IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

Computer Aided Artificial Ankle Joints Design

Tian (Richard) Zhao[1], Matin Vahora[2], Zheng (Jeremy) Li[3]

M.S (Student), Department of Mechanical Engineering, University of Bridgeport, Bridgeport, US[1,2]

Dr., Department of Mechanical Engineering, University of Bridgeport, Bridgeport, US[3]

Abstract: The ankle joint is an essential joint to fulfill people's daily activities. For reasons of diseases and accidents, patients have to accept treatments to rebuild an available condition to enjoy their lives. From the area of engineering design, this paper introduces the basic structure of ankle joint, designing concepts of an artificial ankle joint and some common complications after replacing the ankle joint.

Keywords: Ankle joints; Engineering Design; FE Force Analysis; Pro/E Model

I. INTRODUCTION

The ankle joint plays a very important role in transferring load from people's legs to feet and it is the most important bridge to connect people's legs and feet. Most of the time, more than 90% of the work that done through the ankle is associated with plane of sagittal which is in the side view of a person[1]. In modern society, however, more and more people have to suffer from the pain of their ankle joints because of the arthritis which make them a limited motion in their daily lives. There is a high risk for people to have arthritis no matter how old are they, what sexes are they and where they are from. In general, there are more active mechanical work that done by the human ankle than passive mechanical work, especially when people try to increase their walking speeds[2]. With the development of technology, the traditional treatment of Ankle Arthrodesis has been replaced by a new treatment that is ankle joint replacement with an artificial ankle joint[3]. Since 1973, an artificial ankle joint has been used successfully and the patient benefits a lot from this artificial ankle joint even it has a lot of disadvantages compare with today's products[4]. From that time when the first ankle joint replacement was successful, there are increasingly appetencies for patients to accept ankle joint replacement so that they avoid the suffer from ankle diseases. The ankle not only provide an effortless walking condition, but also make people walk with a smooth gait. Under the cooperation of ligaments, muscles and tendons, people can process a motion easily. But, if any conditions that maintain a healthy ankle joint were broken, it would be a hard time for people to suffer from pain when they are doing activities. Nowadays, there are still a lot of complications with the operation of ankle joint replacement. For example, the most common cases, loosening, infection, anesthesia and nerve injury[5]. A lot of patients have these complications after several years with the replaced artificial ankle joint. It is necessary for an engineer to learn more details of a physical ankle in order to design a well-walking artificial ankle joint and try to figure out the way to avoid these complications such as use a better material or design a near perfect artificial ankle joint model.

II. BASIC STRUCTURES

On the bony side, the ankle is mainly including three bones which are tibia, fibula and talus[6]. The talus is usually called the ankle bone and its top part is located inside of a bowl-like structure that is made of two parts which are the fibula and the lower part of tibia. The bottom part of the talus is supported by the calcaneus which is called heelbone in general. Based on this structure, people's feet can move upward as well as downward easily because of the hinge-like connection of these three main bones. What is more, there is an oil-like material called articular cartilage to provide a nearly frictionless surface for the movement of bones. Articular cartilage has to be thin and hard enough to support people's body weight. Figure 1[7] shows the overall structure of ankle joint.

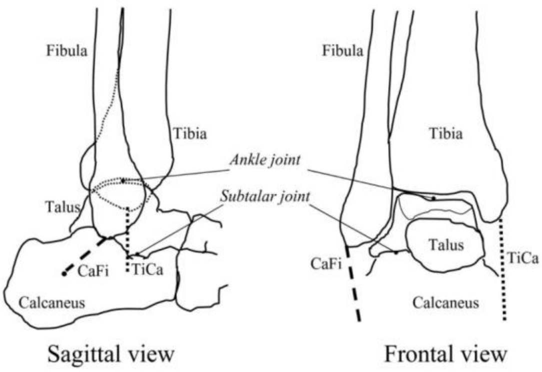

Fig 1. Overall Structure of Ankle Joint

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

In addition, the ligaments and tendons are very significant soft tissues to fulfill the movement of the ankle. The ligaments play the role to connect bones and bones, the tendons, on the other hand, are the soft tissues that used to connect bones and muscles[8]. The ligaments are located in both sides of the ankle joint and they provide a force to make the bones stay together. The tendons also support the ankle joint simultaneously and there is different type of tendons which have different functions. For instance, the Achilles tendon is meanly used for jumping, running and walking. Figure 2[9] shows the ligaments and tendons.

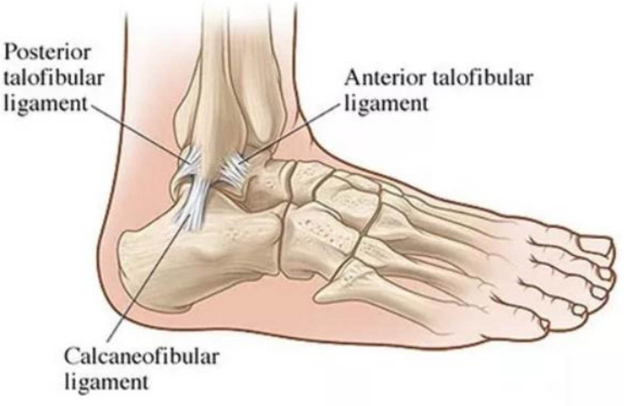

Fig 2. Ligaments and Tendons

III. PRO/ENGINEER BASED MODEL

The assembly 3-D model of an artificial ankle joint was sketched by Pro/EINGEER and it will be showed in Figure 3. The model of artificial ankle joint includes three parts which are top part, middle part and bottom part. The top part of the model will be installed in Tibia and it will be fastened via screws. For the middle part, it is a thin and frictionless-like block because it plays the role to stand the rotation of the ankle joint and it has to be strong enough to withstand the force or pressure that come from human body in different situations such as walking, running and jumping. What is more, it makes people feel comfortable when the middle part is nearly frictionless, or there would be a strange feeling during any motions. Finally, regard to the bottom part of the model, it will be covered on Talus so that the middle part has a base to fulfill its motion.

IV. MATHEMATICAL CALCULATION

When people are in any motions such as walking, running, a torque will be generated on their feet because the stress point is not exactly same as the rotation center which is issued on the ankle joint. For the situation of running, the stress point is mostly on the forefoot and there is a distance between the rotation center and the stress point.

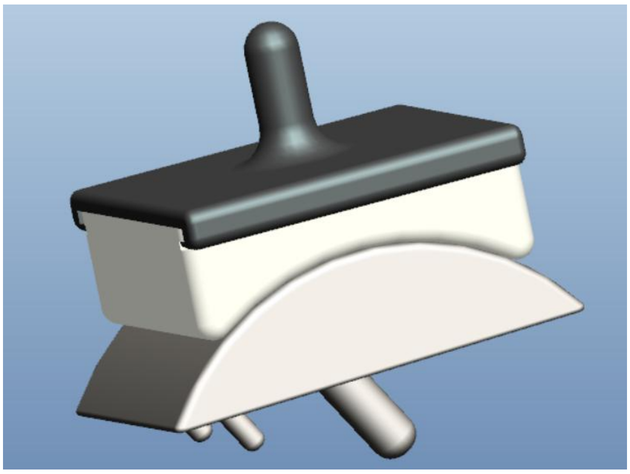

Fig 3. 3-D Pro/ENGINEER Model of Ankle

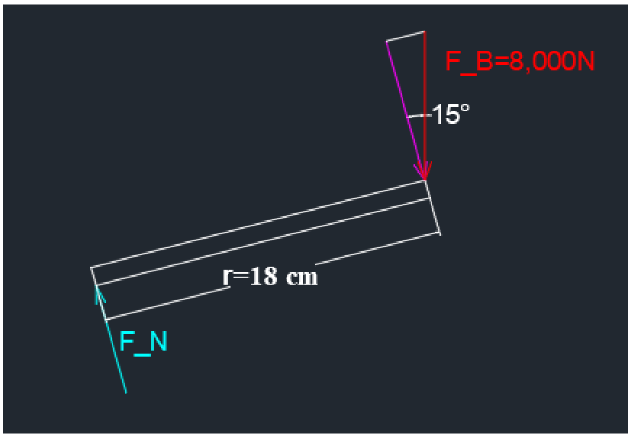

Fig 4. Free Body Diagram

$\tau = F_N \cdot \Upsilon$
$F_N = -F_B cos\theta\Upsilon$

Thus,
$\tau = -F_B \cos\theta\Upsilon$
$= (-8{,}000N)(cos15^\circ)(18cm)\left(\frac{1}{100}m\right)$
$= -1390.93\ Nm$

Therefore, there will be a 1390.93 Nm clockwise torque on the ankle joint when people are running.

V. FE BASED FORCE ANALYSIS

Regarding to the stress taken by the artificial ankle joint, we need to do a lot of analyses to make sure that the ankle joint can fulfill majority situations, such as walking, running and jumping because they will lead different stresses to the ankle joint. For instance, a patient weight 150 pounds and the ankle joint usually take almost 5 times body weight during gait[10]. And there will be a load of nearly 10 times body weight when the patient is running[11]. Also, jumping will generate 2~12 times body weight that will be taken by ankle joint[12].
Assuming a person whose body weight is about 180 pounds, so that a FE analysis can be done via ANSYS Workbench. 8,000 Newtons are loaded during the analysis which is approximately ten times of a person's bodyweight to fulfill the situation of running. What is more, because Titanium Alloy is a common material to make artificial joints, it is applied in ANSYS Workbench. The results are showed below figures.

FE Mesh of the Model

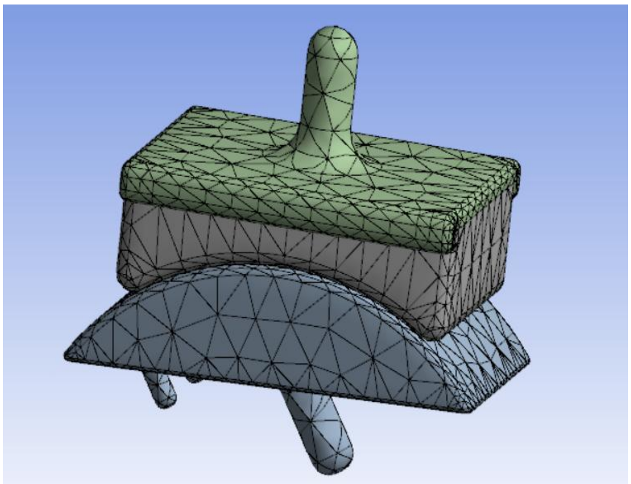

Fig 5. FE Mesh of the Model

The FE mesh of the model is generated by ANSYS workbench automatically in default conditions.

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

Equivalent Stress (von-Mises)

For the stress analysis in this paper, 8,000 Newtons of downward force is loaded because the majority force that the ankle joint takes will be extrusion force which is facing downward and the 8,000 Newtons are basically regarding to the situation of running based on the information upon which is high enough to hold most situations such as walking and jumping. The result in ANSYS showed me that the model is strong enough to hold that situation.

TABLE I RESULTS OF STRESS

Equivalent Stress	Results
Minimum	17299 Pa
Maximum	2.2386e+008 Pa

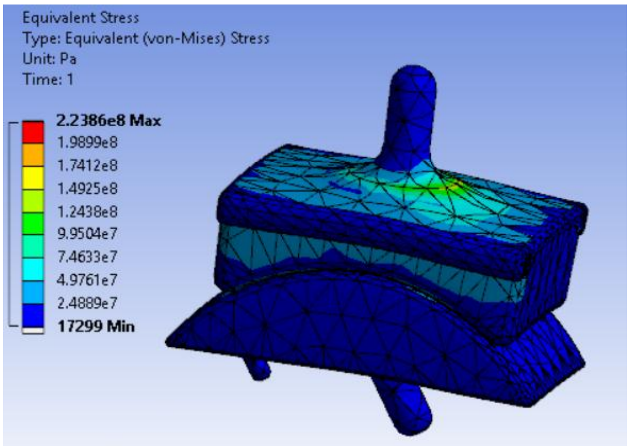

Fig 6. Analysis of Equivalent Stress

The figure shows that the maximum von-Mises stress that the model take is 2.2386e+8 Pa and the minimum von-Mises stress is 17299 Pa.

Total Deformation

The total deformation (displacement) shows the overall deformation of the Pro/Engineer based model of artificial ankle joint. When a model or problem is set in ANSYS Workbench, the deformation of the model is generally showed as the output of the analysis process.

TABLE II RESULTS OF DEFORMATION

Total Deformation	Results
Minimum	0 m
Maximum	7.3318e-006 m

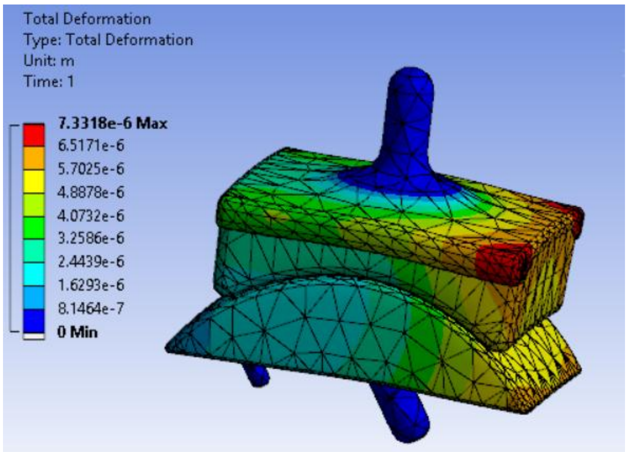

Fig 7. Analysis of Deformation

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

There are two areas that are presented in red which means that the model in these two areas are probably not well designed. To make sure that the model is reasonable, the dimensions should be recalculated in the future.

Equivalent Elastic Strain

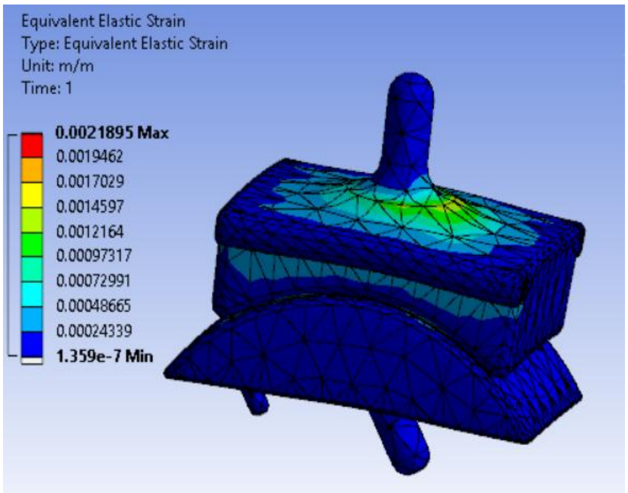

Fig 8. Analysis of Equivalent Elastic Strain

The elastic strain is used to verify the capability of the model to restore to the original state. During a ANSYS based analysis, the elastic strain is a very essential factor to measure whether the model is practical or not.

TABLE III RESULTS OF ELASTIC STRAIN

Elastic Strain	Results
Minimum	1.395e - 007 m/m
Maximum	2.1895e - 003 m/m

The maximum equivalent elastic strain showed in figure 7 is 2.1895e-3 m/m and the minimum strain is 1.395-7m/m. The process in ANSYS workbench shows that nothing is red that is the model has the ability to restore to its original state.

Factor of Safety

Factor of Safety is used to describe the ability of a system to carry load and it is a common used factor for designers to analyze that whether their products are reasonable or not. Factor of Safety is a ratio of absolute strength to actual applied load and the SOLIDWORKS shows me a FOS of 5 which means that the maximum load that the model can hold is approximately 40,000 Newtons based on the actual load of 8,000 Newtons. In other words, the design is safe enough to hold the majority activities of the patients who will use it.

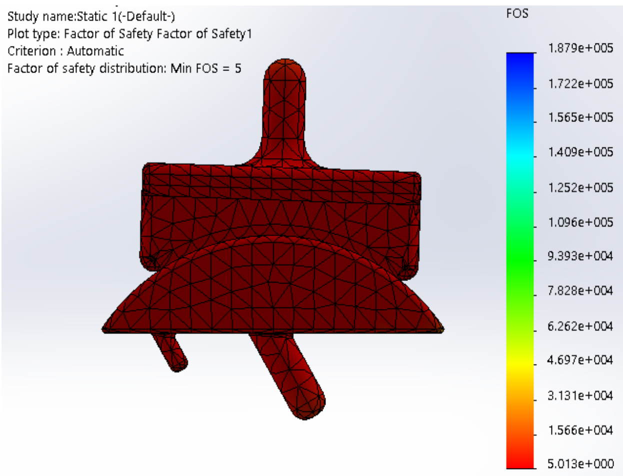

Fig 9. SOLIDWORKS Simulation Based FOS

VI. CONCLUSIONS

In this paper, an artificial ankle joint is designed based on the software of Pro/ENGINEER. In purpose of properly designing the model and helping readers know the design well, some basic information about ankle joint is introduced. Besides, a bunch of FE based ANSYS analyses regarding to the designed model are implemented to verify that the design in this paper is practical. So that patients feel confident to replace their ankle joint if they have to.

REFERENCES

[1] Eng J. J., and Winter D. A. (1995) Kinetic Analysis of the Lower Limbs During Walking: What Information Can Be Gained from a Three- Dimensional Model? Journal of Biomechanics 28(6): 753- 758.

[2] D. A. Winter, "Biomechanical motor pattern in normal walking," Journal of Motor Behavior, Vol. 15, No. 4, pp. 302 - 330, 1983.

[3] Ankle Arthrodesis James Albert Nunley, David Walton, in Case Competencies in Orthopaedic Surgery, 2017

[4] History and evolution in total ankle arthroplasty, Nikolaos E. Gougoulias Anil Khanna Nicola Maffulli, British Medical Bulletin, Volume 89, Issue 1, 1 March 2009

[5] A Patient's Guide to Artificial Joint Replacement of the Ankle

[6] Stresses in the ankle joint and total ankle replacement design, Rahul Kakkar MRCS, M.S. Siddique FRCS, 19 February 2011

[7] Biomechanics of the natural, arthritic, and replaced human ankle joint, Alberto Leardini, John J O'Connor and Sandro Giannini, Journal of Foot and Ankle Research20147:8

[8] Earll M, Wayne J, Brodrick C, Vokshoor A, Adelaar R. Contribution of the deltoid ligament to ankle joint contact characteristics: a cadaver study. Foot Ankle 1996; 17(6):317–24.

[9]GOOGLEhttps://www.google.com/search?rlz=1C1SQJL_enUS781US781&biw=1536&bih=734&tbm=isch&sa=1&ei=etHCWpXSCcf4_Abam6jQDQ&q=ligaments+of+ankle+joint&oq=lig&gs_l=psyab.1.0.0i67k1l5j0l4j0i67k1.197698.197971.0.199889.3.3.0.0.0.0.127.263.2j1.3.0....0...1c.1.64.psyab..0.3.261....0.E4geiti8uLA#imgdii=ICkPtMmQfUKaTM:&imgrc=dyLl0nXGvF1aaM:

[10] Stauffer RN, Chao EYS, Brewster RC. Force and motion analysis of the normal, diseased, and prosthetic ankle joint. Clin Orthop 1977; 127:189–96.

[11] Burdett RG. Forces predicted at the ankle during running. Med Sci Sports Exerc 1982; 14(4):308–16.

[12] McNair PJ, Prapavessis H. Normative data of vertical ground reaction forces during landing from a jump. J Sci Med Sport 1999; 2(1):86–8.