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Stress Analysis of Four-Bar Linkage Transfemoral Prosthetic in Gait Cycle

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Abstract

Artificial knee prosthetic (AKP) requires the flexibility of movement, comfort, functionality and ease of leg optimal setting. This study aims to investigate the stress distribution of a prototype of four-bar linkage mechanical joints focusing on the shaft buffer which is analogous to the knee joint. Finite element method based on commercial software Solidworks® is used to analyze the knee joint reaction due to the dynamic loading when transfemoral prosthetic driven for one cycle of motion (cycle gait cycle) is applied. In accordance with the functions of the AKP, it is important to obtain the technical data regarding to the position and the profile of von Misses stress of the knee joint for each position. The analysis shows that the maximum value of von Misses stress occurs at the angle of 14.57˚ at the phase of mid stance single support, while the smallest von Misses stress occurs at the angle of 0˚ at the phase of initial contact and 30˚ at the phase of the terminal stance.

Keywords: Artificial Knee Prosthesis (AKP), Finite Element Method, Gait Cycle, Transfemoral Prosthetic

INTRODUCTION

Biomechanics is the study of the movement of living things with a scientific approach to mechanics. Mechanics is the branch of physics that studies the movement and how force can cause a movement. Biomechanics presents various theories and mathematical equations needed to understand how living things move. The most important part in the running movement of the prosthetic is balancing the body weight amputee. Prosthetic is able to provide load balancing. Movement is running on a normal person, showing how the second leg balance each load displacement body in movement. At the time of walking and feet touching the floor, the body burden resulting from the effects of the Earth's gravitational pressure will cause upward reaction force. In amputee, prosthetic and transfer of forces on the other foot is said to be good if during the process of running the prosthetic stepping is normal, that does not happen gap with healthy feet.

Walking clone is walking aids needed by persons with disabilities leg amputation due process or congenital disabilities. In the case of amputation above the knee movement mechanism is required artificial knee joints are good so that users feel comfortable when using it. Besides foot imitation products are expected to support the weight of the body when used for walking. Product imitation leg above the knee or above the knee is often referred to as a prosthesis (AKP), which has a performance-based clone knee joint mechanical has a high setting flexibility is still dominated by imported products. AKP domestic product is still concentrating on conventional joint system. For the market with lower-middle segment, foot mock domestic product has a market that is still evolving, to market the AKP with the upper middle segment who want the flexibility of movement, comfort, optimal foot function and ease of setting, the Indonesian people are still dependent on imported products.

Since 2013, Mechanical Engineering Department, Diponegoro University has developed four types of foot mock, above knee prosthesis (AKP), for patients with amputations above the knee [1-4]. AKP first type is designed using a single rod with hydraulic bending joints [1]. The second type is designed using three rods with hydraulic joints [2]. In the third and fourth design, the AKP uses a single stem with a four bar linkage joints [3-4]. The development of the third and fourth of the AKP is of particular interest in this study focusing on stress analysis in two rod buffer (bar 1 and bar 2) in a four bar linkage joint concept that will accept the burden of the body when performing motion gait cycle. The finite element method is applied to perform the stress analysis of AKP.

METHODOLOGY

The present study consists of two steps, firstly, the process of modeling and secondly, the stress analysis. All of them are performed using SolidWorks®. The first stage is to design of the knee prosthesis (AKP). AKP joint mechanism used is a four bar linkage. In the second stage, the stress analysis of 3D models based on finite element method is performed to determine the stress distribution. The main observations made to the buffer rod in this design are analogous to knee and it will receive the load of the human body.

The flow chart of the present work is shown in Figure 1. The first phase of the design of the product showed that the dimensions have been established based on the measurements of the dimensions of the AKP products sold in the market and the observation of the patient of AKP. Joints on the AKP is modeled in 3D with respect to the biomechanics of the human knee joint. Figure 2 shows the design model developed.

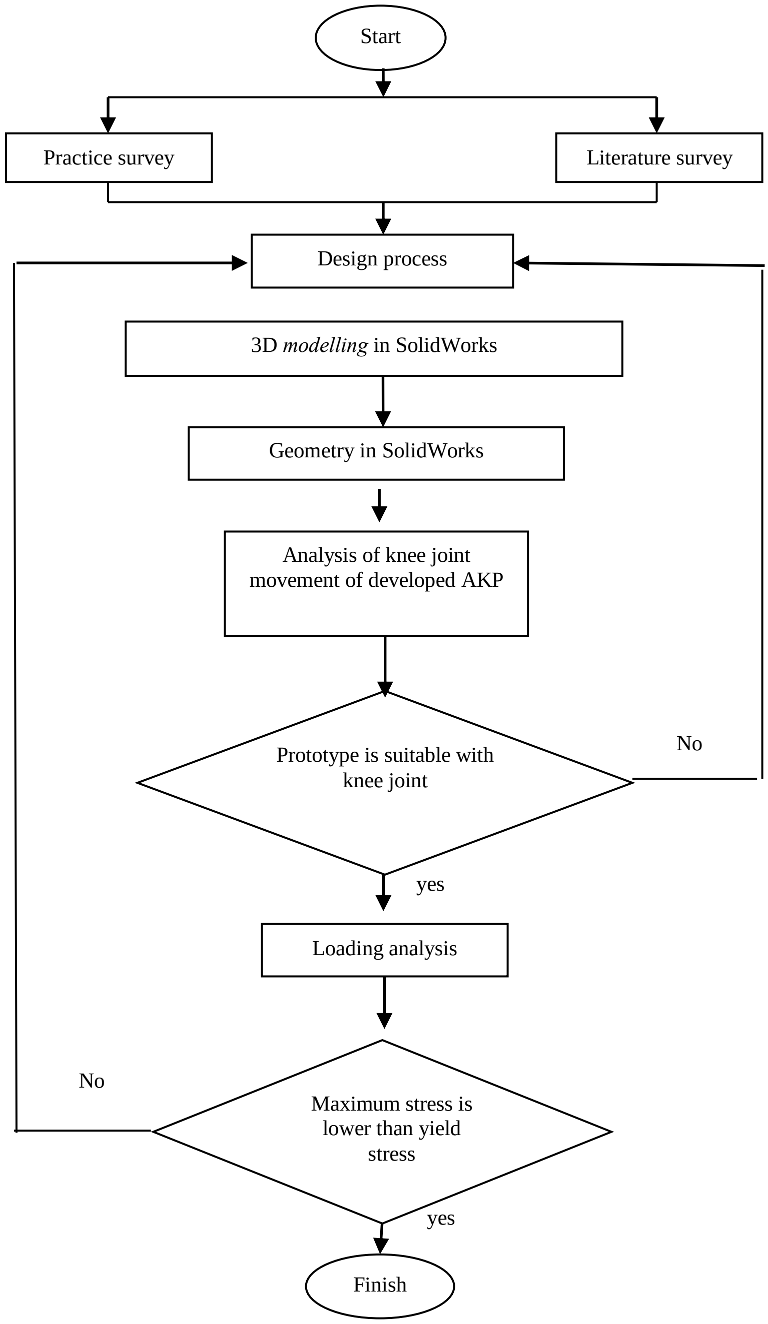

Figure 1: Flow chart of the present research

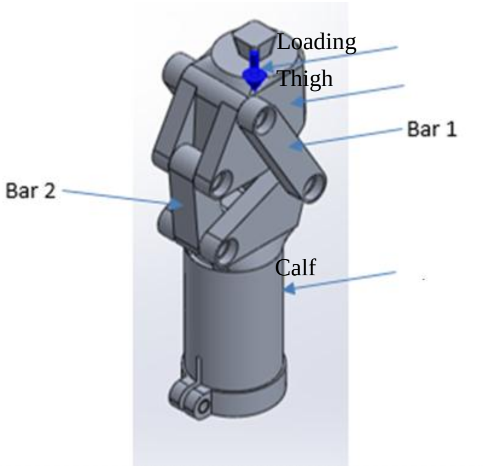

Figure 2: The developed design of *Above knee prosthetic* (AKP)

The material used of the developed AKP is 6061 T6 aluminum alloy. It has a modulus of elasticity of 68.9 GPa, Poisson's ratio of 0.33, and the yield strength of 276 MPa. The maximum load of 1,000 N received by the AKP model is assumed. The meshing process of 3D model is then performed as shown in Figure 3. The 3D model simulated the load when the knee moves at the position 0^0-15^0, 15^0-0^0, and 0^0-30^0. The positions are formed during the initial phase of contact, loading response, and midstance. In these phases buffer rod will accept the body weight.

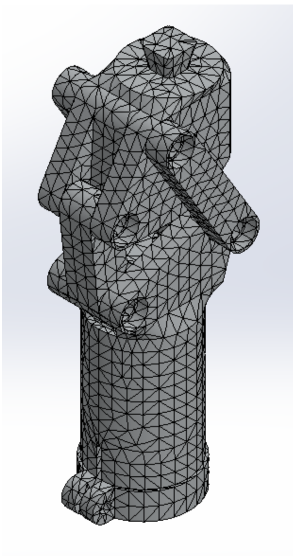

Figure 3: The meshed model of developed AKP

RESULTS AND DISCUSSION

Phase initial contact (Figure 4) is the beginning of the loading response, which is the first period of the stance phase. Knee flexion angle formed is 0^0. Loading response as seen in Figure 5 gives the double support between the initial contact phase and mid-stance phase. Face loading occurs in response to the percentage of time of about 7% of the gait cycle. Knee flexion angle in shape is 15^0. Along with this phase, the weight is transferred to foot during the period stance (right foot dark color) and (left foot, bright colors). The knee flexion angle forms the angle of 0^0, as shown in Figure 6. Phase terminal stance (Figure 7) is called as the inverse of initial contact for the position of right and left foot opposite the initial contact. Terminal stance phase occurrs in the period of 60% of the gait cycle. It can be observed from Figure 7 that the weight of body is transferred to the rest to the bottom of the front foot (toe). From the simulation, it is known that the von Mises stress occurs in the trunk buffer, during a movement from the corner of 0^0-15^0, 15^0-0^0, and 0^0-30^0 shown in Figure 8.

Figure 4: Foot movement at the phase of the initial contact.

Figure 5: Foot movement at the phase of *loading*

Figure 6: Foot movement at the phase of *mid-stance*

Figure 7: Foot movement at the phase of *terminal stance*.

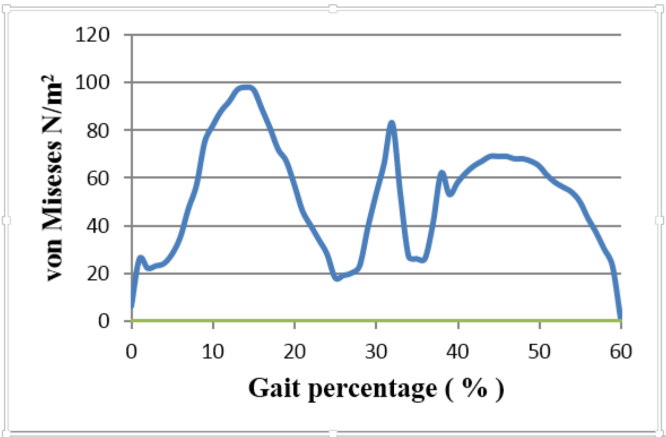

Figure 8: Loading for 0-60% fase *gait cycle.*

Based on Figure 9, it can be seen that the first stress obtained during 15% of gait cycle at 14.57° angle is 98.12 MPa. Then, the stress drops during 25% of gait cycle at 4.6° angle to 19.6 MPa (Figure 10). The stress obtained during 35% of gait cycle at 0.17° angle is 87.27 MPa (Figure 11). The stress at 45% gait cycle is 69.63 MPa at 14.27° angle (Figure 12). There is a maximum stress when the position of the loading phase response is at the angle of 14.57°, that is, 98.12 MPa. This value is lower than the yield strength of 276 MPa. Based on stress analysis, it is noted that the predicted safety factor is 2.8.

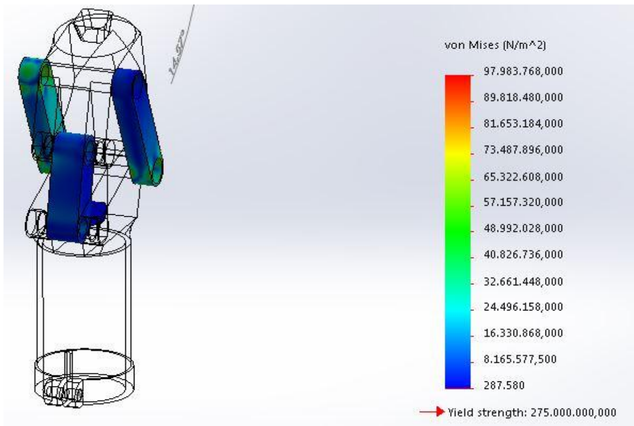

Figure 9: Distribution of von Mises stress for angle of 14.57°

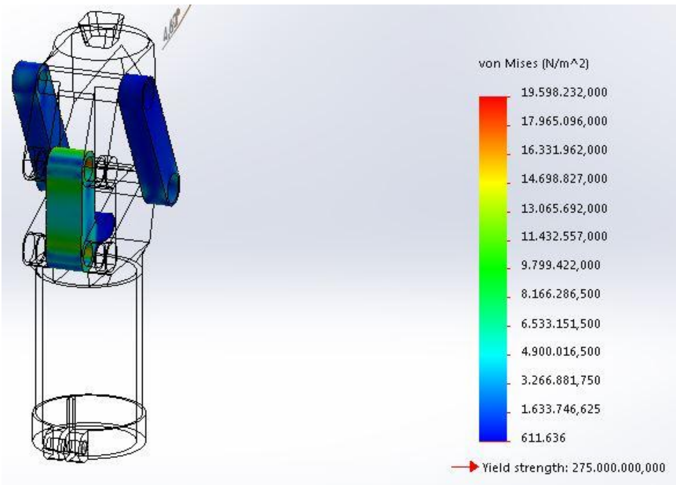

Figure 10: Distribution of von Mises stress for angle of 4.6°

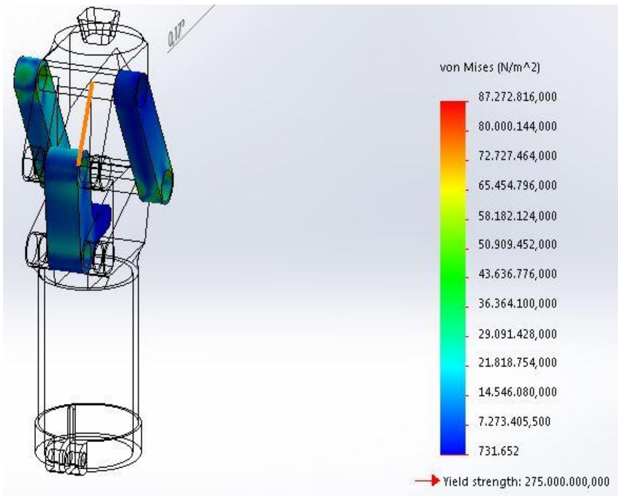

Figure 11: Distribution of von Mises stress for angle of 0.17°

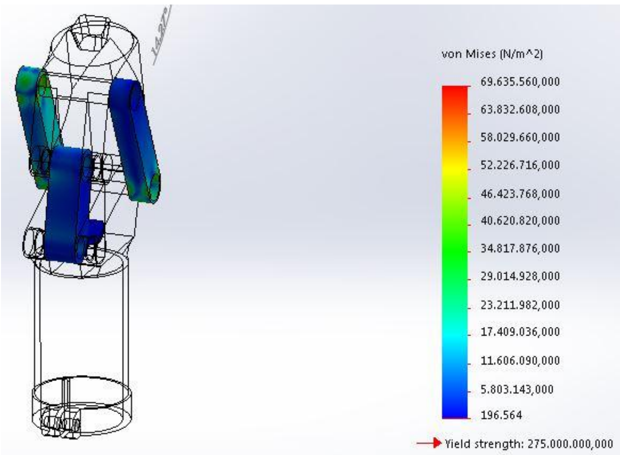

Figure 12: Distribution of von Mises stress for angle of 14.27°

CONCLUSION

In the present study, the artificial knee prostheses (AKP) developed was analyzed during the first step of the gait cycle based on finite element method. It was found based on stress analysis that the developed AKP is safe because the maximum stress is lower than the yield stress.

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