EVALUATION OF VARIOUS MILLING STRATEGIES IN SUPPORTING ADVANCED CAD/CAM ENVIRONMENT FOR BIOMEDICAL APPLICATIONS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical – Advanced Manufacturing Technology)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JUNE 2015

To my beloved mother **Fatimah@Zaharah Binti Awang**

To my beloved wife **Umi Kalthom Binti Abdullah**

To my beloved princess **Nurul Iman Damia**

To my beloved prince **Mohammad Uzair**

ACKNOWLEDGEMENTS

In the name of Allah, the most Gracious and most compassionate

First and foremost, I thank Allah S.W.T for blessing and giving me strength to accomplish this study.

My sincere gratitude to my supervisor, Dr. Aini Zuhra Binti Abdul Kadir, for her guidance and supervision throughout the tenure of this study. It would not be possible without her invaluable support, advice, on-going motivation and encouragement.

I am also indebted to Majlis Amanah rakyat (MARA) for providing funding assistant during my study. Special thanks to all my Master colleagues that have morally helping me conducting this research. As also thank you to the management of Kolej Kemahiran Tinggi MARA (KKTM) Balik Pulau for allowing me to use their facilities in conducting the research.

Last but not least, a special dedication to my beloved mother; Fatimah@Zaharah Binti Awang, my beloved wife; Umi Kalthom Binti Abdullah, my princess; Nurul Iman Damia and my little prince Mohammad Uzair, that has been the source of my strength and inspiration, as well as siblings and close friends, for their unconditional support and love.

ABSTRACT

The purpose of this study is to simulate various types of milling strategies for knee implant that provides the shortest machining time with integration of conceptual algorithm based on high level data structure known as STEP-NC. STEP-NC, an acronym for Standard for the Exchange of Product Model Data for Numerical Control is developed by the ISO committee with the intention of replacing the outdated G-codes used for machine execution. STEP-NC may provide comprehensive information such as material properties, part feature, the best machining time on cutting strategies and working step for the process. In this study, three cutting strategies such as Spiral, Helical and Concentricused in roughing and strategies of multi axis sweeping with tool axis mode Lead and Tilt, Thru a guide and Normal to Surfaceused in finishing process were simulated using traditional CAD/CAM environment using CATIA V5R19to analyze the shortest machining time in machining a knee implant model. The constant parameters were Feed/tooth 0.01 mm, Cutting Speed 40 m/min and Tool Diameter 10 mmwhile variable include Depth of cut 2mm and 3mm, Tooth Path Styles Spiral, Helical and Concetric and tool path overlap 50% and 75% for roughing process. While for finishing process, the constant parameters were Feed/tooh 0.01 mm, Cutting Speed 60 m/min, Depth of cut 0.2 mm and Tool Diameter 6mm Bull Nose while variable include multi axis sweeping with tool axis mode Lead and Tilt, Thru a guide and Normal to surface. From the simulation results, it was found that the best machining time is helical strategy for roughing process completed at 4 hours 23 minutes and 27 secondsand tool axis mode with lead and tilt for finishing process at 4 hours 7 minutes and 5 secondsas compared to others having a machining time of more than 4 hours 24 minutes and 26 seconds. In supporting the development STEP-NC standard, a conceptual algorithm model to portray an advanced CAD/CAM environment was proposed. The conceptual model may assist process planners to assign appropriate machining strategies where the interface may suggest a suitable tool path with the shortest machining time for complex features. In conclusion, various machining strategies can be evaluated with respect to various input parameters in giving a shortest machining time with better accuracy results.

ABSTRAK

Kajian ini di lakukan adalah bertujuan untuk mensimulasikan pelbagai jenis strategi pemotongan terhadap model implant kepala lutut bagi mendapatkan masa pemesinan yang paling singkat dan mengintegrasikan prototaip STEP-NC sebagai sokongan terhadap sistem data yang tinggi. STEP NC dibangunkan oleh jawatankuasa ISO untuk menggantikan G kod yand sedia ada yang digunakan bagi pengoperasian mesin. G kod hanya mengatucarakan mesin dari titik ke titik untuk di operasi dan banyak kekurangan maklumat yang diperlukan seperti parameter-parameter pemesinan, ciri-ciri model dan kepantasan masa pemesinan tidak dapat di paparkan di peringkat pengatucaraan CNC. Di samping itu juga, pembekal berlainan pengoperasian mesin di khaskan untuk pembekal itu sahaja dan tidak boleh dintegrasikan bersama. Lain pula dengan STEP-NC yang boleh menyediakan struktur data dan berupaya memberikan maklumat-maklumat yang di perlukan seperti sifat-sifat bahan, kepantasan masa sesuatu kaedah operasi pemesinan, ciri-ciri bahagian, dan langkah kerja untuk proses pemesinan dapat di laksanakan. Dalam tesis ini, tiga kaedah pemotongan '*spiral,' helical'* dan '*concentric'* untuk proses pemontogan kasar dan tiga kaedah pomotongan '*lead and titl'*, '*thru a guide'* dan '*normal to surface'* bagi pemotongan akhir telah dilakukan simualasi menggunakan cara tradisi dengan menggunakan perisian CATIA V5R19 untuk menganalis masa pemesinan terpantas dalam pemesinan model kepala lutut. Parameter malar yang digunakan adalah *Feed/tooth* 0.01 mm, *Cutting Speed* 40 m/min d*an Diameter* alat pemotongan 10 mm, sementara itu parameper bolehubah adalah kedalaman pemotongan 2mm dan 3mm, *Tooth Path Styles* adalah Spiral, Helical dan Concetric dan *Tool Path Overlap* adalah 50% dan 75% untuk pemontongan kasar. Manakala untuk pemontongan akhir parameter malar adalah *Feed/tooh* 0.01 mm, *Cutting Speed* 60 m/min, kedalaman pemotongan 0.2 mm dan Diameter alat pemotongan 6mm Bull Nose sementara itu parameter boleh ubah adalah *multi axis sweeping* dengan *tool axis mode Lead and Tilt*, *Thru a guide* dan *Normal to surface*. Daripada keputusan simulasi yang telah dijalankan telah didapati masa pemesinan terbaik adalah jenis potongan helical untuk pemotongan kasar dengan masa 4 jam 23 minit 27 saat dan Tool Axis Mode dengan Lead and Tilt untuk pemotongan akhir dengan masa 4 jam 7 minit 5 saat berbanding dengan masa pemesinan lebih dari 4 jam 24 minit 26 saat. Dalam menyokong pembangunan piawain STEP-NC, satu model konsep algorithm mengambarkan persekitaran CAD/CAM termaju telah dicadangkan. Model konsep tersebut boleh membantu perancang proses untuk menetapkan strategi pemesinan yang sesuai dengan memudahkan pilihan masa pemesinan terbaik bagi bentuk yg komplek. Kesimpulannya, pelbagai strategi pemesinan boleh di nilai dengan pelbagai parameter didalam memberi masa pemesinan terpantas dengan keputusan yang lebih baik.

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i.	Application Interpreted Model	AIM
ii.	Application Reference Model	ARM
iii.	Brinnel Hardness	HB
iv.	Computer Numerical Control	CNC
v.	Computer Aided Manufacturing	CAM
vi.	Cobalt Chromium	CoCr
vii.	International Electrotechnical Commission	IEC
viii.	International Standard Organization	ISO
ix.	Nickel	Ni
x.	Nickel Titanium	NiTi
xi.	Numerical Control	NC
xii.	Revolution Per Minute	RPM
xiii.	Standard for the Exchange of Product Model	STEP
xiv.	Stainless Steel	SS
xv.	Spindle Speed	N
xvi.	Ultimate Tensile Strength	UTS
xvii.	Yield Strength	YS
xviii.	Young Modulus	YM

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Metal has been used as implants since 100 years ago. Advancements in biomaterials turn massively in biomedical devices industry. Materials that to be used for biomedical material need not cause host response for tissue necrosis in the body. Up to now, three most used metal implants are stainless steel, Cobalt Cromium alloys and Titanium alloys. To use or choose these three materials are depend on the specific implant applications. Specific implants applications are Cardiovascular, Orthopaedic, Dentistry, Craniofacial and Otorhinology.

Whatever implant division and type of metals that to be used, the important is that they do not possess bio-functionalities like blood compatibility, bone conductivity and bioactivity. Hence, surface modifications are required. Improving their bone conductivity has been done by coating with bioactive ceramics like hydroxyapatite or blood compatibility by coating with biopolymers.

For orthopaedic implants, metals are required to have excellent toughness, elasticity, rigidity, strength and resistance to fracture. For total joint replacement, metals are needed to be wear resistance; therefore debris formation from friction can be avoided. Stainless steel is a very strong and corrosion resistant alloy. There are many different types of stainless steel. The austenitic stainless steels (Chromium-Nickel stainless class), particularly types 316 and 316L, are most widely used for orthopaedic implants. The stainless steels used in orthopaedic implants are designed to resist the normal chemicals found in the human body. Cobalt-chromium alloys are also strong, hard, biocompatible, and corrosion resistant. They are particularly preferred for their high strength. These alloys are used in a variety of joint replacement implants, such as hip replacement and knee replacement where high strength is required. While cobalt-chromium alloys contain mostly cobalt and chromium, they also include other metals, such as molybdenum, to increase their strength. Titanium alloys are considered to be biocompatible. The lightness and good mechano-chemical properties make them increasingly popular in orthopaedic implant. They are also the most flexible of all orthopaedic [1].

To do the machining for these orthopaedic biomedic materials is tough enough. These due to cutting speed of these material is low. Cutting speed also called surface speed or simply speed is the speed difference (relative velocity) between the cutting tool and the surface of the workpiece it is operating on. It is expressed in units of distance along the workpiece surface per unit of time, typically surface feet per minute (sfm) or meters per minute (m/min). When the cutting speed is low so the feed rate for the tool travel going through to the material is low. Feed rate also often styled as a solid compound, feedrate, or called simply feed is the relative velocity at which the cutter is advanced along the workpiece; its vector is perpendicular to the vector of cutting speed. Feed rate units depend on the motion of the tool and workpiece; when the workpiece rotates (e.g., in turning and boring), the units are almost always distance per spindle revolution (inches per revolution or millimeters per revolution). When the workpiece does not rotate (e.g., in milling), the units are typically distance per time (inches per minute or millimeters per minute), although distance per revolution or per cutter tooth are also sometimes used. Feedrate also is depending on the types of tool material to be used. Normally used is high speed steel and carbide insert. High Speed Steel and Carbide Insert also depend on the grade of what material to be cutting. It ranges from low toughness to high toughness. Because of these, biomedical material is having high toughness and need low cutting speed. Therefore, the feed rate should not be too high, and the time required to do the machining is normally long. Machining time is a total tool path length divided to the feed rate that has been used. If the length of the tool path is long, machining time required is also long. In addition, if the feed rate is low, the machining time is also higher.

There are many cutting strategies for the toolpath inside the CAD software such as CATIA. For roughing process, cutting strategies normally include Spiral, Helical, Zigzag and Concentric. While for finishing are Sweeping, Multi Axis Sweeping, Isoparametric, Contour Driven, Multi Axis Contour Driven and Profile contouring. The study aims to compare these various strategies in obtaining the best machining time. The cutting strategies or tool path styles that are selected are Spiral, Helical and Concentric for the roughing process. While for the finishing process, the tool path style includes Sweeping for 2D finishing and Multi Axis Sweeping for 3D finishing. For Multi Axis Sweeping, the suitable Tool Axis Mode needs to be selected. Three Tool Axis Modes are selected and to be compared. There are Lead and Tilt, Thru a guide and Normal to Surface.

In the current machining simulation practice, the user will analyze each one of the strategies in order to check the machining time of the tool paths. This can be time consuming. Machining parameters such as tolerance information, feature information and cutting tools information are missing and cannot be utilized at computer numerical controlled (CNC) level. STEP-NC, an acronym for Standard for the Exchange of Product Model Data for Numerical Control was designed to replace ISO 6983/RS274D or G-codes with a modern, associative communications protocol that connects CNC process data to a product description of the part being machined.

Part 10 for STEP NC is the part of ISO 14649 specifies the process data which is generally needed for NC-programming within all machining technologies. These data elements describe the interface between a computerised numerical controller and the programming system (i.e. CAM system or shop-floor programming system). On the programming system, the programme for the numerical controller is created. This programme includes geometric and technological information. It can be described using this part of ISO 14649 together with the technology-specific parts (ISO 14649-11, etc.). This part of ISO 14649 provides the control structures for the sequence of programme execution, mainly the sequence of working steps and associated machine functions [18]

The "machining_schema" defined in this part of ISO 14649 contains the definition of data types which are generally relevant for different technologies (e.g. milling, turning, grinding). The features for non-milling technologies like turning, EDM, etc. will be introduced when the technology specific parts like ISO 14649-12 for turning, ISO 14649-13 for EDM, and ISO 14649-14 for contour cutting of wood and glass are published. It includes the definition of the workpiece, a feature catalogue containing features which might be referenced by several technologies, the general executables and the basis for an operation definition. Not included in this schema are geometric items and representations, which are referenced from ISO 10303's generic resources, and the technology-specific definitions, which are defined in separate parts of ISO 14649 [18].

This part of ISO 14649 cannot stand alone. An implementation needs in addition at least one technology-specific part (e.g. ISO 14649-11 for milling, ISO 14649-12 for turning). Additionally, the schema uses machining features similar to ISO 10303-224 and ISO 10303-214. The description of process data is done using the EXPRESS language as defined in ISO 10303-11. The encoding of the data is done using ISO 10303-21 [18].

Therefore, this study intended to simulate three cutting strategies of roughing process which are spiral, helical and concentric and three cutting strategies of finishing which are lead and tilt, thru a guide and normal to surface to provide the shortest machining time of knee implant model. The study also intended to propose a machining strategies conceptual algorithm utilising STEP-NC as a data structure.

1.2 Problem Statement

Manufacturing worldwide always ask for faster and become fastest. Slowest manufactured suffered of cost lost is waiting. Machining produced biomedical knee implant is tough enough and expensive to machine. To machine this type of biomedical material need a careful analysis in determining the best machining time with best strategies to reduce the wasting cost. One of the machining strategies is tool path styles.

The length of the toolpath styles plays a very important role in the performance of machining time. Wrong choose of toolpath styles, the length of tool travel become longer that can be effect of machining time. The best machining time is the shortest length of tool path. So, in this study is to do the comparing which is the shortest length of tool path travel by types of toolpath styles that have been selected. Due to the model is knee component and very curvy surface area so machining milling operation divided by roughing, semi finishing and finishing process. Each of single process was different of tool path styles. For roughing process used spiral, helical and concentric toolpath styles. For semi finishing used sweeping. While for finishing process used multi axis sweeping with three different tool axis modes. The tool axis mode that be tested were lead and tilt, thru a guide and normal to surface.

In the current machining simulation practice, the user needs to analyze the toolpath cutting strategy manually. They need to test one by one which is the best machining time to use. If many parts to be tested, a lot of time is wasted from the trial and error activities. Furthermore, analysis will still need to perform for each strategies involved. Figure 1.1 illustrated a flow chart to choose machining time in current NC practice.

A new standard, STEP-NC, aims to overtake these lacks. A STEP-NC file includes all the information for manufacturing, as geometry description of the entities, workplane, machining strategies, tools, etc.

STEP-NC has the advantage of holding a set of comprehensive machining data and therefore is suitable to perform various optimization analyses which include the best machining time from various cutting strategies. In this case, the best machining time is the shortest time where the tool travels during machining. If cutting path incur the highest time, then it can affect the cost of the product and becomes uneconomical.

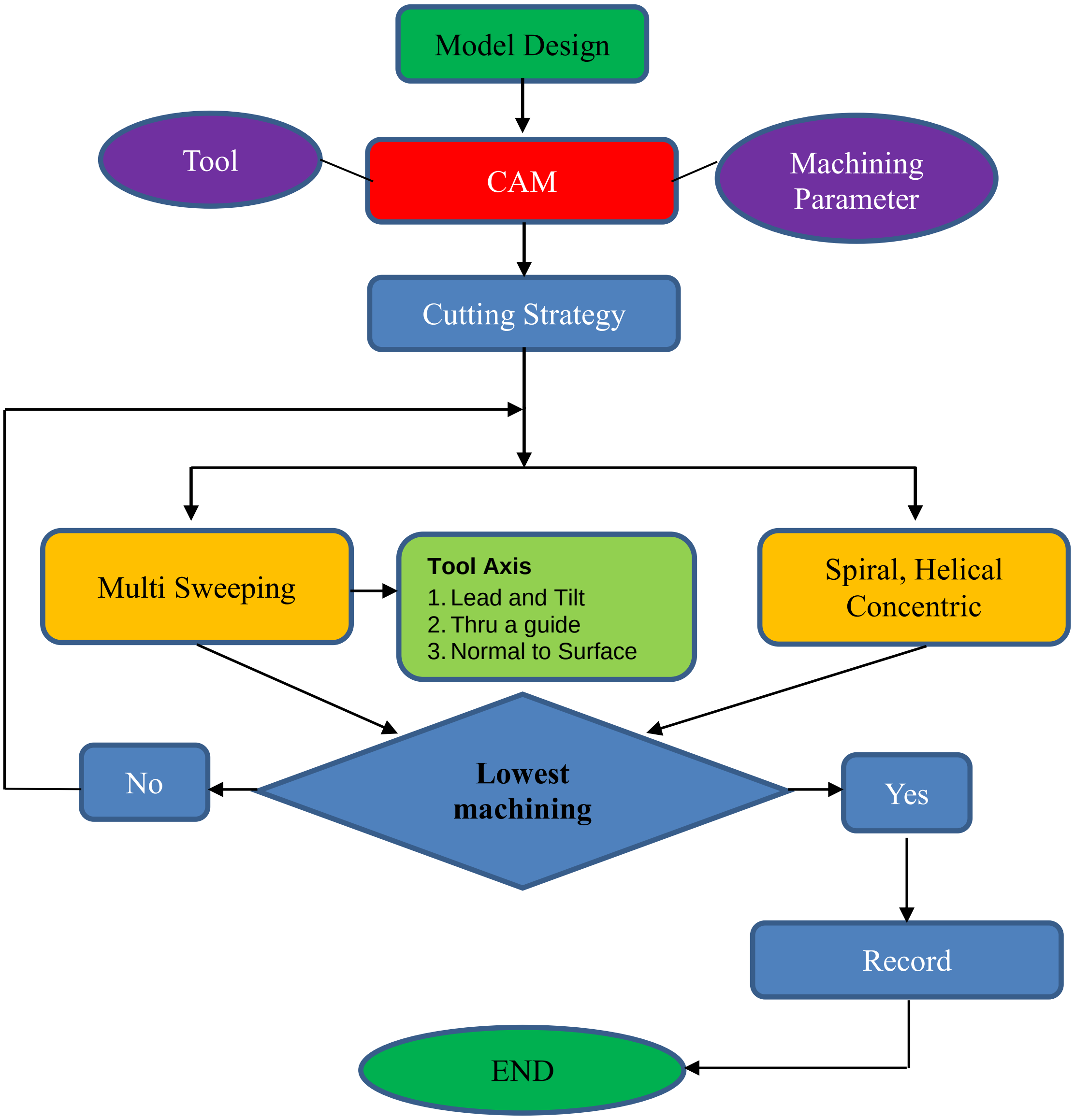

Figure 1.1: Flow chart to choose machining time for current NC

1.3 Objectives of the study

The objectives of this research are to:

i. Simulate various types of milling strategies for knee implant that provide shortest machining time.

ii. Propose a machining strategies conceptual algorithm utilising STEP-NC as a data structure.

1.4 Scope of the study

i. The material used is Ti6Al4V.

ii. The parameters considered is Cutting Speed (m/min), feed/tooth (mm), depth of cut (mm).

iii. The tool that use is High Speed End Mill with Carbide

iv. Model that used Knee Implant Femoral Component

v. Cutting strategies that use which are

   Roughing Process: Spiral, Helical and Concentric

   Finishing (2D): sweeping

   Finishing (3D): Multi Axis Sweeping with Tool Axis mode are Lead and Tilt, Thru a guide and Normal to Surface

vi. Simulation Software : CATIA V5R19

vii. Data structure based on STEP-NC is used in supporting CAD/CAM environment. STEP-NC (ISO 14649 Part 10, 11, 111, 21).

1.5 Thesis outline

The thesis is divided into five chapters. Chapter 1 is an introduction to the research which explains the overview about the biomedical material, cutting simulation analysis strategies, STEP-NC as high level data structure as well as the objectives and scopes of the study. Chapter 2 is literature review which explains about the biomedical materials, machining parameters analysis, comparison between current standard NC and STEP-NC and data collection of previous research regarding the machining strategies. Chapter 3 elaborates about the methodology to conduct the simulation analysis using CATIA software and machining strategies propose a conceptual algorithm STEP-NC utilizes as a data structure. Chapter 4 is about some preliminary work to familiarization of software CATIA and explanations about the results and data analysis covering all the machining strategies that have been explain in previous chapter. Chapter 5 concludes the thesis and highlights the recommendation for future improvement.

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