UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND FINITE ELEMENT ANALYSIS OF HIP JOINT PROSTHESIS

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Design) with Honours.

by

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I hereby, declared this report entitled "Design And Finite Element Analysis Of Hip Joint Prosthesis" is the results of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Design) with Honours. The members of the supervisory committee are as follow:

………………………………

(Principal Supervisor)

ABSTRAK

Osteoarthritis adalah penyebab utama masalah pinggul. Menurut Cristofolini (1997), Melebihi 800 000 penggantian pinggul sedang dilaksanakan di seluruh dunia setiap tahunnya. Hal ini penting untuk mengetahui prestasi gentian tulang pinggul terutama kestabilan dan umur panjang. Dalam projek ini, simulasi berangka berasaskan kaedah finite element analysis digunakan untuk menganalisis perilaku mekanik gentian tulang pinggul sendi pinggul. Analisis elemen hingga dilakukan pada tiga model dimensi gentian tulang pinggul pada model padat. Hal ini untuk menyiasat perilaku suatu prosthesis hip joint akibat beban. Kemudian, analisis tersebut diulangi pada dua bentuk yang berbeza dari sendi pinggul, yang merupakan salah satu jenis lurus (Moore) gentian tulang pinggul dan bengkok (Charnley). Kedua-dua kepala femoral dan cawan acetabular yang tetap sama pada dimensi mereka.

Setelah itu, analisis yang sama dilakukan dengan tujuh jenis material yang boleh kategori pada tiga kelas yang logam, polimer dan seramik sifat mekanik pada setiap bahan tidak sama. Tujuannya adalah untuk mengoptimumkan pemilihan reka bentuk dan bahan dengan memiliki stres perpindahan, rendah dan memakai pada umur kelelahan yang sangat tinggi. Selanjutnya, batang yang mengalami stres tertinggi dan model perpindahan adalah dioptimumkan dengan membuat perbandingan antara desain batang dan pemilihan material untuk prostesis bersama.

ABSTRACT

Osteoarthritis is the major reason that causes hip problem. According to Cristofolini(1997), there are more than 800 000 hip replacement being implemented worldwide annually. It is important to know the performance of hip prosthesis especially the stability and the longevity. In this project, numerical simulation based on finite element method is used to analyze the mechanical behavior of hip joint prosthesis. Finite element analysis is carried out on three dimensional model of prosthesis on solid models. This is to investigate the behavior of an hip joint prosthesis under loading. Then, the analysis is repeated on two different shape of hip joint, which is of one type of straight (Moore) hip prosthesis and curve (Charnley). Both of the femoral head acetabular cups are remain same on their dimension.

After that, the same analysis is carried out with seven type of material that can be categories on three classes which is metal, polymer and ceramic were mechanical properties on every material is not same. The aim is to optimize the design and material selection with have low stress, displacement and wear at a very high fatigue life. Subsequently, the stems that had highest stress and displacement models were the optimized by making a comparison between stem design and material selection for joint prosthesis.

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DEDICATION

Special Dedication Of This Grateful Feeling To My…

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Mr. Mohamed Azlanudin Bin Yahya & Mrs. Norhayati Bte Haron,

Lecturer: Mr. Wahyono Sapto Widodo
And

Loving Friends
For Their Love, Support And Best Wishes

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CAD	-	Computer Aided Design
CAE	-	*Computer-aided engineering*
FEM	-	Finite element method
FEA	-	Finite element analysis
MPa	-	Mega Pascals(N/mm2)
mm	-	Millimetres
Cr	-	Chromium
Ni	-	Nickel
US	-	United States
NZ	-	New Zealand
C	-	Celsius

CHAPTER 1

INTRODUCTION

1.1 Background

The human skeleton consists of rigid bones that are joint by joint which can rotates to enable movement. The hip joint is an outstanding example of a congruous joint. Both the acetabular and the femoral head are symmetrical, and the joint space is equal at all points with slight deviation to permit adequate lubrication. This symmetry allows for rotation about a fixed axis and simplifies the muscle action on that joint. The hip joint serves a very important biomechanical function. While supporting the majority of the human body with estimation 2/3 of total bodyweight and the joint must simultaneously facilitate smooth articulation of the lower limbs to enable bi-pedal gait. During routine daily activities, forces on the order of 5.5 times bodyweight are transferred between the femur and pelvis [Bergmann, 2001].If these joint unable to articulate courses by disease or injury, the human movement become difficult and become even impossible. The pain was produce from the movement from flexing the joints is known as arthritis disease.

Today's technology, the ability to replace damaged joints with artificial prosthesis has provided assistance for millions of patients who otherwise would be very limited in the activities of the most fundamental and avoid living with pain. It is estimated that about 16 million people in the United States affected by arthritis, one of the many conditions that can lead to hip replacement. Hip replacement is used to relieve pain, improve function and address the disparity is caused by defects and diseases. According to the latest data, [K. Rogoff, 2007] 250.000 of the hip performed each year in the United States alone. Because a large number of joint replacement is the

300, 000 hips replaced every year worldwide, and the high costs involved, there is continuing strong demand for further improvement of orthopaedic devices, which lasted more than 20 years in the human body

Research in this area is going on since long time to develop new material and design, which will replace affected hip without incurring much pain to the patient and which withstand to maximum limitation of human activity. Recently many researchers working in this area applied finite element method to determine the failure of the artificial hip prosthesis.. The restoration of free and painless human movement by the implementation of artificial joint have become very important to patient were suffering for a very long time.

1.1 Problem Statement

Hip joint prosthesis is one of the most successful operations worldwide. However the number of reoperation and revision increase each year. Usually the reason for the revision is mechanical endurance of the material and design were lead to failure of the prosthesis. Prosthetic design and material selection greatly influence average survival rates of hip joint prosthesis. The wide selection of design and material for the prosthesis will produce various result of performance. The design of hip prosthesis and the material properties like mechanical strength is an important factor for the prosthesis. By understanding the design concept and mechanical properties on material selection, the optimum product of hip joint can be produce. The design and material toughness of the hip replacement is the criteria to make the prosthesis functioning last long.

1.2 Objectives

The overall aim of this project is to develop and validate methods by using finite element analysis based on stress and strain analysis on the three dimensional hip model developed using Finite element analysis software. It is clear that patient specific computational models have the potential to revolutionize the way that disorders of the hip joint are diagnosed and treated. However, first careful checked and validated the parameters that incorporate both computational and experimental techniques must be established.

The overall objectives of this project are:-

a) To design the hip joint prosthesis with two different shape using finite element analysis software.
b) To analyze the hip prosthesis on mechanical toughness on different material selection using finite element analysis software.
c) To optimise the design and material for the hip joint prosthesis.

1.3 Scopes of Project

The study concentrates on the design and analysis using finite element software of the hip joint prosthesis while implementing to the human body. The scope of study is briefly as follow:-

a) Structural design and material selection analysis using Ansys software
b) Structural analysis of the prosthesis excluding the hardware fabrication and physical mechanical test

1.4 Gantt Charts

To ensure the project is accomplished on time, a Gantt charts has been built to show out the schedule of the project flow. It is a guide and useful method which is use to assist in tracking and monitoring the entire project progress. Attachment **Appendices A** is the Gantt chart of the PSM 1 and **Appendices B** for PSM 2.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In order to accomplish this project, the knowledge about the tools and procedure that will be used will be identified. This chapter explain in detail of the hip joint prosthesis, materials were used and reason to do the hip joint prosthesis.

The development of prosthetic hip joint is about a relation and integration between biomechanics and biomaterial. The knowledge of the joint biomechanics and the development of biomaterial are important for the hip joint prosthesis. The important element must be identified to perform structure alteration so the normal distribution of strength can been done to the artificial bone.

Figure 2.1: Typical Hip Joint Prosthesis (Zimmer Inc., 2010)

One of the most disturbing problems in hip joint prosthesis is the wear of acetabular cup. With an increase in number of articulations, a significant volume of material loss occurs (Pyburn & Goswami, 2004) by performed a finite element analysis to determine the stress distribution during the weight-bearing conditions for different stem shape. A stem design with broad lateral areas help transfer more loads during normal human activity and reducing the risk of hip prosthesis failure. Similar finite element studies (Pyburn E, Bennet & Goswami 2004) were performed to evaluate the importance of hip stem design for a successful total hip replacement. In a study reported by the author (Bhatt, 2008), several wear mechanisms were studied to examine the wear behaviour leading to prosthetic component loosening leading to hip dislocation. Four major contributing factors included in the study of wear rate were surface roughness, clearance between articulating surfaces of femoral head and acetabular cup liner, coefficient of friction, and sliding distance.

Although computational models have provided substantial additional insight to hip biomechanics above and beyond that obtained through experimental studies, substantial voids remain. In particular, simplifying model assumptions have often resulted predictions that are inconsistent with experimental measurements. Most models have not been validated by direct comparison with experimental data.

2.2 History

The hip joint can be affected by numerous pathological conditions like arthritis, rheumatoid arthritis, aseptic osteoporosis, results of trauma and others were determine an important functional deficit due to pain and stiffness. One can therefore easily understand why the possibility of a surgical treatment able to eliminate pain and restore joint mobility has always fascinated orthopaedic surgeons. The first attempts were made by orthopaedic physician who consists of the interposition of a biological material between the model joint surfaces. The first hip joint prosthesis surgical with the use of a bio material was performed 60 years ago when Smith-Petersen on 1939 interposed a metallic cup of chrome-cobalt alloy (vitallium) between the head of the femur and the bone socket. After the experience of Moore and Bohlinan on 1943, the first substitution of the femoral head on a large scale is owed to the Judet brothers (1946), who used a femoral head in polymethylmethacrylate (PMMA) linked to a stem that was inserted in the femoral neck as far as the lateral cortex. (Judet and Judet, 1950).

All these prosthesis were failures, either the cause by biomechanical or biomaterial. Subsequent to these failures, the prosthesis was made of chrome cobalt alloy. After other experience in substituting the femoral head using different kinds of materials by using material like Bakelite, ivory and stainless steel. The first end prosthesis with end medullar stem is owed to Austin Moore on 1943. His prosthesis, which was afterward widely used, was of chrome cobalt alloy, with a holed-in stem to allow bone growth and a collar to be placed on the femoral. A change in the prosthesis of Moore was made by Thompson on 1954.

The first total substitution of the hip joint prosthesis was due to McKee and Farrar, when in 1956 they began the era of prosthetic substitution of the hip. The prosthesis of McKee and Farrar on 1966 was of chrome cobalt alloy and constituted by a large head with diameter of 40 mm linked to a stem similar to Thompson's, to be inserted in the medullar canal and articulated with a bone socket, also made of chrome cobalt alloy. Originally the prosthesis was fixed with screws, and then it was cemented with acrylic cement, thanks to the research of Charnley on 1970. The prosthesis of McKee and Farrar has been modified by Postel with the insertion, into the acetabular cup in order to reduce friction and favour lubrication.

However, the development and extensive spread of the total prosthesis the hip is owed to John Charnley (1961, 1979), who introduced low friction prosthesis and the routine use of acrylic cement as means to fix the prosthetic stem to the femoral canal and the acetabular cup to the pelvis. The prosthesis of Charnley was used on a large scale and is still in use today, even if small changes have been made to the original model. It is made of a stainless steel stem with a small head with diameter of 22 mm, the stem is inserted in the medullar canal of the femur, previously modelled with a broach of corresponding form, and fixed to the bone with acrylic cement (PMMA). The bone socket was originally made of Teflon, but afterward was given up because of numerous failures due to rapid wear and consequent tissue reaction. After numerous attempts and research the best material was shown to be ultrahigh molecular weight polyethylene (UHMWPE). The cementation of the prosthetic component and the metal- polyethylene coupling allowed one to obtain a high rate of success. The result prosthesis with these characteristics were numerous, but all with heads of larger diameter. the prosthesis of Muller with a head diameter of 32 mm, the prosthesis of Bucholz with 38 mm, the trapezoidal prosthesis of Amstutz with 28 mm, and several others.

The aim of reducing bone resections to a minimum and preserving the bone patrimony brought up the idea of the resurfacing prosthesis (Muller, 1970), but the high rate of failures, both numerous and precocious, made them give up. On time passing by and the increasing spread of the prosthesization of the hip, it became evident that one of the more frequent problems of joint prostheses was the stability of the fixation of the prosthetic component to the bone.(Barbucci R.,2002)

Figure 2.2: Hip Joint Prosthesis on Human Skeleton (Orthodoctor.com)

Chronological of hip joint replacement techniques and materials development have been discussed in detail in this paper and a summary of prosthesis developments presented shortly below.