UNIVERSITI TEKNIKAL MALAYSIA MELAKA

OPTIMIZATION OF CUTTER PATH FOR MACHINING COMPLEX 3D SURFACE

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

by

SITI NORASHIKIN BINTI ZOLKAFLEE
B050910101
900715065240

FACULTY OF MANUFACTURING ENGINEERING

2013

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **Optimization of Cutter Path for Machining Complex 3D Surface**

SESI PENGAJIAN: **2012/13 Semester 2**

Saya **SITI NORASHIKIN BINTI ZOLKAFLEE**

mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)

☐	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)
☐	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
☑	TIDAK TERHAD	

Disahkan oleh:

(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat Tetap:

No 458 BLOK 20

FELDA CHINI 2

26690 PEKAN, PAHANG

Cop Rasmi:

Tarikh: ____________________

Tarikh: ____________________

** Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled “Optimization of Cutter Path for Machining Complex 3D Surface” is the results of my own research except as cited in references.

Signature	:	……………
Author’s Name	:	SITI NORASHIKIN BINTI ZOLKAFLEE
Date	:	3 JUNE 2013

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 Process) (Hons.). The member of the supervisory is as follow:

……………………………….

(Dr Raja Izamshah Bin Raja Abdullah)

DEDICATION

Special dedicated to my beloved father En. Zolkaflee bin Md Zanan and my mother Ismingaton binti Giman where consistently and patiently supporting me in this research and lastly for all friends of their help and friendship.

ACKNOWLEDGEMENT

In preparing this thesis, there are too many people I am indebted to in this world. They have contributed towards my understanding and thought. First of all I would like to express my gratitude to ALLAH s.w.t for blessing on me though this while in completing this research. I also would like to thanks to all those who gave me strength and encourage completing this Project Sarjana Muda (PSM) especially to my main supervisor Dr Raja Izamshah Bin Raja Abdullah. He had been so helping me thought his advice and time he spent just to ensure accomplishment of this project. My humble appreciation also goes to technician En. Fauzi and En Hanafiah for his valuable guidance and advice. Last but not least, I would like to say my special thanks to my entire friend for their help, my parent and family where their patient and encouragement to help me always to be right track.

ABSTRACT

Accuracy of machined components is one of the most critical considerations for any manufacturer. These challenges include the introduction of complex geometry and difficult to machine alloys. Monolithic parts are utilized in the aerospace industry to reduce stresses, prolong service life, and reduce weight. The fabrication of parts with these features is associated with high cost, induced by higher machining time and material cost, as compared to aluminum or hardened steel. In a competitive industrial environment the production cost must be reduced. This can be achieved through the reduction of the number of manufacturing processes; the complex part geometries require the use of sophisticated computer aided manufacturing (CAM) tools.

This report investigates the machining performance using the step strategy for machining complex 3D surface. Four different step strategies namely parallel, scallop/constant stepover, contour and pencil are investigate by evaluating their machining performance on machining the complex 3D surface made of aluminum alloy.

ABSTRAK

Ketepatan komponen dimesin adalah salah satu pertimbangan yang paling penting bagi mana-mana pengilang. Cabaran-cabaran ini termasuk pengenalan geometri kompleks dan sukar untuk aloi mesin. Bahagian monolitik digunakan dalam industri aeroangkasa untuk mengurangkan tekanan, memanjangkan jangka hayat perkhidmatan, dan mengurangkan berat badan. Fabrikasi bahagian dengan ciri-ciri yang berkaitan dengan kos yang tinggi, disebabkan oleh masa pemesinan dan kos bahan yang lebih tinggi, berbanding dengan aluminium atau keluli keras. Dalam persekitaran perindustrian yang berdaya saing kos pengeluaran mesti dikurangkan. Ini boleh dicapai melalui pengurangan bilangan proses pembuatan; geometri sebahagian kompleks memerlukan penggunaan komputer yang canggih dibantu pembuatan (CAM) alat.

Laporan ini menyiasat prestasi pemesinan menggunakan strategi langkah untuk pemesinan permukaan 3D kompleks. Empat langkah strategi yang berbeza iaitu selari, kapis / stepover berterusan, kontur dan pensil menyiasat dengan menilai prestasi pemesinan mereka pada pemesinan permukaan kompleks 3D diperbuat daripada aloi aluminium.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

%	-	Percentage
°	-	Degree
°C	-	Degree Celsius
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
CMM	-	Coordinate Measuring Machine
CNC	-	Computer Numerical Control
HEM	-	High Efficiency Machining
HSM	-	High-Speed Machining
HSS	-	High-Speed Steel
NC	-	Numerical Control
Ra	-	Average Roughness

CHAPTER 1

INTRODUCTION

1.1 Background

Advances in the aerospace industry have created several engineering challenges. These challenges include the introduction of complex geometry and difficult to machine alloys. Monolithic parts are utilized in the aerospace industry to reduce stresses, prolong service life, and reduce weight. The fabrication of parts with these features is associated with high cost, induced by higher machining time and material cost, as compared to aluminum or hardened steel. In a competitive industrial environment the production cost must be reduced. This can be achieved through the reduction of the number of manufacturing processes; the complex part geometries require the use of sophisticated computer aided manufacturing (CAM) tools.

The CAM tools must have the capability to handle multi-axis programming, detection and avoidance of tool gouging and collision, in addition to proper tool selection. The CAM software should also include the capability of predicting cutting forces, temperature, tool deflection and process dynamics. The use of five-axis milling is preferred to reduce the geometric errors generated during 3-axis machining. However, five-axis milling is a very complex process that involves several tasks (e.g.; tool orientation, gouge and collision avoidance). Ball nose end mills are widely used in multi-axis milling to facilitate the tool orientation process. This may result in geometric errors in the form of scallops. These errors need further finishing operations to reach the desired surface finish.

However, to reduce the geometric errors, a very dense tool path should be created. This may result in very lengthy CNC programs that are difficult to handle by the machine tool controllers. To improve the manufacturing process efficiency, other types of milling cutters (flat, filleted, conical, etc.) are introduced to five-axis milling. The new cutter geometries led to the reduction of CNC program size, while reducing the surface error by better matching the tool geometry with the part surface. On the other hand, the cutter positioning and gouging problem becomes more complex. Several checks became essential to detect and avoid undercuts and back gouging. (Amro Youssef.M , 2004)

1.2 Problem Statement

Process efficiency and product quality are essential to the competitiveness of manufacturing industries. The continuing challenge is to make parts within the specified tolerance and with the least amount of time and cost. In the machining industry, high quality and cost effective machining can be achieved by the optimization of the machining processes. Traditional experience-based process planning methods often generate less than optimal machining plans and tend to be conservative in the selection of cutting conditions. The conservative cutting conditions represent low machining efficiency and do not always guarantee quality in the machining of complex parts. Out-of-tolerance machined products are not uncommon in practice. As a result, it is very important to develop a process optimization method that is based on scientific knowledge of machining and is able to generate optimized process plans to achieve highest machining efficiency and to ensure product quality.

Quality of the complex parts is directly evaluated with its measure performance such as surface finish and dimensional accuracy. While the machining performance can be evaluated as a function of machining time, tool wear and cutting force.

A lot of research has been conducted for determining optimal cutting parameters in machining complex parts. However, the machining performance is also affected by the cutter path strategies. For optimizing the machining process, a proper selection of cutter path strategies must take into account and should not be neglected. As there was several operation strategies or the algorithm for island machining such as tanto fan, combin tanto, and combin parelm which are axis tool path, the machining performance, the properties and the final result of the workpiece will be differentiate. Therefore, it is essential to investigate the effects of axis toolpath on machining performance in complex parts milling.

1.3 Objective

The objectives of the project are:

i. To study the step machining axis tool path namely tanto fan, combin tanto and combin parelm.
ii. To evaluate the machining performance of each axis tool path for machining the complex 3d surface.
iii. To determine the best axis tool path in defined tool path for machining complex 3d surface to get the better surface finishing.

1.4 Scope of Project

This project focuses on the effects of different step machining strategies detailing in differences of the tool axis on the machining performances for milling complex 3d surface. Three different tool axis namely tanto fan, combin tanto and combin parelm are generated. A 10 mm carbide endmill cutter is used for machining of aluminium and too steel workpiece. The machining performances include machining time, dimensional accuracy, and surface roughness were measure for results evaluation.

CHAPTER 2
LITERATURE REVIEW

2.1 Milling

Milling is a type of machining process that involves material removal. In milling, the workpiece will be cut to remove the unwanted part in order to get the shape and the dimension. Milling can be seen as the wide range of material removal process which It involving the process of cutting, shaping, grinding and finishing. All of this process can be categorized in as milling as the process involved the removal by the act of cutting tool that rotates across into the workpiece. According to Smith (2008), basically, milling is an operation that involves a coordinated linear, or multiple axis feeding motion of the multi-edged cutter as it rotates across into the workpiece. A milling operation is an 'intermittent cutting action', where each individual cutting insert continuously enters and exit the cut, unlike turning, which is basically a continuous machining operation, once the cut has been engaged.

Milling process typically used to produce parts that are not axially symmetric and have many features, such as holes, slots, pockets, and even three dimensional surface contours. Parts that are fabricated completely through milling often include components that are used in limited quantities, perhaps for prototypes, such as custom designed fasteners or brackets. Another application of milling is the fabrication of tooling for other processes. For example, three-dimensional molds are typically milled. Milling is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that milling can offer, it is ideal for adding precision features to a part whose basic shape has already been formed.

2.2 5 – Axis Milling Machining

5-axis computer numerical controlled (CNC) machine tools are widely used in machining dies, molds, turbine blades, and aerospace parts. These parts usually have complex geometry and are represented by parametric or free-form surfaces. As compared to 3-axis machining, the 5-axis machining offers many advantages such as higher productivity and better machining quality. In 5-axis machining, the orientation of the tool can be determined by the two additional degrees of freedom so as to obtain efficient cutter paths. To achieve high efficiency and interference-free cutter path planning, many algorithms for determination of the cutter path direction and interval and detection and avoidance of the cutter interference have been developed. Based on these algorithms that are implemented in a computer-aided manufacturing (CAM) system, the cutter paths that comprise cutter location and orientation trajectories are determined and represented by a series of linear or spline motion commands. To conduct on-line 5-axis machining, the motion commands generated by the CAM system are loaded to the CNC machine that adopts a real-time interpolator. The CNC interpolator can convert the cutter path to motion trajectories of the five separate axes in order to coordinate their motion in 5-axis machining. Many interpolators for different types of curves have been developed. Among them the linear and the spline interpolators are the most popular in parametric surface machining.

The cutting tools commonly used in 5-axis machining are end mill cutters. The cutter's end can be flat, spherical, or filleted. Fig.2.1 shows a typical filleted end mill cutter with a tool radius of *rt* and a corner radius of *rc*. (Lo C.C, 1997)

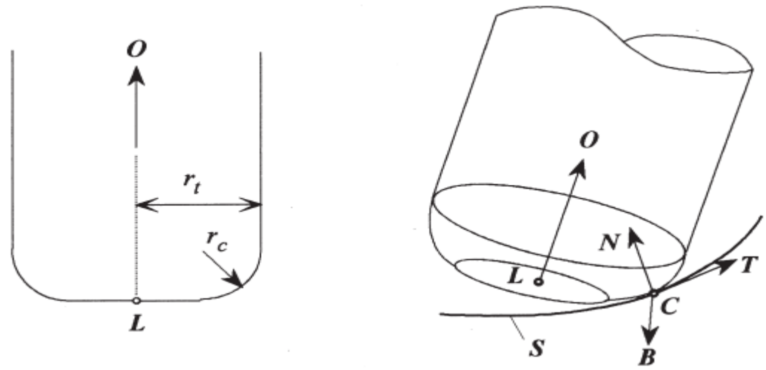

Figure 2.1: A filleted end mill cutter in machining of a sculptured surface.

2.3 End Milling

Kalpakjian.S et al (2006) has explained end milling is an important and common machining operation because of its versatility and capability to produce various profiles and curved surfaces. The cutter, called an end mill has either a straight shank which is for small cutter sizes or tapered shank which is for larger sizes and is mounted into the spindle of the milling machine. End mills may be made of high-speed steels or with carbide inserts, similar to those face milling. The cutter usually rotates on an axis perpendicular to the workpiece surface, and it also can be tilted to confirm to machine-tapered or curved surfaces. End mills are available with hemispherical ends (ball nose mills) for the production of sculptured surfaces, such as on dies and molds. Hollows end mills have internal cutting teeth and used to machine the cylindrical surfaces of solid, round workpieces. End milling can produce a variety of surfaces at any depth, such as curved, stepped and pocketed. The cutter can remove material on both its end and its cylindrical cutting edges. Both vertical spindle and horizontal spindle machines, as well as machining centers, can be used for end milling workpieces of various sizes and shapes. The machines can be programmed such that the cutter can follow a complex set of paths that optimize the whole machining operation for productivity and minimum cost.

2.3.1 Ball - End Milling

Ball-end milling has been widely used in the manufacture of free form surfaces such as those embodied in dies and moulds, turbine engine blades and aircraft structural components. Geometrical shapes of product become more and more complex and can be made only with ball-end milling on modern CNC machining centers. Prediction of cutting forces during milling with ball-end milling cutter is very important. In the cutting process planning stage the knowledge of cutting forces helps the technologist to determine the cutting parameters for machining. Prediction of cutting forces supports the process planning, the selection of suitable cutting conditions to reduce wear, tool deformation and breakage and the design of better fixing devices which improve the product quality. Basic models cutting forces in milling with ball-end milling cutter, presented in researches, are determined by means of theoretical and practical knowledge and experiments (Zuperl et al., 2005). Input parameters such as, cutting parameters, cutter geometry, cutter and workpiece material (Kopac et al., 2001) are needed for the determination of the model of cutting forces in ball-end milling. The output parameters and/or the model results are the cutting force. The analytical cutting force model for ball-end milling cutter is presented in our work.

2.4 Tool path in Milling Machining

Tool path is the path that a cutting tool traverses in order to remove material to create a shape. It includes series of coordinate positions that determine the movement of a tool during a machining operation. Considering the tool path in machining are really important because the tool path will exactly influence the machining performance and properties of the workpiece. There were some elements which need the tool path to be importantly considerate during the machining.

Modern machine shop (2011) has explained about the tool path in machining. Corners in the overall tool paths are an important consideration. In order to produce optimized tool paths for machining, the CAD/CAM system must be able to deal effectively with internal sharp corners in the workpiece. A corner treatment function for machining rounds the sharp motion out of the tool path. If allowed to remain, this sharp motion would be seen by the controller's look-ahead function, which would reduce the feed rate accordingly. A CAM system that can generate fluid tool motions during corner machining can maintain more consistent high feed rates. Knowledge of stock remaining allows tool paths to be created in areas where previous tools did not remove all of the material. There are many methods to remove this uncut material, including pencil tracing and rest milling. The tool path trajectory for these follow-up machining strategies is optimized based on the knowledge of stock remaining from the previous tool path. For example, the tool trajectory is optimized to protect the tool and the holder from gouging based on the remaining stock. Milling machining may also include helical ramping functionality that is used for pocket machining. The helical ramping function determines helical movement based on entry angle and geometry. This function is most important when the tool reaches a closed area of workpiece. It can make the cut shorter and safer by eliminating air cutting, as a result of tailoring the tool path to the geometry of the enclosed feature.

2.5 Strategy in Complex 3d Surface Milling

2.5.1 Zig Zag

The zig-zag pattern (shown in heavy dotted lines) is cut first. Then the outer tool path (light solid line) is cut. Regardless of the shape of the pocket or number of islands, only one starter cut is required at the beginning of the zig-zag. The tool may or may not be withdrawn and moved between completing the zigzag and starting the outer tool path.

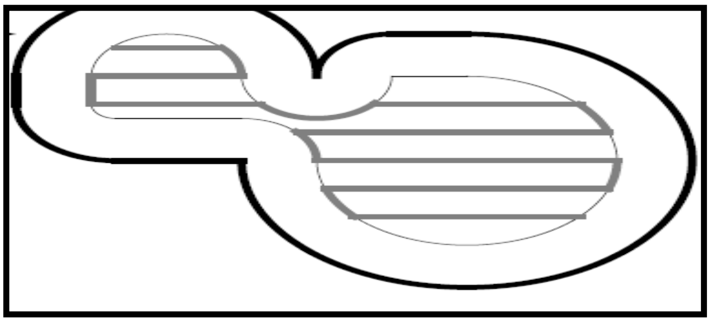

Figure2.2: Zig-Zag tool path (Kramer, 1991).

2.6 Axis Tool path in Complex 3d Surface Milling

2.6.1 Tanto fan

This is the basic strategy which ensures good continuity through the different tool motions. It is less used for flank contouring in structural parts as you don’t control collision with the drive. To a safety use, add a guiding curve. Tool is tangent to the