International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 10 | Oct 2022 www.irjet.net p-ISSN: 2395-0072

Design & Development of Prosthetic Leg

Abhishek Dixit[1], Sumit Dhage[2], Mahesh Kavre[3]

[1,2]UG Student Mechanical Engineering Department, Terna Engineering College, Navi Mumbai
[3]Assistant Professor Mechanical Engineering Department, Terna Engineering College, Navi Mumbai

---***---

Abstract - *This article aims to design a prosthetic leg prototype that can be used by above knee amputees especially the people who cannot afford to invest in costly and expensive high-end prosthetics. This product can be used to sit, stand and walk comfortably without any backlash or jerk to the user. The size of the product is carefully designed to be an approximate replication of knee joint and has a relatively light weight as compared to its high-end counterparts. The knee mechanism is cast entirely from aluminum & the conical spring used is manufactured using spring steel. The knee joint mechanism has a cap and belt to be tied to the leg of the amputee using a belt and lower end of the knee is connected to the rod which connects the knee end to the ankle. The product is successfully tested and is modelled using Creo 4.0 and analyzed in Ansys Structural. Prosthetics manufacturing has reached great heights in technology and have achieved perfect muscular movement like a biological leg. But maximum people having leg disability cannot afford such high-tech technology for their leg. Our attempt is to achieve a similar movement of a leg at minimum cost and based on this attempt we are considering the manufacturing. The lower middle-class people of the society find it difficult to purchase such prosthetic from private orthopedic centers so we have aimed to make it easier for those people to buy the product. Our low-cost project can also influence other producers to make such low-cost prosthesis and make them believe that it can be possible. This is not just beneficial for the producers but also to the consumers as it lowers the overall cost of such prosthesis due to aggressive competition.*

Key Words: Amputees, Prosthetics, Creo 4.0, Prototype, Ansys Structural, Casting

1.INTRODUCTION

Prosthesis is an artificial device that replaces a lost body part due to unfortunate tragedies, disease or during child birth. If a prosthesis is utilized for upper limb, it is usually known as upper extremity prothesis whereas if the prosthesis is targeted for hips and below it, then it is known as lower extremity prosthesis.

According to the research, there is one huge problem that still stood before all prosthetic users. Due to rapid rise of bio-technology and new age prosthetics, the price of prosthetics grew exponentially. Thus, making it nearly impossible for poor and low-class people from even think about trying the option of prosthetics. The project is specifically designed to target the Indian market as there is a lack of alternatives in this price segment. Thus, instead the market could be diverted to our product which is specifically targeted for those users who cannot opt for high end prosthetics and neither wish to use a wooden cane or crutches [1].

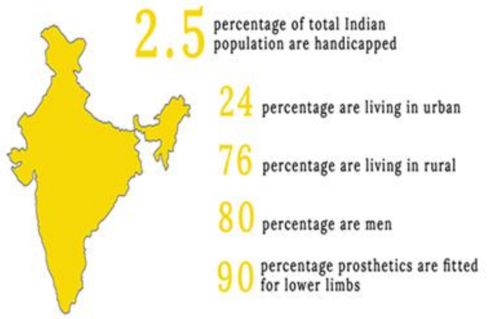

Fig -1: Demographics of Prosthetics Potential

2.METHODOLOGY

The Indian market lacks the cost effective and efficient lower limb prosthetics that can reach the people in need. Most Indians use 'Jaipur Foot' a low-cost Prosthetic maker that makes prosthetics from wood and is usually charges minimal amount with no profit aspect and as a part of NGO. But this alternative is less effective to use as it cannot be used in wet conditions and due to its low durability, it is not appropriate for prosthetics. The Jaipur Foot has no other outlets in India and the client has to go to Jaipur to get themselves for measurement and get its custom prosthetic.

The project has a means to extend the rod to adjust the height of the prosthetic as per the requirement of the user. This eliminates the need of making prosthetic specific to a single user and makes it possible to be mass manufactured. The project also has a special addition to the preexisting prosthetics, during sitting action the user does not require extension of the leg, so the knee mechanism has a locking system has gets activated once the required degrees of rotation is achieved by the knee joint. [2]

To maximize the scope of the project, certain procedures were followed through the project:

1. Market Survey
2. Selection of mechanism & material

3. Design & analysis of Components
4. Assembly & Prototyping

3.DESIGN PROCEDURE

The design procedure is illustrated using the following flowchart:

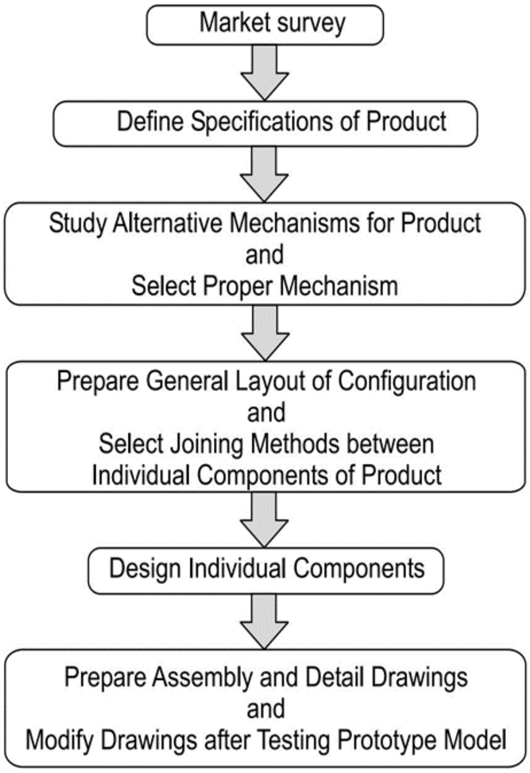

Fig. -2: Design Procedure

3.1 Market Survey

In India, out of 100 people facing disability 23 are suffering with Tran femoral amputation. Various solutions are present for such amputations. However, maximum people cannot afford such expensive products. My electric prosthesis cost thousands of dollars and take weeks to manufacture. We aim to manufacture it at minimum cost. Due to extensive research in the field, such prosthetics are available at half the price of the imported ones that cost more than 1-2 Lakhs.[3]

Major Problems Faced by Prosthetic Solutions:

I. Cost:

The price range of high end and complex prosthetic range from $3000 (bionic legs).

II. Time Required:

The usual waiting time after ordering of prosthetic product is usually high but the original time required may vary as per the ordered product.

III. Unavailability:

The product is manufactured at low rate, it is not easily available for ever increasing demands of the customers.

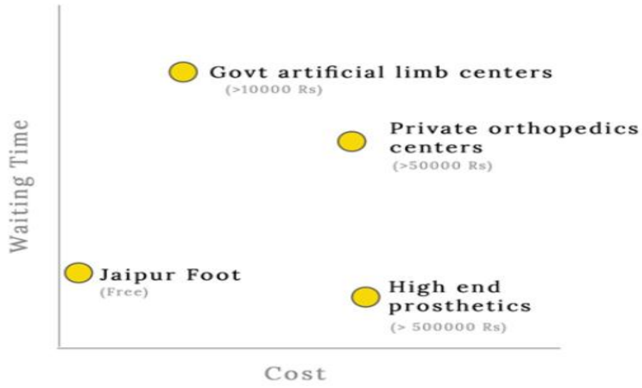

Fig. -3: Existing Solutions in India

3.2 Selection of Mechanism and Material

According to the requirements, aluminum is shortlisted as the material for the knee mechanism due to its light weight & easy of manufacturing. MS Steel is selected as material for connecting rod. The belt as connectors is made of Velcro cloth and plastic respectively. Various different mechanisms were studied prior to prototyping[4], A few are mentioned as below:

1. Uni axial spheroidal joint mechanism
2. Linkage mechanism

3.3 Design and Analysis of Components

Design criteria for various components were decided beforehand:

<u>For Spring</u>:

The maximum load was 30N and the factor of safety was selected as 3. Spring steel was selected as the material for the spring with a yield strength of 1000 N/mm2 .
For Spring Steel,
Assuming wire diameter = 2mm
where,
Ultimate Tensile Strength = Sut,
Tensile Yield Strength = Syt,
Shear Yield Strength = Ssy,
Shear Stress = τ

Load = P,
Modulus of Rigidity = G
Deflection = δ,
No. Of Coils = n,
For 2mm wire,
Sut = 1420 n/mm2
(Tensile strength) S_{yt} = 0.75 Sut
= 1065 n/mm2
(Shear strength) S_{sy}= 614.5 N/mm2
(τ) Shear Stress (max) = S_{sy}/F.S
Assuming F.S = 3,
τ = 614.5/3
τ = 204.835
Checking actual Stress,
$\tau_s = 8*w*c/\Pi d^2$
Where load (w) = 30N
τ_s = 8*30*10*/Π*22
= 2400/Π*4
= 190.98 N/mm2
τ_s< 204.835 N/mm2
Spring wire is acceptable
D = C*d
= 10*2
D = 20mm
$\delta = 8*30*202*n/G*d^4$
where,
P = 30N
G = 80*103 N/mm2
δ = 8*30*202*n/80*103*24
n = 10*80*24*103/8*30*202
n = 6.7
n~7
Solid length = n*d
= 7*2
= 14mm
Total gap = (n-1)* 2
Free length = solid length + total gap + δ
= 14 +(6*2) + 10
= 36mm

Pitch (p) = free length / (n-1)
= 36 / 6
= 6mm

The design was conducted with reference to PSG design data book and the following results were gained:

1. Wire Diameter: 2 mm
2. Coil Diameter: 10 cm
3. Free length: 36 cm
4. Pitch: 6

<u>Design of connecting rod:</u>

It is assumed that the load is acting in axial direction, and the rod will undergo static buckling.

The following Parameters are taken to design the rod:

Table -1: Design Parameters

Parameter	Value
Column Length (L)	0.4 m
Cross-sectional area (A)	736 mm²
Second moment of inertia (I)	3250121 cm⁴
Distance to the neutral axis (c)	50 mm
Eccentricity (e)	0
Design factor (n)	5
Modulus of elasticity (E)	170 GPa
Yield strength (Sy)	165

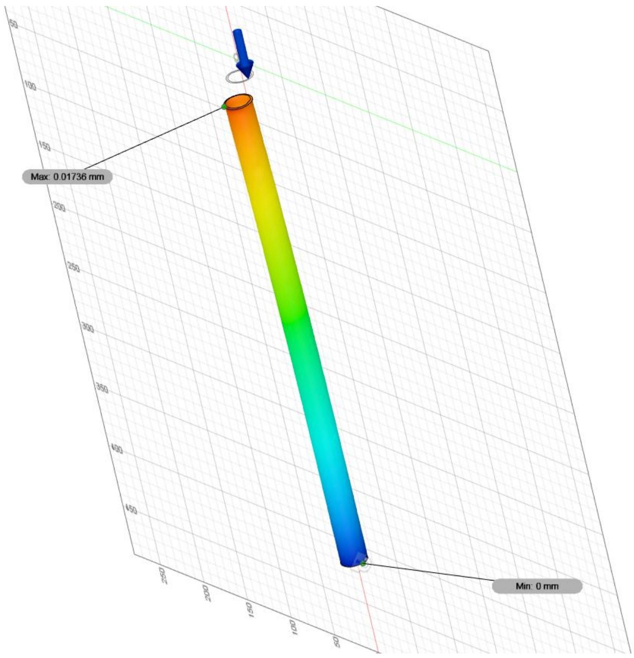

Fig. -4 Simulation of Connecting Rod

Table -2: Design Result

Parameters	Value
Effective length constant (C)	0.65
Radius of gyration of column (r)	6645.24 mm
Slenderness ratio of column (S)	0.06
Effective slenderness (S_{eff})	0.04
Critical load of failure (F_c)	121436.99 N
Allowable load (F_a)	24288 N

For Knee Mechanism:

Using preliminary design calculations and design evaluation, material was selected based on maximum rigidity and light weight appluication

Material: Aluminum 6061

Table -3: Properties

Density	2.7E-06kg / mm3
Young's Modulus	68900MPa
Poisson's Ratio	0.33
Yield Strength	275MPa
Ultimate tensile strength	310MPa
Thermal conductivity	0.167W / (mm C)
Thermal expansion Coefficient	2.36E-05 / C
Specific heat	897 J / (kg C)

The properties of the material were added into the analysis in the form of unput to the software. The loads and constraints are provided to the software along with the design parameters.

The following results were obtained from the simulation:

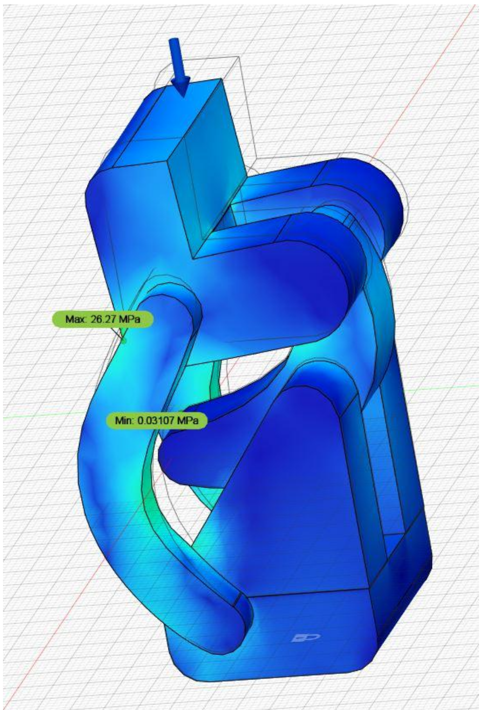

Fig. -5: Equivalent Stress

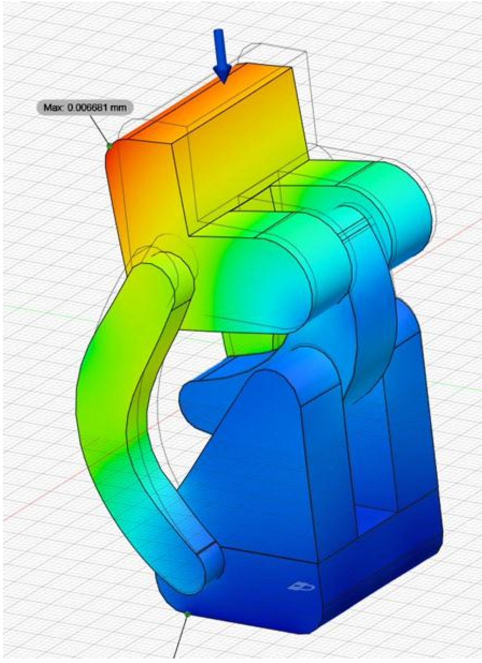

Fig. -6: Total Deformation

The structural analysis shown in above figures were computed in Ansys Structural Software.

Table -4: Simulation Results

Properties	Minimum	Maximum
Safety factor	5	7
Stress	0.31 MPa	26.27 MPa
Displacement	0 mm	6 mm
Reaction force	0 N	40.91 N
Equivalent Strain	4.502 E	5.239E

4. MANUFACTURING

After design, the parts were fabricated as per the requirements and were assembled using fasteners. The knee mechanism was entirely cast in a foundry using a foam mold, the spring was purchased, the rod was operated on lathe and threaded to fit the knee. The cast components were further machined using CNC machining to make a fit more accurate. Once the components were fitted altogether , the assembly was tested in the workshop to check for working and check for any defects during manufacturing.

Once the prosthetic was strapped on the amputee, user had to provide it with an initial hip flexion to shift from stance phase to walk phase. The pin then compressed the spring as soon as the toe of the prosthetic touched the floor and as soon as the heel was touched the spring began to expand and release its stored energy to provide the required assistance to the amputee. Thus, the cycle continued as long as the amputee did not stop providing it with a forward momentum

Fig. -7: Assembly of Mechanism

5.WORKING

The spring action acts against the weight of the load of the body and keeps the leg in stance phase. However, when the leg shifts into the motion phase. The linear load of the body on leg becomes more of an angular force. It actuates the lever to compress the spring and thus enabling the leg to bend and eventually to walk. Then again when the load on the leg is lifted the spring comes back up and locks the leg into the stance phase.

The side brackets of the knee help the knee to bend at a specified degree. With this leg the user is able to walk, stand and even sit using the leg. The movement however is limited to user and also requires a lot of practice to be able to walk using a prosthetic leg. The lever mounted between the assemblies plays a crucial role in enabling the swing phase of the leg. The motion of the swing phase moves a leg in an oscillatory motion about the pivot (knee).

The Project is an excellent adaptation of the four-bar linkage mechanism. However advanced Prosthesis even utilizes a more advanced six bar linkage.

The ankle is the second mechanism of the leg. The ankle is made of a cross linkage of bars at a central pivot point. It allows the Foot of the Leg to move in a vertical direction. The ankle joint provides the movement for the leg that is required for it to walk on an inclined surface. When a user is walking on a downward slope. The ankle adjusts to the surface and tilts in a plane parallel to the surface. Similarly, when walking on an uphill slope the foot adjusts to it.

The ankle joint provides a movement about the vertical axis which is crucial for the swing phase. As without a motion across the vertical, the foot of the leg would hit to the uphill surface and there would be no proper footing on the floor. However, a restricting force is required on the foot and ankle. So that it would not be too much flexible.

The restricting motion can be done in the further two ways:

- Either provide a spring type restriction (extension spring)
- Or make a foot flexible enough to accommodate the changes made as per the surface.

Here, both the arrangements provide the same results. However, we decided to go with a spring type restriction as it would be highly efficient and also be rigid enough to take the load of the body.

6.RESULTS AND DISCUSSION

6.1Material improvements:

The prototype model resulted in increased weight due to metal components used. The connecting rod between the knee and the foot was a cast iron rod and the whole assembly of the knee was made by aluminum. More chances are that the material will begin to rust and its weight carrying capacity will also decrease. Thus, discussions were done and materials were decided accordingly.

I. For the knee assembly, carbon fiber can be used as it is light weight and has very high strength and durability.

II. For the connecting rod, Polyvinylchloride (PVC) pipes or rod of suitable diameter can be used based on the weight which is to be carried.

6.2Alternate Fastening Methods:

For connecting the various parts of the knee, Nut and Bolts were. This increased the friction between the parts due to the threads between the bolts and also generated some unstable movement between them. Also, couplings were used to join the socket and the knee; this increased the weight of the leg. Thus, discussions were done and various solutions were inculcated.

I. For the assembly of the knee Cotter and Pin can be used as it creates less friction and is easy to assemble and disassemble the parts. Or Circlips can be used for holding the pin.

II. For joining the socket with the knee Sleeve nut or nut and bolts would be the most effective choice.

6.3Improvement in machining methods:

Lost foam casting was done to cast the various parts of the knee. Since Polystyrene was used for making the patterns pores and blow holes were generated. As a result, different machining methods were used for getting a finished surface.

Thus, instead of Using polystyrene patterns as in lost foam casting molding, Wooden Patterns can be used to reduce errors.

6.4Prototype Testing:

After protypes were tested out, we identified that the predefined phases of GAIT were achieved with ease and comfort. The user had no difficulty in use of the product. The weight of the project was not unbearable to the user yet the user felt that there was a slight unbalance in the legs. Due to which the user was not quite able to coordinate its prosthetic leg. However, the leg felt useful to the tester since, the user had only experienced a wooden prosthetic and was quite pleased with the results obtained[7].

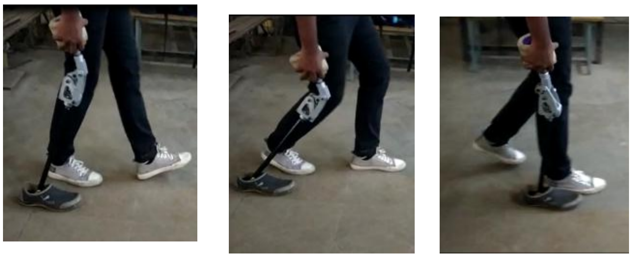

Fig. – 8 Phases of Motion

3. CONCLUSIONS

In this paper we conclude that the project is a success which inherently always produces a smooth, even comfortable gait motion wherein each phase is identical with each and every user that tested the project. The spring action caused a significant relief to the user in which approximately 5% of the body weight was provided by the spring. This project can provide means included within the mechanism to sit on a chair wherein the lock activates and provides comfort during sitting as the user. The prototype has been developed as per requirements and specifications. Thus, the aim of developing a "Economical Lower Extremity Prosthetics" is accomplished successfully.

REFERENCES

[1] Claire A. Donnelley, BS, Corin Shirley, CPO, Ericka P. von Kaeppler, BS, Alexander Hetherington, CP, Patrick D. Albright, MD, Cost Analyses of Prosthetic Devices: A Systematic Review, Archives of Physical Medicine and Rehabilitation, ACRM 1404-15

[2] C.Wermillion, Joint Movement Limiting Arrangement for Prosthetic Legs, US Patent 3, 663, 967, 1972 - Google patents, May 23 1972.

[3] V. N. Murthy Arelekatti, Amos G. Winter, Design of Mechanism and Preliminary Field Validation of Low-Cost, Passive Prosthetic Knee for Users With Transfemoral Amputation in India, ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference

[4] Dewen Jin, Professor Ruihong Zhang, PhD, Rencheng Wang, PhD, Associate Professor, Jichuan Zang, Professor Rehabillition Engineering Center, "Kinematic And Dynamic Performance Of Prosthetic Using Six Bar Mechanism", Department of Precision Instruments, Tsinghua University, Vol. 40, No. 1, Pages 39–48, January/February 2003.

[5] Harsimran Jeet Singh Sidhu, Design and Fabrication of Prosthetic leg, A journal of composite theory, ISSN: 0731-6755

[6] V. Bhandari,"Design of Machine Elements" Vol.2 ,pp 433-500,Mc Graw Hill, ISBN, 2012.

[7] Elliot J. Rouse, Nathan, C. Villagary-Carski, Robert W. Emerson, Hugh, M. Herr, "Design and Testing of a bionic Dancing Prosthesis", Volume 60, issue 5, Page 1181 – 1190, 2013.

[8] Rajput, S., Burde, H., Singh, U. S., Kajaria, H., & Bhagchandani, R. K, Optimization of prosthetic leg using generative design and compliant mechanism, material proceedings: Volume 46, Part 17, 2021, Pages 8708-8715