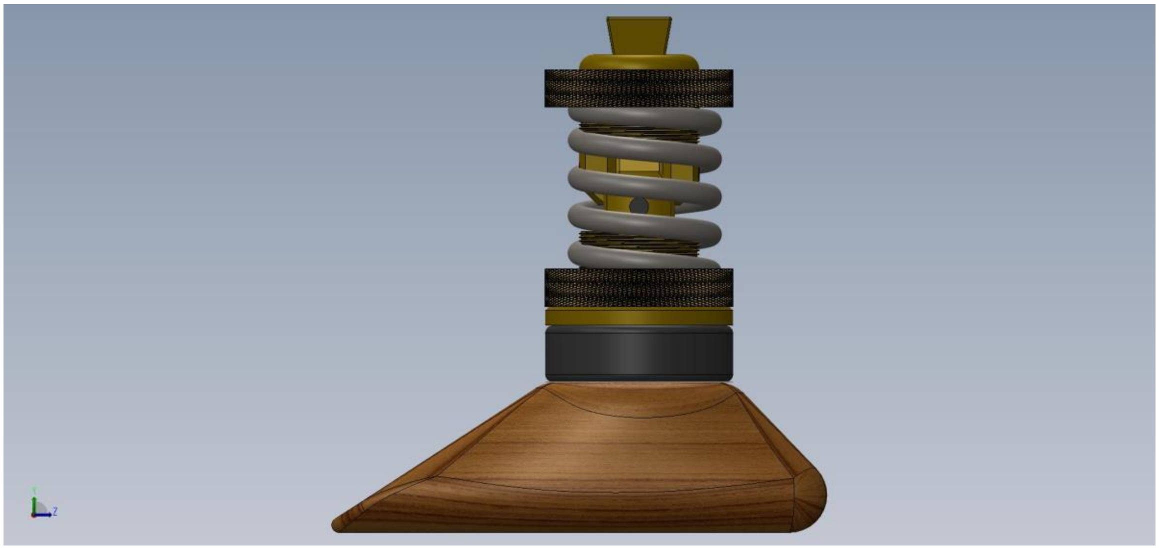


- ✓ This main pin connects the foot to the rubber mount and the bottom of the u joint.

4.3.12 Assembled Prosthetic Foot (Side – Left)



4.3.13 Assembled Prosthetic Foot (Side – Right)



4.3.14 Assembled Prosthetic Foot (Top)

4.3.15 Assembled Prosthetic Foot (Bottom)

4.3.16 Assembled Prosthetic Foot (3D)

4.4 Hardware Implementation

4.4.1 Universal Joint (Lower)

4.4.2 Universal Joint (Upper)

4.4.3 Spring

4.4.4 Spring Guiders (Washers)

4.4.5 Rubber Mount

4.4.6 Foot

4.4.7 Rubber Mount Holing

4.4.8 Foot Holing

4.4.9 All Parts

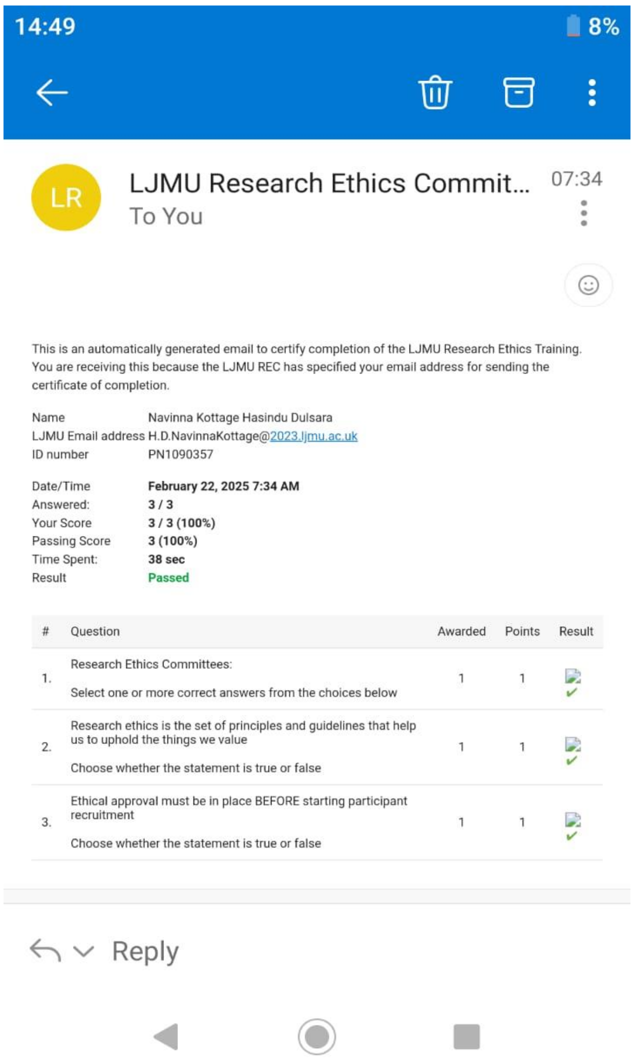
4.4.10 Final Foot Assembling

4.5 Cost Analysis

<table>
<tr><th>Purpose</th><th>Cost</th></tr>
<tr><td>Materials</td><td>Carbon Steel = Rs.1,700.00
Stainless Steel (Spring) = Rs.2,400.00
Rubber Mounts = Rs.300.00
Teak = Rs.800.00</td></tr>
<tr><td>Labour Costs</td><td>Lathe = Rs.7,500.00
Assembling = = Rs.10,000.00</td></tr>
<tr><td colspan="2">Total Cost = Rs.22,900.00</td></tr>
</table>

CHAPTER 05 – Testing and Analyzing

5.1 Ethical Guidelines (LJMU)



14:49 8%

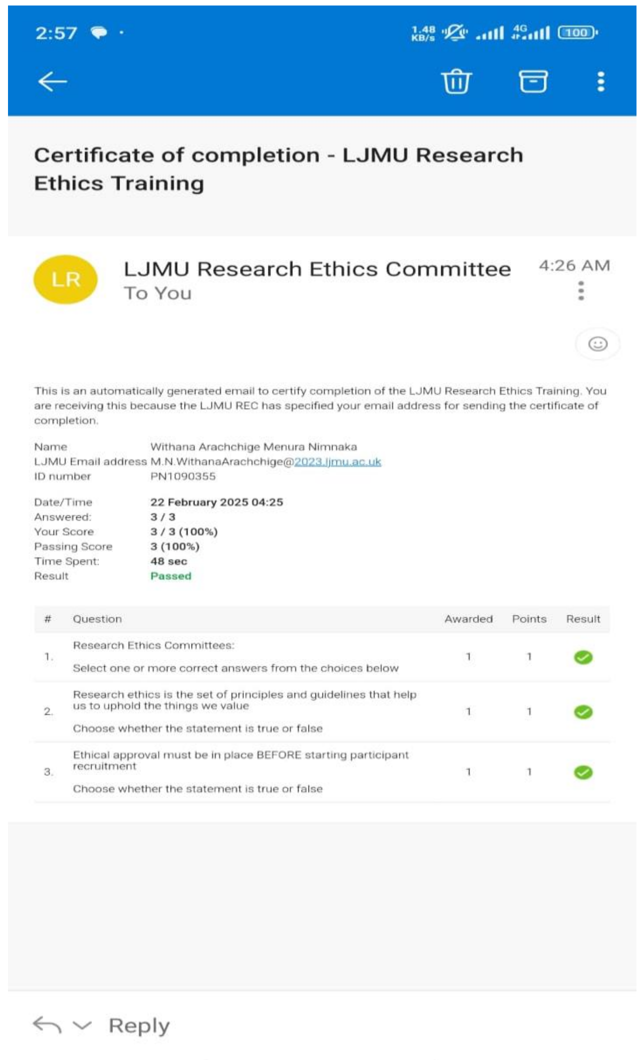
LR LJMU Research Ethics Commit... 07:34
To You

This is an automatically generated email to certify completion of the LJMU Research Ethics Training. You are receiving this because the LJMU REC has specified your email address for sending the certificate of completion.

Name	Navinna Kottage Hasindu Dulsara
LJMU Email address	H.D.NavinnaKottage@2023.ljmu.ac.uk
ID number	PN1090357
Date/Time	**February 22, 2025 7:34 AM**
Answered:	**3 / 3**
Your Score	**3 / 3 (100%)**
Passing Score	**3 (100%)**
Time Spent:	**38 sec**
Result	**Passed**

#	Question	Awarded	Points	Result
1.	Research Ethics Committees: Select one or more correct answers from the choices below	1	1	✔
2.	Research ethics is the set of principles and guidelines that help us to uphold the things we value. Choose whether the statement is true or false	1	1	✔
3.	Ethical approval must be in place BEFORE starting participant recruitment. Choose whether the statement is true or false	1	1	✔

Reply



2:57

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LR LJMU Research Ethics Committee 4:26 AM
To You

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Name	Withana Arachchige Menura Nimnaka
LJMU Email address	M.N.WithanaArachchige@2023.ljmu.ac.uk
ID number	PN1090355
Date/Time	**22 February 2025 04:25**
Answered:	**3 / 3**
Your Score	**3 / 3 (100%)**
Passing Score	**3 (100%)**
Time Spent:	**48 sec**
Result	**Passed**

#	Question	Awarded	Points	Result
1.	Research Ethics Committees: Select one or more correct answers from the choices below	1	1	✔
2.	Research ethics is the set of principles and guidelines that help us to uphold the things we value. Choose whether the statement is true or false	1	1	✔
3.	Ethical approval must be in place BEFORE starting participant recruitment. Choose whether the statement is true or false	1	1	✔

Reply

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LJMU Research Ethics Committee 04:26
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Name	Rodrigo Mirantha Ashen
LJMU Email address	S.P.Rodrigo@2023.ljmu.ac.uk
ID number	PN1090367

Date/Time	**February 22, 2025 4:25 AM**
Answered:	**3 / 3**
Your Score	**3 / 3 (100%)**
Passing Score	**3 (100%)**
Time Spent:	**2 min 45 sec**
Result	**Passed**

#	Question	Awarded	Points	Result
1.	Research Ethics Committees: Select one or more correct answers from the choices below	1	1	✔
2.	Research ethics is the set of principles and guidelines that help us to uphold the things we value. Choose whether the statement is true or false	1	1	✔
3.	Ethical approval must be in place BEFORE starting participant recruitment. Choose whether the statement is true or false	1	1	✔

11:54 65

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LJMU Research Ethics Committee 08:00
To You

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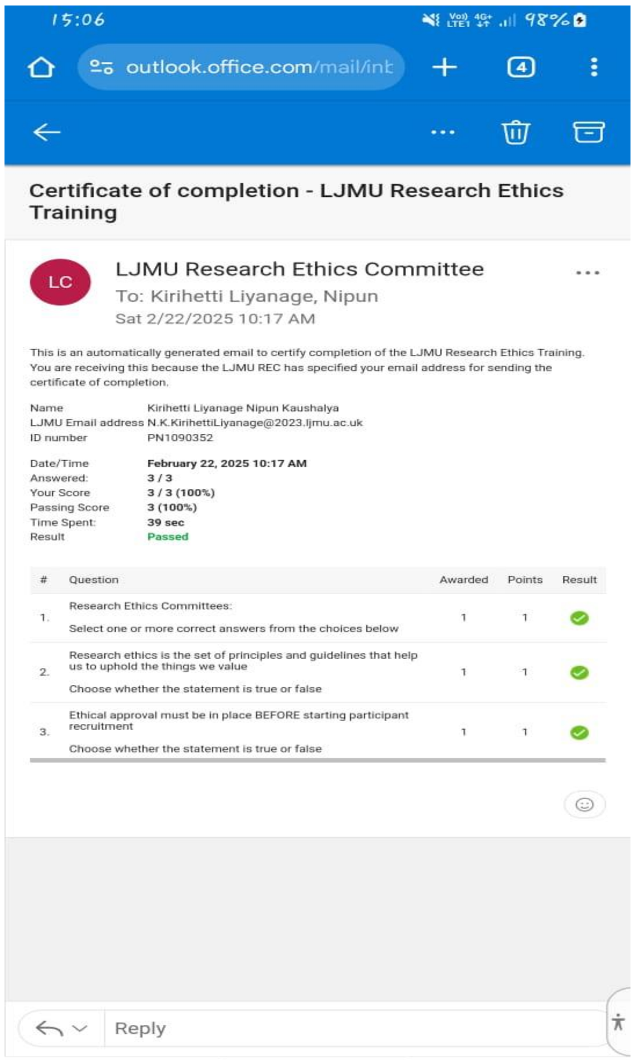
Name	Rankothge Adithya Lakshan
LJMU Email address	A.L.Rankothge@2023.ljmu.ac.uk
ID number	PN1090365

Date/Time	**February 20, 2025 8:00 AM**
Answered:	**3 / 3**
Your Score	**3 / 3 (100%)**
Passing Score	**3 (100%)**
Time Spent:	**6 min 37 sec**
Result	**Passed**

#	Question	Awarded	Points	Result
1.	Research Ethics Committees: Select one or more correct answers from the choices below	1	1	✔
2.	Research ethics is the set of principles and guidelines that help us to uphold the things we value. Choose whether the statement is true or false	1	1	✔
3.	Ethical approval must be in place BEFORE starting participant recruitment. Choose whether the statement is true or false	1	1	✔

Reply

Email | 20 Calendar | Feed | Apps


15:06
98%
outlook.office.com/mail/inb

Certificate of completion - LJMU Research Ethics Training

LC

LJMU Research Ethics Committee
To: Kirihetti Liyanage, Nipun
Sat 2/22/2025 10:17 AM

This is an automatically generated email to certify completion of the LJMU Research Ethics Training. You are receiving this because the LJMU REC has specified your email address for sending the certificate of completion.

Name	Kirihetti Liyanage Nipun Kaushalya
LJMU Email address	N.K.KirihettiLiyanage@2023.ljmu.ac.uk
ID number	PN1090352

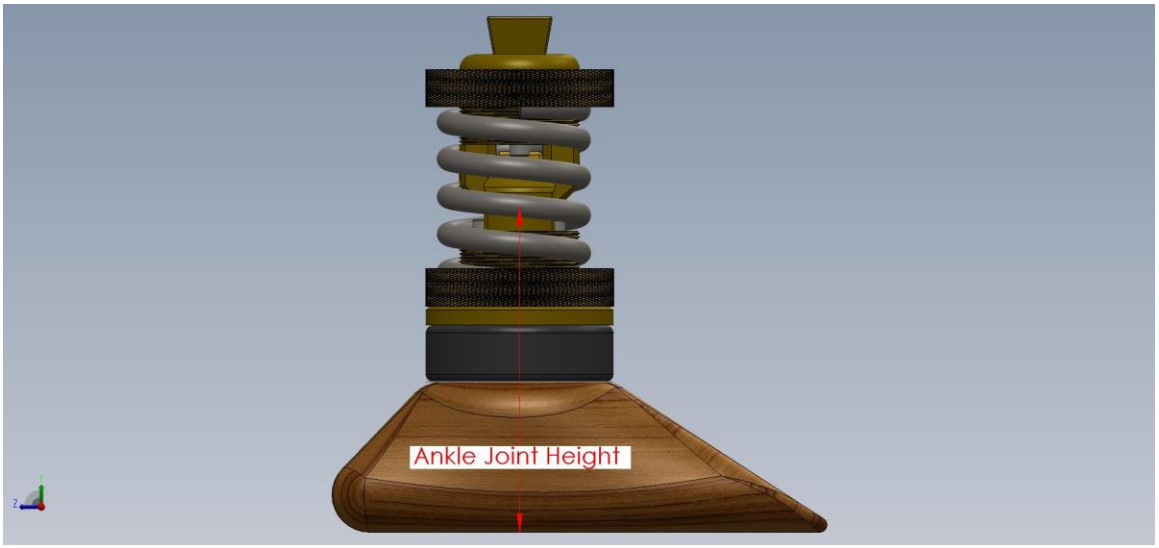
Date/Time	**February 22, 2025 10:17 AM**
Answered:	**3 / 3**
Your Score	**3 / 3 (100%)**
Passing Score	**3 (100%)**
Time Spent:	**39 sec**
Result	**Passed**

#	Question	Awarded	Points	Result
1.	Research Ethics Committees: Select one or more correct answers from the choices below	1	1	✓
2.	Research ethics is the set of principles and guidelines that help us to uphold the things we value Choose whether the statement is true or false	1	1	✓
3.	Ethical approval must be in place BEFORE starting participant recruitment Choose whether the statement is true or false	1	1	✓

Reply

5.2 Test Results

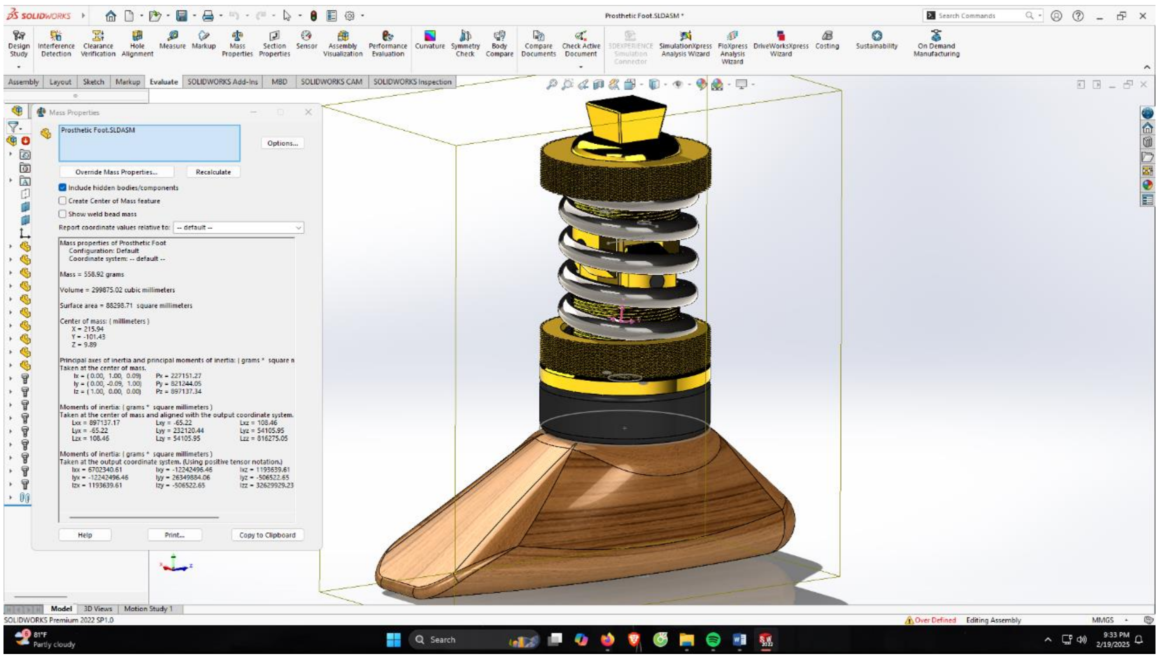
5.2.1 Ankle Motion



To simulate and evaluate the **ankle motion**, we established the **center point of the ankle joint** as the center of a theoretical cube that represents the area where the prosthetic ankle operates. The **height of the cube from the floor level** corresponds to the **ankle joint height**, which varies depending on the user's specific measurements and the alignment of the prosthetic with the active leg. This design allows for customization based on the user's leg anatomy, as the height and position of the ankle joint are influenced by the individual's **unique body mechanics**.

The angle of motion for each direction - **dorsiflexion, plantarflexion, inversion, and eversion** - is controlled by the integrated **universal joint**, which facilitates natural movement. The motion range, precision, and adaptability to different surfaces are key aspects that determine the comfort and usability of the prosthetic.

5.2.2 Total Mass



The total mass of the prosthetic foot was calculated using **SolidWorks**, which provided an initial estimate of **558.92 grams**. This mass is essential for understanding the overall weight of the prosthetic, as it impacts the **comfort** and **mobility** of the user. A lighter prosthetic is generally preferred as it allows for **easier movement** and **less strain** on the user's residual limb.

However, due to the decision (because of high cost) to use **carbon steel** for the universal joint instead of the originally planned **titanium**, the total mass of the final design was increased. The actual weight of the hardware design, including all components made with carbon steel, is **2.30 kilograms** higher than the initial estimate.

5.3 Analyzing

During testing, the prosthetic ankle and foot mechanism encountered challenges in maintaining **stability under load**. The primary issue stemmed from the **angular torque exerted by the universal joint and the compression spring**, which prevented the system from effectively supporting the user's weight. The intention was for the spring to absorb and regulate movement while ensuring a **stable stance**, but in practice, it failed to resist the torque forces adequately. This instability was particularly evident during **standing and walking**, where the prosthetic exhibited unexpected shifts in orientation. Additionally, the lack of a precise **guiding mechanism** for the joint allowed for **uncontrolled movements**, further reducing overall stability. These issues indicated that the current design requires modifications to improve **weight distribution, movement control** for a more functional and comfortable experience.

CHAPTER 06 – Conclusion and Further Developments

6.1 Further Developments

To address the **instability and uncontrolled movement** observed in testing, several design improvements are necessary. First, the **spring mechanism needs to be optimized** to provide better **load-bearing capacity** and **angular torque resistance**. A **progressive spring system** or an **adjustable tension mechanism** could offer more **customized support**, allowing users to **fine-tune the stiffness** based on their body weight and activity level. Additionally, incorporating **dampers or guiding rails** alongside the universal joint can help **control rotational movements** and **prevent excessive motion** in unintended directions.

Material selection is another crucial factor in **enhancing durability while reducing weight**. Future iterations could explore **titanium alloys** or **composite materials** to achieve a **lighter and more efficient structure** without compromising strength. Moreover, refining the **rubber mounts** with **multi-layered shock-absorbing materials** can significantly **reduce impact stress** and improve **user comfort**. An **interchangeable sole system** can further enhance adaptability, allowing users to select different **grip levels** based on their daily activities. These refinements will ensure that the prosthetic remains **functional, cost-effective, and user-friendly**, making it a **viable solution for amputees seeking enhanced mobility**.

6.2 Conclusion

Overall, the entire project was not able to achieve the expected range of motion from the prosthetic leg due to the mechanical failure in the prosthetic leg, making it difficult to perform the required leg movements.

Furthermore, the prosthetic leg, which was created using elements rather than hypothetical elements, was not in the standard weight range that a prosthetic leg should have, which was also a reason why the prosthetic leg did not achieve the expected weight ranges.

Therefore, it was not possible to use the prosthetic leg we made on a person who had lost a leg because it was too risky. Thus, in the end, it appears that this project has failed. But it also helped us learn about many things we need to know when creating prosthetic legs like this. And may be will help that research persons who are going to design a prosthetic foot like this.

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Appendices

Spring constant

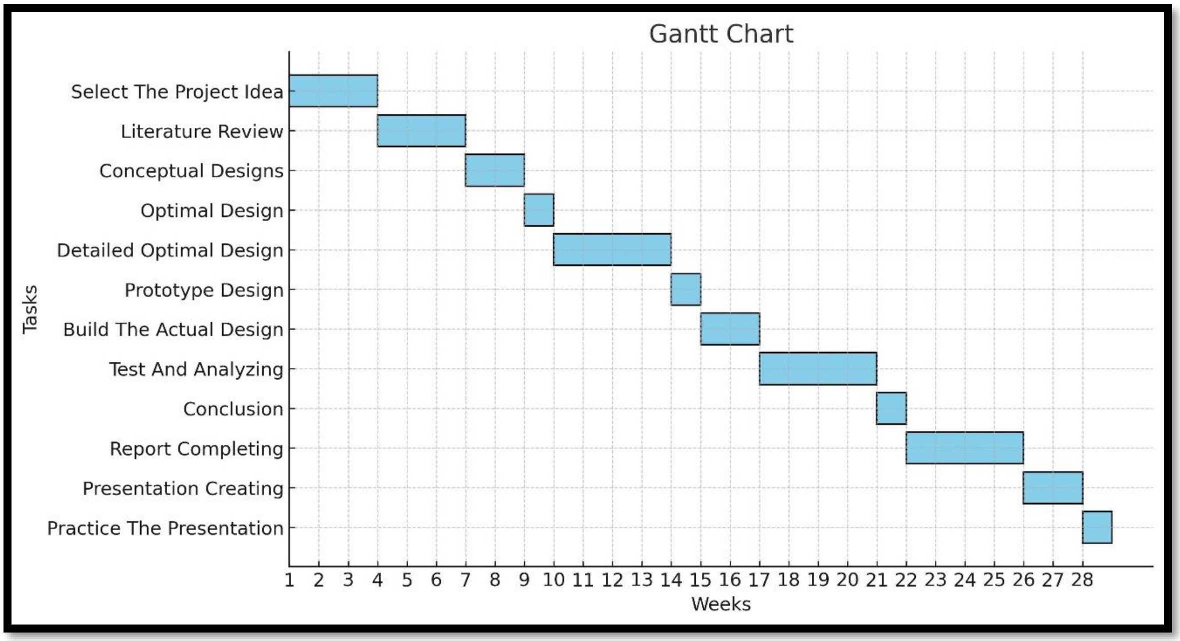
The force applied to the spring

$$k = \frac{F}{x}$$

Distance the spring is compressed or stretched away from its equilibrium

$$k = \frac{d^4 G}{8 D^3 N}$$

Gantt Chart



Gantt Chart
Select The Project Idea
Literature Review
Conceptual Designs
Optimal Design
Detailed Optimal Design
Prototype Design
Build The Actual Design
Test And Analyzing
Conclusion
Report Completing
Presentation Creating
Practice The Presentation
Tasks
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Weeks

END