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Study of Passive Transfemoral Prosthesis

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Abstract

Artificial limbs for lower extremity amputees are designed and fabricated by prosthetists. In this study, we present the conceptual design of a fully-passive transfemoral prosthesis based on physical symmetries. This paper shows solid modelling of passive transfemoral prosthesis parts as per design of ALIMCO. All parts are assembled as per defined by ALIMCO in Pro-Engineer 4.0 package software capabilities and the analysis was performed by using the software ANSYS Workbench 14.0 The objective of this study is found out improvement in design for better comfort and fitment to transfemoral amputed patients.

Keywords-Transfemoral prosthesis, Finite element method, ALIMCO, Transtibial Prosthesis, ANSYS

1. Introduction

The lower limb prosthesis is a device that substitutes a part of a limb missing either due to amputation or a congenital defect. The prosthesis is assembled using off-the-shelf components and a custom-made socket for its attachment to the residuum [1].Transfemoral prosthesis is such type of a lower artificial limb that replaces leg missing above the knee. The residual portion of thigh is called stump. The main research challenges in the design of transfemoral prostheses are the efficiency with respect to the metabolic/external energy consumption and the adaptability to various walking conditions. In both literature and market, different kinds of transfemoral prostheses are present [2]. They can be classified as follows:

- **Passive transfemoral prostheses** - These prostheses can be considered efficient from the mechanical point of view but the overall efficiency is hampered by the considerable amount of extra metabolic energy consumption [3] .Moreover, due to the constant mechanical characteristics, these devices can't adapt to different conditions as shown in figure(1).
- **Variable damping transfemoral prostheses** - These prostheses use external power to adapt their dynamics to different gait pattern. For example, in [4] and [5], the dynamical behaviour of the prosthesis during walking relies on the control of a magneto rheological damper, which produces the required breaking torque for the knee joint.

- **Powered transfemoral prostheses** - These prostheses are capable to inject power in order to provide active ankle Push-off generation, so to reduce the extra metabolic energy consumption [6], [7], [8], [9].

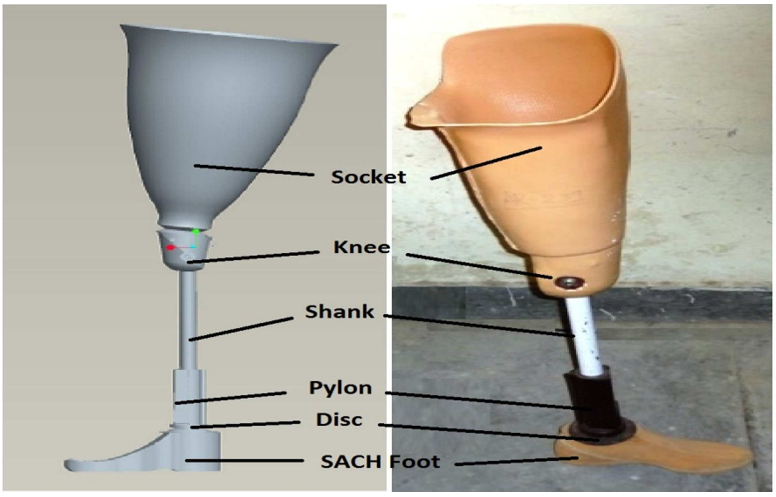

Figure 1: Passive Transfemoral prosthesis (a) Pro-e model and (b) Actual ALIMCO model

2. Material Properties

Table 1: The materials of the prosthesis adopted by ALIMCO are as follows:

Material	Young modulus (GPa)	Poisson's ratio	Yield strength (MPa)	Density (g /cm^3)
Polypropylene	11.72	0.3	35	0.92
Mild steel	210	.33	250	7.80
Repol Polypropylene	2.02	.301	34	1.01
Rubber	15.4	.45	15	1.1

3. Above-Knee Prosthesis Description

There are various causes of amputation. Common causes are vascular disease, cancer, infection, trauma, and birth defects. Lower limb amputations may be performed at different levels along the lower limb. A Transfemoral or above-knee (A/K) amputation is an amputation performed through the thigh (femur). ALIMCO (Artificial limbs manufacturing Corporation of India) is producing different kinds of prosthesis at larger scale. One of product is passive transfemoral prosthesis. The artificial limb consists of a foot-ankle unit which needs to be attached to the remain-der of the amputee's natural leg or stump. The foot ankle unit is attached directly to the socket frame. The artificial shank can be attached to the foot ankle unit and then attached to the knee unit which in turn, is attached to the socket frame for an above-knee amputation [10]. Transfemoral prosthesis consists of 21 parts [11]. All parts are 3D modelled in Pro-Engineer and actual ALIMCO model is as described below:

3.1. Socket

The shape and size of socket depends upon residual limb of amputee. In above-knee socket, the ischial bone supports all loads; the loads are applied on the control nods at the ischial plane of the socket proximal end [10]. Today the sockets are roughly quadrilateral in shape. They attempt to have total contact between the stump and the socket. The material of the socket is polypropylene. Such sockets are shown as in figure (1).

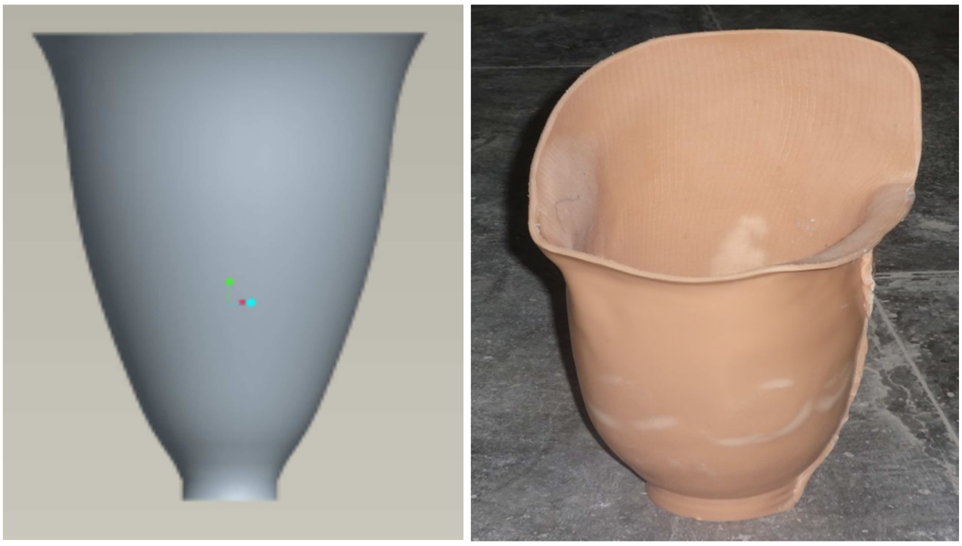

Figure 2: (a) Pro-e model and (b) Actual ALIMCO model of socket of transfemoral prosthesis

3.2. Knee

Knee is an important part in transfemoral assembly. As per ALIMCO design, it is weak part in prosthesis. For heavy weight bearing it is covered by polypropylene sheet. The material assigned to knee is Repol Polypropylene. Pro-e model and actual ALIMCO model of knee is shown in figure 3.

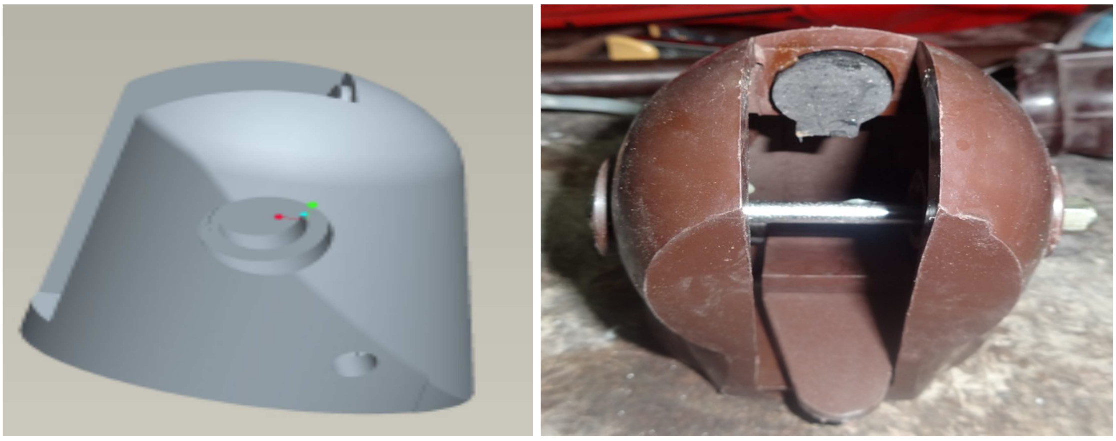

Figure 3: (a) Pro-e model and (b) Actual ALIMCO model of knee joint

3.3. Concave disc

Convex disc is used between knee and socket. Main purpose of fitting it to transfer load to knee and alignment of socket. The material assigned to convex disc is Repol Polypropylene. This part is made by injection moulding. Software model is shown as in figure 4.

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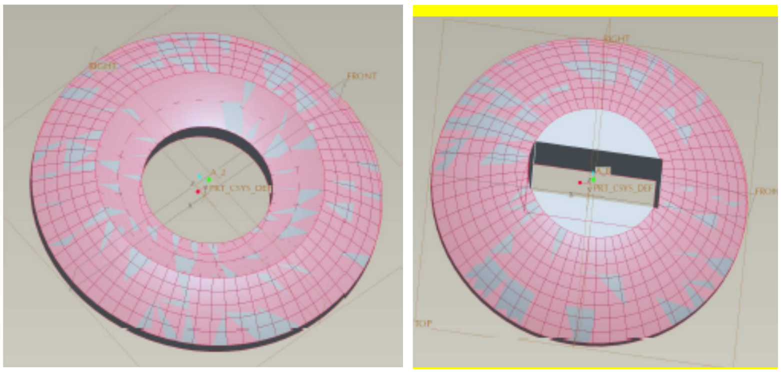

Figure 4: Pro-e model of (a) Concave and (b) convex disc

3.4. Convex disc

Concave disc is the complementary part of convex disc. Material used is Repol Polypropylene. Concave and convex discs help alignment of socket. This part is also made by injection moulding. Pro-e model is shown as in figure 4.

3.5. Knee Lock and Shoe Nut –Bolt

Knee lock part is used to lock and unlock shank of prosthesis. It enables person bending and unbending of leg as per desired. Material used is Repol Polypropylene. Software model of knee lock is as shown in figure-5(a). Nut and bolt are locking parts of above knee prosthesis figures 5(b) & (c). The material assigned to nut and bolt is zinc coated mild steel.

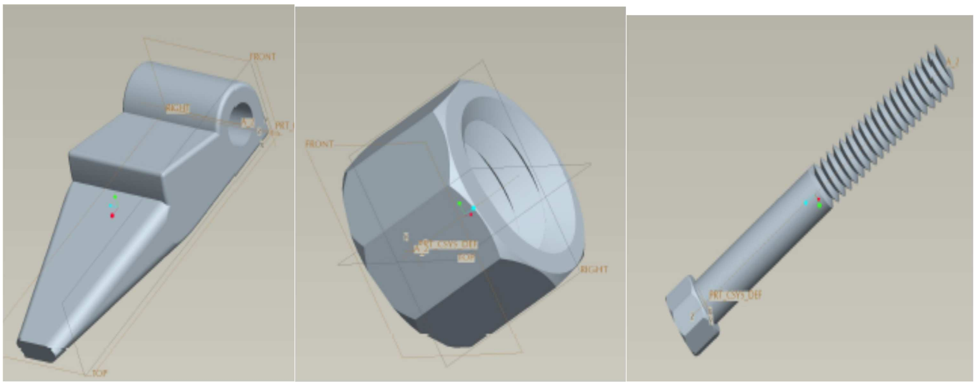

Figure 5: Pro–e model of (a) Knee lock, (b) Nut and (c) Bolt

3.6. Knee Washer and Pylon Pin

As name implies knee washer is used in locking nut and bolt assembly in knee part of transfemoral prosthesis. The material assigned to knee washer is mild steel. Pylon pin is locking device for pylon and shank. The material assigned to pylon pin is also mild steel. The pro-e model actual ALIMCO geometry of knee washer and pylon pin are shown in figure (6).

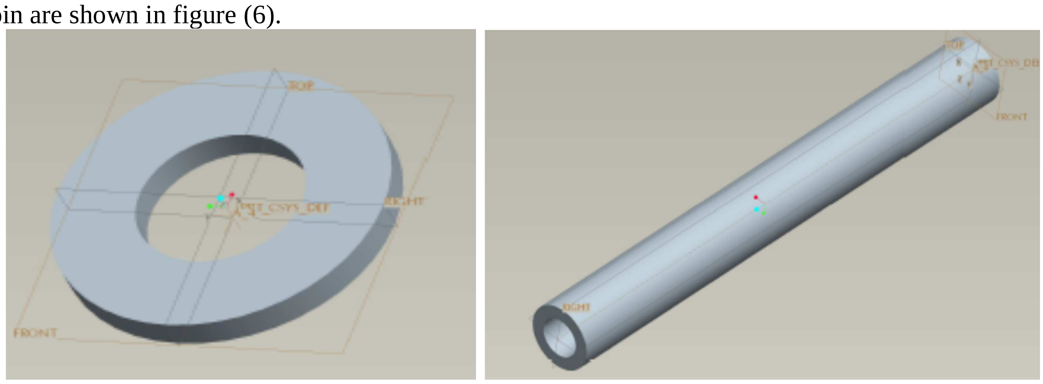

Figure 6: Pro–e models of (a) knee washer and (b) pylon pin

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3.7. Pylon and Shank

Pylon is connecting assembly for shank to SACH foot. It also helps in alignment of shank. The material used is repol polypropylene. Shank is connecting assembly in between knee and pylon. The length of shank depends upon the length of amputee stump. The primary purpose of the shank is to transfer the vertical loads caused by the weight of the amputee to the foot and on to the floor. The material assigned to shank is mild steel. Pro-e model of pylon and shank is as shown below:

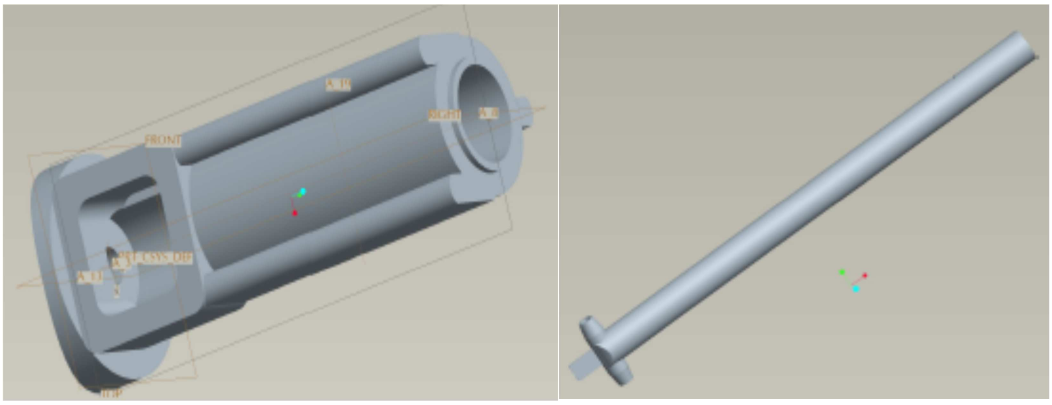

Figure 7: Pro–e model of (a) pylon and (b) shank of trans-femoral prosthesis

3.8. Pylon Disc, Socket Lock Bolt and Socket Lock Nut

Pylon disc enables easy bearing of pylon on SACH foot. It also helps alignment of foot respective to socket. The material assigned to pylon disc is repol polypropylene. This bolt is used to lock socket and knee assembly. The material assigned to nut and bolt is zinc coated mild steel. The material assigned to socket lock nut is zinc coated mild steel. Actual pro-e model of pylon disc, socket lock bolt and socket lock nut were shown in figure 8.

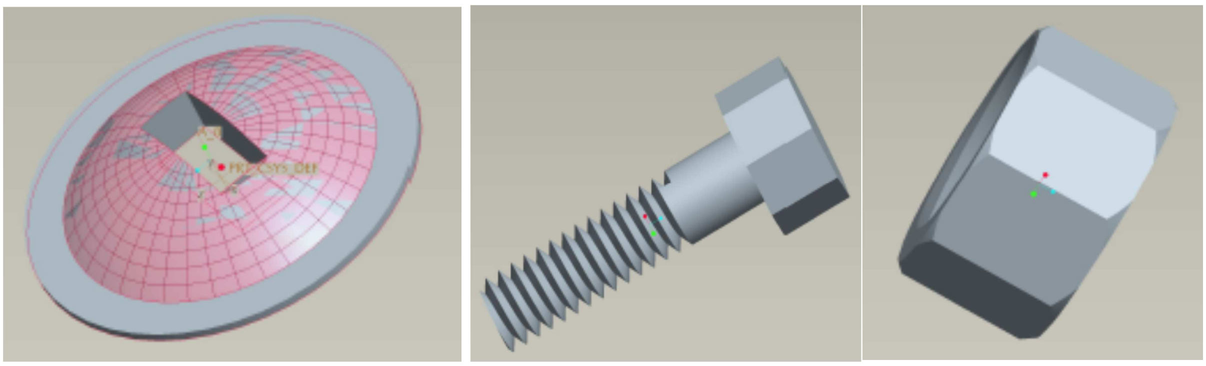

Figure-8: Pro–e model of (a) pylon disc (b) socket lock bolt and (b) socket lock nut of trans-femoral prosthesis

3.9. Socket Washer, Knee Lock Pin , Shoe Washer and SACH Foot

Heavy washer is used in connection between knee and socket. The material assigned to socket heavy washer is zinc coated mild steel. Knee lock pin is used to support knee lock. It is supporting part in knee. The material assigned to knee lock pin is zinc coated mild steel. Shoe washer is connecting assembly part in locking of shoe to pylon. SACH (Solid Ankle Cushion Heel) foot is made of layers of rubber. It is non-articulated type. The layers of rubbers are glued to each other. Ankle action is provided by the soft rubber heel which compresses under load during the early part of the stance phase of walking. The material assigned to shoe washer is zinc coated mild steel. Actual pro-e model of socket washer, knee lock pin, shoe washer and SACH foot were shown in figure 9.

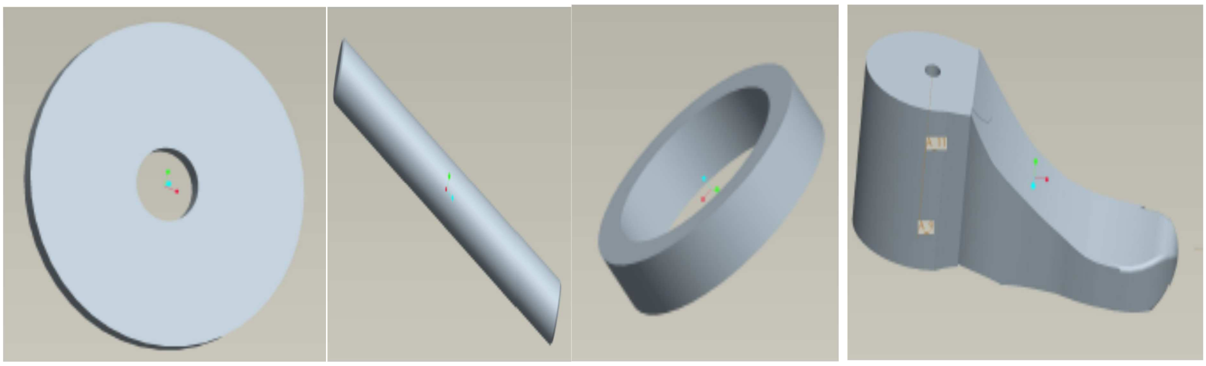

Figure-9: Pro–e model of (a) socket washer (b) knee lock pin (c) shoe washer and (d) SACH Foot of trans-femoral prosthesis

4. Finite Element Analysis

Finite element method was used to conduct a stress analysis and show the force distribution along the device. The finite element mesh view of socket, knee joint, shank, pylon, and SACH foot are shown in figure (10).

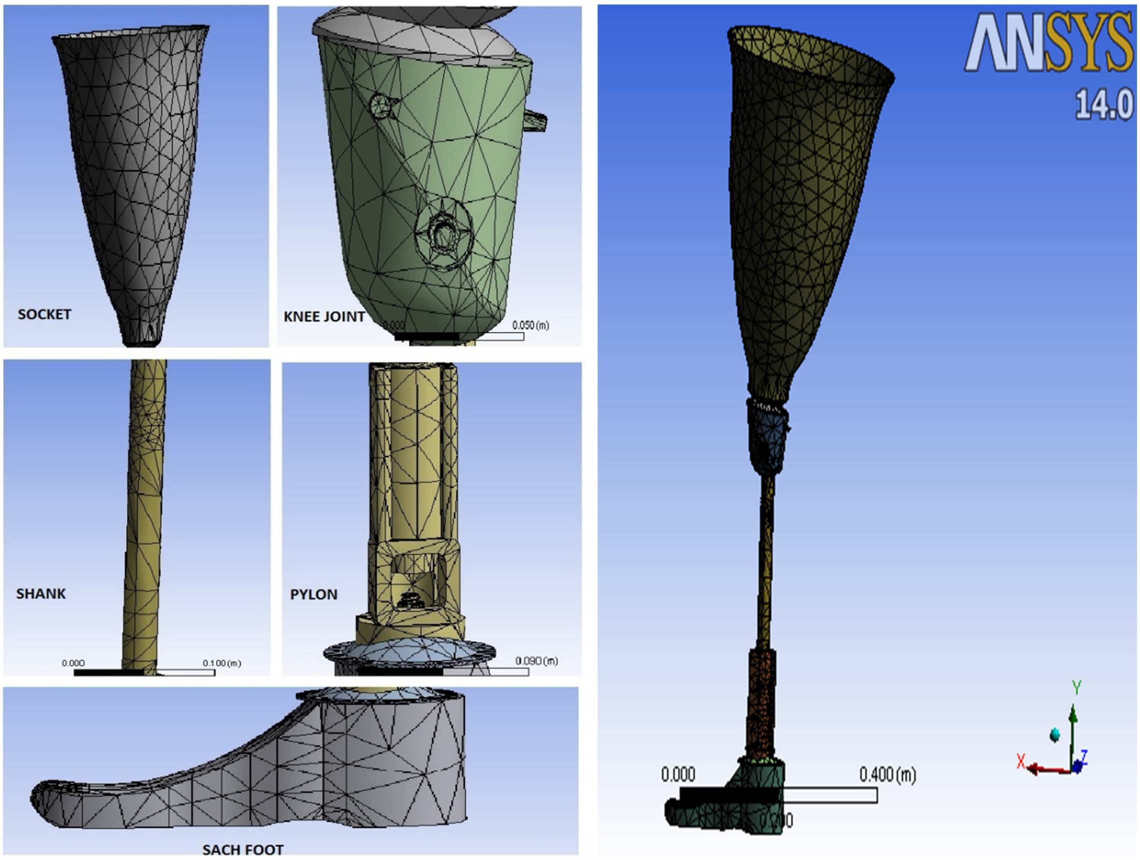

Figure 10: ANSYS mess view of (a) different parts and (b) complete assembly of trans-femoral prosthesis

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5. Experimental Loading According to ISO 10328

The long term performance of the above-knee socket prosthesis depends on the kinematics, pressure and stresses generated within the socket. Retrieval studies have shown that the pressure between the residual limb and the socket as well as the stress distribution is the most dominant factors in socket design [10]. The prosthetic limb will be analysed using the general consideration such that as Transfemoral prosthesis is weared by amputee, whole body weight is transferred to the ground. The considering body weight as load, it is applied to socket. The prosthetic limb will be analysed using the international standard for structural testing of lower limb prostheses (ISO 10328). This paper focuses on static proof test loading, which forms a design basis for dynamic and cyclic testing. Three test levels are defined in the ISO specification: P3, P4, and P5. P3 testing corresponds to a foot appropriate for a patient with mass of up to 60 kg (A60), and P4 to a patient with mass of up to 80 kg (A80). P5, the strongest of the standard strength levels, corresponds to most other patient sizes, including a mass exceeding 100 kg (A100) [12]. Average weight of body is approximately 960N.

Table 2: Category of patients according to ISO 10328 standards [13]

Category	**Patient's weight**
P3	Max 60 kg
P4	Max 80 kg
P5	Max 90 kg

This paper focuses on static proof test loading. After finding the locations and directions of loads, the next step is to apply forces and set constraints or supports. These forces are applied to interior side of socket. Foot of above knee prosthesis is fixed. In the specific case of the prosthesis object of this study, principal static proof tests are required. Due to the particular nature of this device, only static tests were planned. The load level chosen for the tests is also related to the average weight 960.

6. Results and Discussion

The results for equivalent (von-Mises) stress, shear stress, elastic strain, directional deformation strain energy, and total deformation of designed Models were obtained by using (ANSYS workbench 14.0) program.

Table 3: Result at different loading conditions.

Loading Step	Applied Force (N)	Max Equivalent VM stress (Pa)	Total Deformation(m)	Shear Stress(Pa)	Equivalent Elastic Strain	Strain Energy(J)
I	589	1.176e8	0.11231	2.8384e7	0.065094	0.017755
II	785	1.5681e8	0.1519	3.7846e7	0.087882	0.031564
III	883	1.7641e8	0.17089	4.2576e7	0.098855	0.039948
IV	950	1.8981e8	0.18388	4.5812e7	0.10637	0.046251

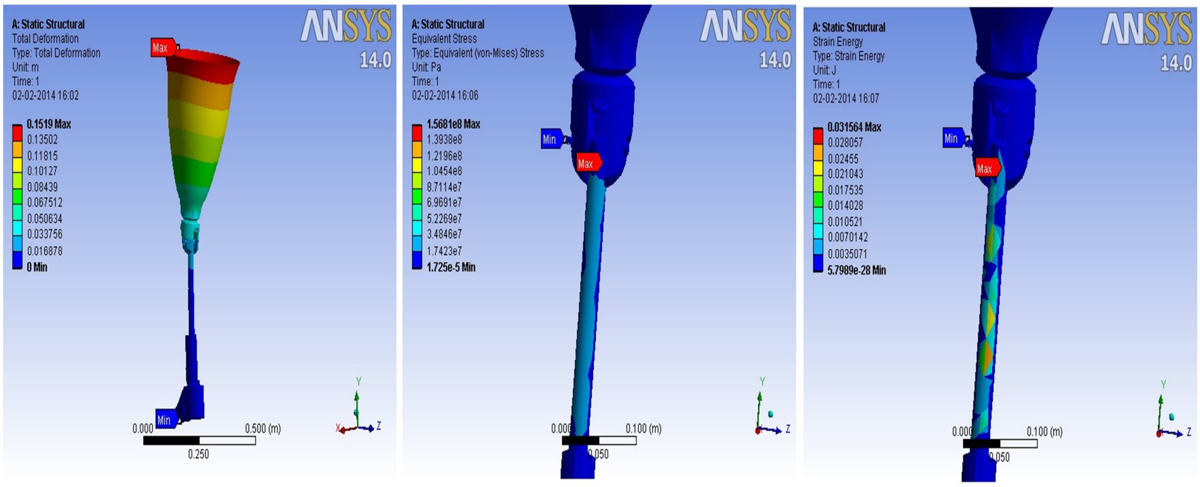


Figure 11: Finite element result in ANSYS of (a) Total deformation, (b) equivalent stress and (c) Strain energy

Figure 11(a) shows total deformation in above knee prosthesis. It is clear that on wearing trans-femoral prosthesis higher strain occurs at the brim of socket. For removing higher stress brim of socket is non-uniformly manufactured so stress concentration in upper layer of socket is non-uniformly localised.

Equivalent Von-Mises stresses acting on different parts of above knee prosthesis is as shown in figure 11 (b). It is clear higher stresses are acting on shank during trans-phase of gait cycle. Shank made of mild steel has high absorbing capacity and zinc coat on it increases corrosion resistance.

Diameter of the shank modelled and analysed is 25.4 mm according to ALIMCO design. Length of shank depends upon patient. Exact length of shank is 390 ± 1 mm. But length varies according to requirement of patient. Extra part is cut and remaining part is used as connecting part between knee and Pylon. Strain energy is energy restored in body due to application of load.in analysis it is found strain energy is higher in knee and shank part of trans-femoral prosthesis figure 11 (c).

Elastic strain is found higher at knee assembly. As knee is made of repol polypropylene polymer, it has higher shock absorbing capacity. Figure 12 shows equivalent elastic strain at different knee portion. For higher load knee is covered by polypropylene sheet of socket. It makes knee part stronger and safe.

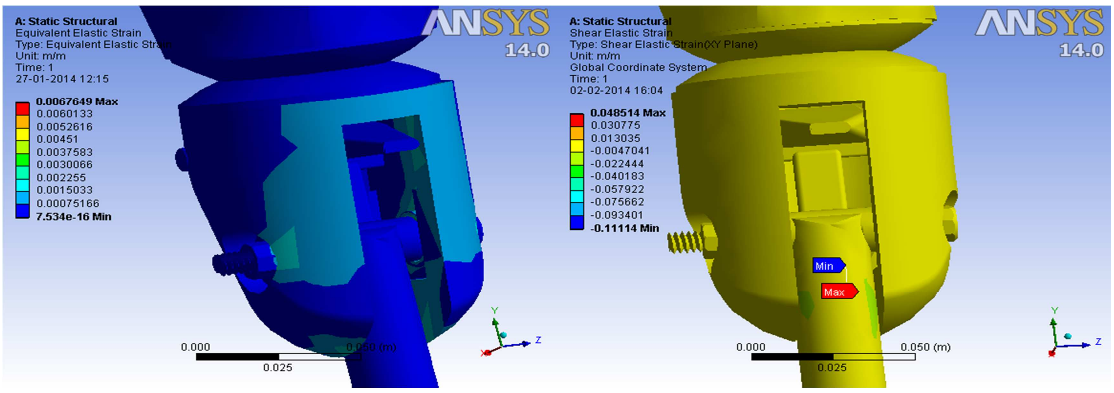
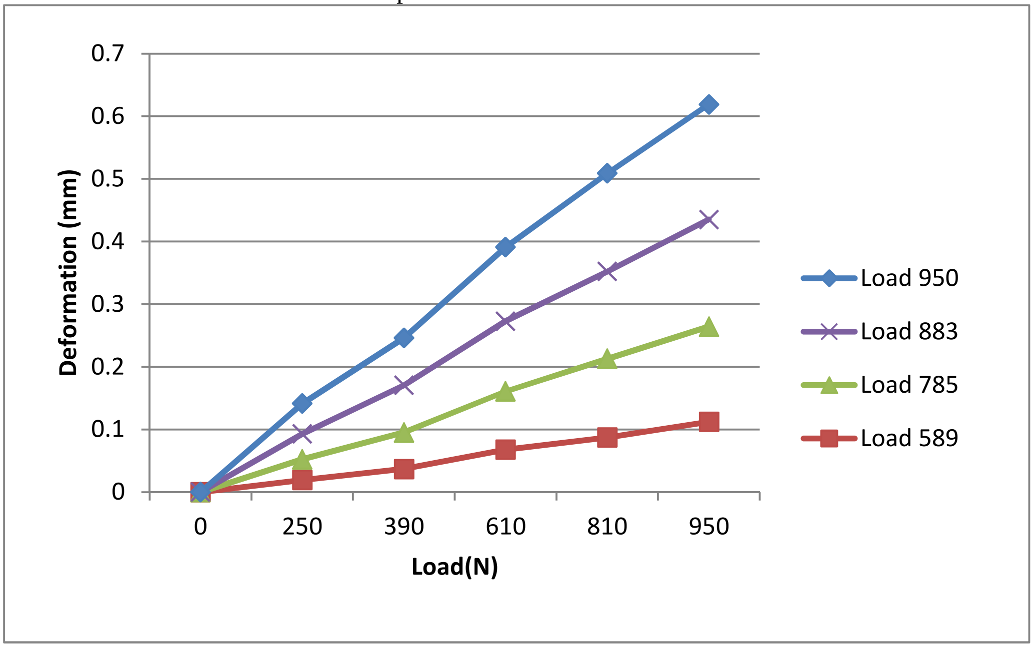


Figure-12 Finite element result in ANSYS of (a) equivalent elastic strain and (b) shear elastic strain

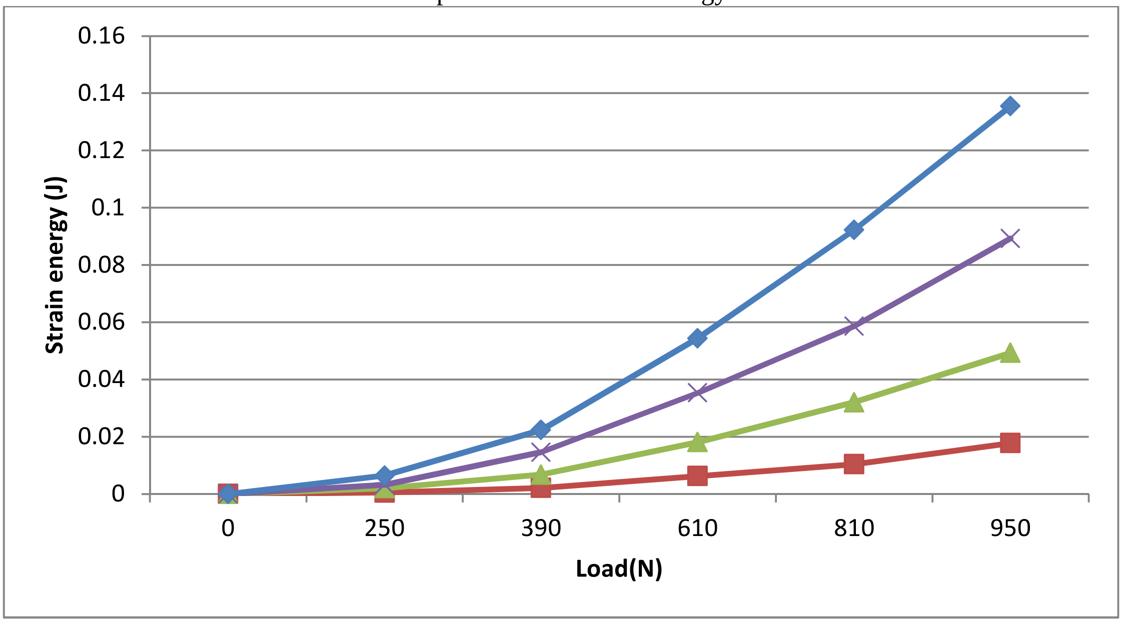
Graph 1 is drawn between Load (N) applied and total deformation (m) as residual limb resides into socket. From graph it is clear that as load increases on transfemoral prosthesis deformation increases. Load is directly proportional to deformation. Each series has been drawn with respect to maximum load applied to socket.

Graph 1: Load vs deformation



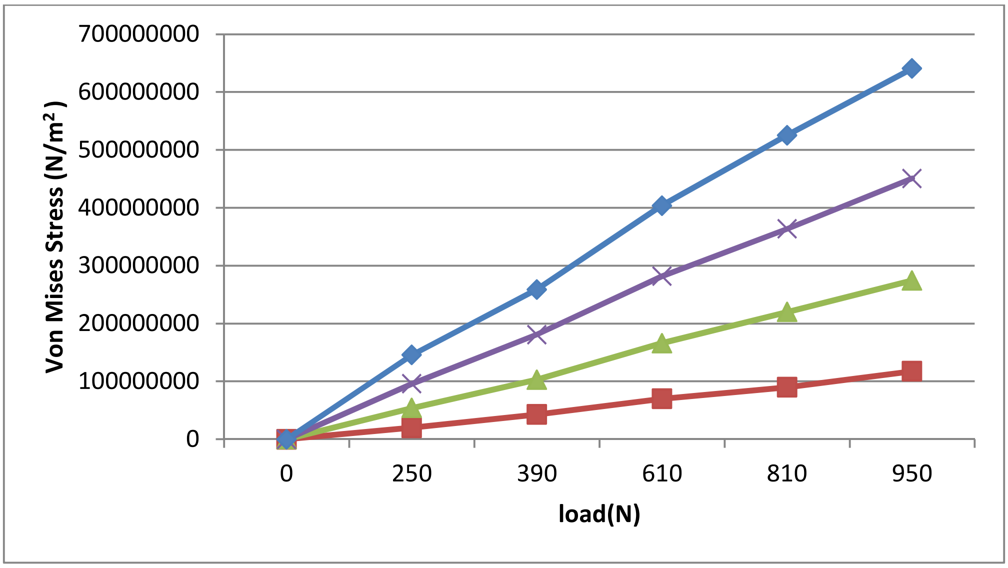
Graph 2 shows relation between load (N) and strain energy (J) at maximum Load applied to socket. The nature of graph is parabolic. It is known that strain energy will be restored in the body when the load is applied gradually or suddenly or with an impact [14].

Graph 2: Load vs strain energy



Graph 3 shows relation between load applied and maximum Von-Mises stress acting in transfemoral prosthesis. It is clear that as load increases Von Mises stress increases forming linear relationship. From ansys results, maximum Von-Mises stress occurs at socket brim.

Graph 3: Load vs von-Mises stress



7. Conclusion

Passive transfemoral prosthesis is a good and easy solution to be used by amputee patients that who can't afford actuated transfemoral prosthesis due to higher in cost. Such types of transfemoral prosthesis require low maintenance cost. Life of above knee prosthesis depends upon patient how he cares. After two or three year, there is need of little maintenance. Based on the results and discussion, polypropylene is cheap, light in weight and widely available material for socket. It has good toughness for weight bearing. It is useful for both children as well as adults. Certain parts of trans-femoral prosthesis develop stresses that are higher than the yield stress of polypropylene. Some parts of above knee prosthesis (knee joint, foot and socket) need higher wear and tear resistance. These parts should be made strong. In final words, this model is a good substitute person suffering above knee amputation in developing country like India where a person suffering such type of physical deficiency can't afford high cost power actuated transfemoral prosthesis. But being passive a person spends 80% more energy than a natural walking. Due to this person attends unnatural gait. There is need of sophistication in this field with relevant cost.

References

[1] Mark R. Pitkin, 2010, Biomechanics of Lower Limb Prosthetics, Springer Verlag Berlin Heidelberg

[2] R. Unal, R. Carloni, E. E. G. Hekman, S. Stramigioli and H. F. J. M. Koopman, 2010, Biomechanical Conceptual Design of a Passive Transfemoral Prosthesis, 32nd Annual International Conference of the IEEE EMBS

[3] R. Waters, J. Perry, D. Antonelli and H. Hislop, 1976, Energy Cost of Walking Amputees: The Influence of Level of Amputation, Jour. Bone and Joint Surgery, vol. 58A, pp. 42-46

[4] J. H. Kim and J.H. Oh,2001, Development of an Above Knee Prosthesis Using MR Damper and Leg Simulator, IEEE Int. Conf. on Robotics and Automation

[5] H. Herr and A. Wilkenfeld, 2003, User-adaptive Control of a Magneto Rheological Prosthetic Knee, Industrial Robot: An Int. Jour., vol. 30, pp. 42-55

[6] F. Sup, A. Bohara and M. Goldfarb,2008, Design and Control of a Powered Trans-femoral Prosthesis, Int. Jour. Robotics Research, vol. 27, pp. 263-273

[7] W.C. Flowers,1973, A Man-Interactive Simulator System for Above-Knee Prosthetics Studies, PhD Thesis, MIT

[8] D. Popovic and L. Schwirtlich,1988, Belgrade Active A/K Prosthesis, in de Vries, J. (Ed.), Electrophysiological Kinesiology, Int. Congress, Excerpta Medica, pp. 337-343
[9] S. Bedard, P. Roy, 2003, Actuated Leg Prosthesis for Above-Knee Amputees, 7314490 US Patent
[10] Bakr Noori Khudher, 2012, Stress Analysis of the Above-Knee Prosthesis during Gait Cycle, Al-Rafidain Engineering
[11] Artificial Limb Manufacturing Corporation (ALIMCO) Kanpur, India www.artlimbs.com
[12] Albert E. Yousif, the Design, Development and Construction of an Adjustable Lower Extremity
[13] C. Colombo, E.G. Marchesin1, L. Vergani , E. Boccafogli , G. Verni, Optimization Studies of Trans-tibial Prostheses: Numerical Models and Experimental Tests
[14] Dr. R. K. Bansal, A text book of Strength of materials, Chapter 4 Strain energy and impact loading

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