UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TOOL PATH COMPENSATION STRATEGY FOR MACHINING THIN WALL LOW RIGIDITY COMPONENT

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

by

MUHAMMAD ZAID BIN SALEH
B050910274
881003045013

FACULTY OF MANUFACTURING ENGINEERING
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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 (Process) (Hons.). The memberof the supervisory committee is as follow:

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ABSTRAK

Masalah utama yang dihadapi dalam proses pemesinan komponen berdinding nipis adalah berlakunya pesongan pada permukaannya yang mengakibatkan kesilapan dimensi pada permukaannya. Dinding pada permukaan bahan kerja memesong selari dengan pengurangan ketebalan bahan semasa proses pemotongan dilakukan pada bahan kerja. Bagi menyelesaikan masalah ini pengeluar telah mencuba pelbagai cara bagi mencari kaedah yang paling sesuai bagi proses pemotongan untuk menghasilkan komponen berdinding nipis. Terdapat beberapa kaedah atau strategi yang telah digunakan seperti penjadualan kadar suapan, melakukan perubahan pada keadaan pemotongan dan mengehadkan kuasa pemotongan dengan kaedah multi-pass. kaedah yang dilakukan ini mengurangkan ralat pada permukaan bahan tetapi juga mengurangkan produktiviti komponen yang dihasilkan. Projek ini membentangkan kaedah pampasan laluan alat untuk menghasilkan komponen berdinding nipis yang efektif dengan membuat perubahan pada laluan mata alat. Kaedah ini adalah bergantung kepada perubahan yang dilakukan pada laluan pemotongan mengikut nilai lebihanbahan yang tidak terpotong pada permukaan bahan kerja. Keberkesanan atau prestasi kaedah ini dinilai dengan mengira tahap ketepatan dan kekasaran pada permukaan bahankerja yang dihasilkan. Hasil daripada penyiasatan yang dijalankan menunjukkan bahawa pesongan yang berlaku pada bahan kerja meningkat disetiap kali pengurangan ketumpatan bahankerja. Kaedah yang telah digunakan telah berjaya mengurangkan lebihan pada permukaan sebanyak 85%.

ABSTRACT

The main problem associate with the machining of thin-wall component is the part deflection which resulting a dimensional surface error. The wall will deflect parallelly with the reduction in the thickness of the material during the material removal process. To solve this problem various attemps have been made in finding the most appropriate cutting method for producing the thin walled feature. There are several method or strategy were used such as scheduling feed rate, conservative cutting conditions and multi-pass machining to limit cutting forces. Such an approach reduces surface error but hampers productivity of machining operation significantly. This project presents a methodology for tool path compensation for effectively machining thin walled component by modifying the tool paths. The cutter compensation method is based on the adjustment of cutter path with respect to the magnitude of surface errors obtained from the preliminary machining with ideal cutter path. The effectiveness of the compensation strategy is then evaluated by measuring the component accuracy and the surface roughness. As a result of investigations carried out, show that the deflection that occurs at the workpiece was increase every time a decrease in density of the workpiece. The method has been used successfully to reduce the excess on the surface of 85%.

DEDICATION

Special dedicated to beloved mother, Mu'minah Binti Abdul Hadi, my beloved father, Saleh Bin Tahir

ACKNOWLEDGEMENT

Firstly i would like thank to Allah almighty for the love and giving me strength to complete this research. Thank to my parents Mu'minahBinti Abdul Hadi and Saleh Bin Tahir for the love, pray, support, the encouragement and guidance giving to me in complete this research.

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LIST OF ABBREVIATION, SYMBOLS AND NOMENCLATURE

%	-	Percent
2D	-	2 Dimension
3D	-	3 Dimension
Al	-	Aluminium
ANN	-	Artificial Neural Network
CAM	-	Computer Aided Manufacturing
CATIA	-	Computer Aided Three-Dimensional Interactive
CMM	-	Coordinate Measuring Machine
CNC	-	Computer Numerical Control
C^o	-	Degree Celsius
FEA	-	Finite Element Analysis
Gpa	-	Giga Pascal
HV	-	Hardness Vickel
kg	-	kilogram
m	-	meter
min	-	minute
mm	-	millimetre
Mpa	-	Mega Pascal
MYR	-	Malaysia Ringgit
NC	-	Numerical Control
PNN	-	Polynomial Neural Network
R_a	-	Arithmetic Average of Absolute Value
RPM	-	Revolution Per Minute
Ti	-	Titanium

CHAPTER 1
INTRODUCTION

1.1 Background

Machining of aerospace structural components involves several thin-wall rib and flange sections. These thin-wall sections are dictated by design consideration to meet required strength and weight constraints. These components are either forged or cast to the approximate final shape and the end milling process is used to finish machine the parts; or the component is machined from a solid block of material by end milling with roughing and finishing cuts.

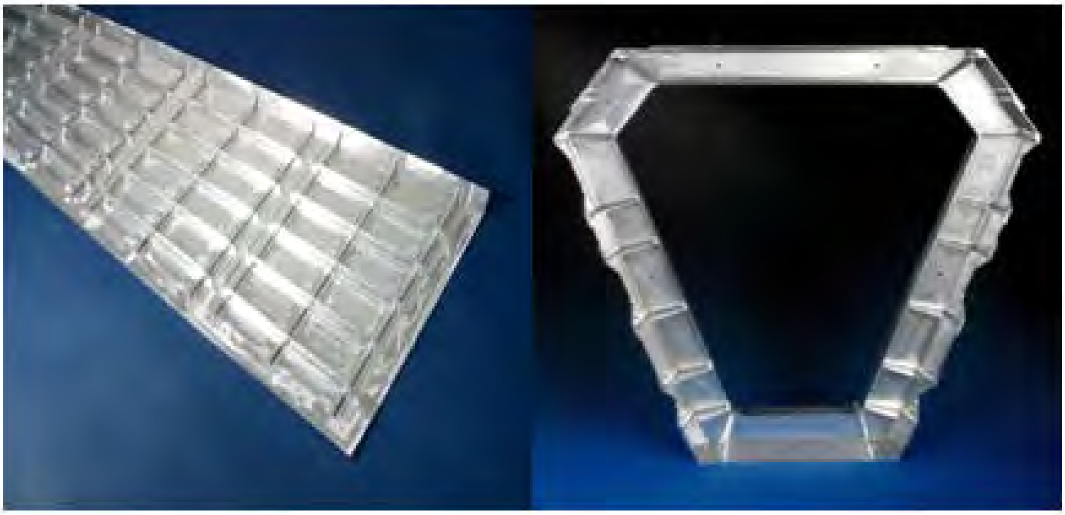

Figure 1.1 Monolithic component

Due to the poor stiffness of thin wall feature, deflection is more likely to occur in the machining of thin wall part. It is occur due to the force that generated during the machining process which resulting a dimensional surface errors at the thin wall feature. This research investigates the error compensation using tool path compensation strategy for machining thin wall low rigidity component.

1.2 Problem statement

To remain competitive, manufacturer constantly seeks to improve their product quality by producing 'right first time' machined component. The tight dimensional tolerance of aerospace component poses a great challenge for the manufacturer especially for machining a component that contains a thin-wall feature. Because of the poor stiffness of thin-wall feature, deformation is more likely to occur in the machining of thin-wall part which resulting a dimensional surface errors.

In current industry practice, the resulting surface errors are usually compensated through one or more of the following techniques: (i) using a repetitive feeding and final 'float' cut to bring the machined surface within tolerance; (ii) manual calibration to determine 'tolerable' machining conditions; (iii) a lengthy and expensive trial and error numerical control validation process; and (iv) using a step machining approach, which alternately milling each side of the surface.Distinctly all of these existing techniques on machining thin-wall feature have a tendency to lower productivity and difficulty in ensuring the component accuracy.

1.3 Objective

The objective of this study as follow:

i. To develop a tool path compensation strategy for milling thin-wall low rigidity component
ii. To evaluate the effectiveness of the compensation strategy by measuring the dimensional accuracy and surface roughness profile

1.4 Scope of the research

The scope of the research is to determine efficiency of the tool path compensation strategy to milling the thin wall feature using CNC milling machine. This research will find the error value of the surface of thin wall feature that produce by nominal tool path machining. Next, error compensation of the thin wall surface from the nominal tool path machining is determine and apply to the compensate strategy tool path. Workpiece material that beuse in this research is aluminium and the form of the workpiece is I beam form as one of the rib structure at the monolithic component. The effectiveness of the compensation strategy is then evaluated by measuring the component accuracy and the surface roughness value using CMM and surface roughness tester respectively.

CHAPTER 2
LITERATURE REVIEW

2.1Introduction

The study on machining of thin-wall component involves many disciplinary areas such as theories and methods of metal cutting, mechanics of machining process and structural mechanics. In this chapter, topics that related to analyse the deflection prediction onmachining thin-wall structures are reviewed. They include the existing methods and models for the analysis of machining thin-wall structure, force modelling and factors that affect the magnitude of the force generated in the machining process, factors that affect the magnitude of wall deflection and consideration and technique for machining titanium alloys. The purpose of reviewing these topics is to provide a theoretical base for the remainder of this thesis.

2.2Definition of thin wall

There are few definitions to characterise thin-wall component. A guide to differentiate between thin-wall and thick-wall cylinders is based on the uniform stress distribution throughout the wall thickness. The theory of thin-wall cylinders and spheres is based on this assumption which indicates a ratio of wall thickness to diameter of about 1/10 represents the dividing line between thin-wall and thick-wall cylinders. Yang (1998) gave a guide to differentiate between super-thin plates, thin plates and thick plates for approximation theory of plate bending as;

Super-thin plates	=	$h/p < (1/100)$
Thin plates	=	$(1/100) \leq h/p \leq (1/5)$
Thick plates	=	$h/p > (1/5)$

where p = shorter length of two edges in the plate

h = plate thickness

The above definitions of thin-wall component can be a general guide-line to characterised thin-wall component. However, for the case of this project the thin-wall component is based on whether or not the wall deflects sufficiently to affect machining accuracy. To be specific, a thin-wall component is where elastic deformation of the wall is larger than or equal to the allowed tolerance requirement and can be written as;

$$\delta \geq T$$

where δ = elastic deformation of the wall

T = allowed machining tolerance

2.3Reviews on related work in machining thin wall component

There are several factor that causes the error at the thin wall surface,In China, there are several researchers hadanalyzed the factor that causes surface error and tool distortion when the thin wall is machined by milling machine and found that the factors are cutting forces, feed rate, cutting depth,etch.

Budaket. al (1993) stated that the thin wall dimensional form error is occurred due to static deflection and dynamic displacement produces poor surface finish in milling.Shyong and Liao (2000) states that the mainly issue of dimensional error of the thin wall component is deflection of the tool and the workpiece during milling process. They also stated that the workpiece with high rigidity and fixed firmly will produce small deflection and can be neglected but the deflection of the tool and workpiece is large and can produce surface form error in the peripheral milling of the flexible component.

Ratchev et al. (2004) stated that the periodically varying milling force process of thin wall milling which statically and dynamically is complicated process that excite the tool and part structures leading to significant and often unpredictable deflections. Static deflection produce dimensional forms errors and dynamic displacements impact on poor surface finish quality.

According to Wan et. al (2008) the error at the thin wall surface is mainly made up of the force-induced deflection which result in deviation of the depth of cut. Weifangchen et.al (2009) states that the big causes that lead to the error of the thin wall surface is occur because of deformation of the workpiece due to clamping force and cutting forces that produce a significant deviation between theoretical surfaces and the actual machined ones.

To solve the problem of error at the surface of thin wall, many research has been made to find the best way to get the efficient and productive thin wall. According to Bera et.al (2011), most of researches are focussing in reduction of cutting force induced tool or workpiece deflection error and very few are focused on reduction of combine tool and workpiece deflection error. They categorized the research attempt that focussing on reduction of deflection induce surface error in to three group.

I. Process design approach which controls cutting forces during machining by varying cutting parameters such as feed rate or cutting widths so that deflections do not exceed beyond specified limits,
II. On line adaptive control approach proposes shifting of cutting tool in real time necessitating use of measurement sensors and hardware,
III. Off-line tool path modification approach consisting of correcting tool path on the basis of known surface error before performing actual milling operation.

They states that the research that widely used to reduce cutting force induced surface errors during milling operation is of line tool path modification. This methodology originally was proposed by Lo and Hsiao (1998) which was based on measured values of surface error. Some researcher reduces the surface error with feed rate scheduling method. This method was decrease the productivity of the part because it use long time and make many tool path to produce the thin wall feature (M.wan 2003).

Elbestawi and Sagherian(1990) stated that flexibility of the cutter and fixtures is the main problem that associated with the deflection of thin walled workpiece that faced by process planner in the industry. This problem is usually solved with the following technique.

I. Trial and error method in order to determine acceptable machining conditions
II. Using final float cut to bring the machined surface within tolerance
III. Using more conservative cutting condition

All of the defined techniques will decrease the productivity of the component because it use many workpiece and long time to produce the required product. According Cho et.al.(2003), in the one investigation of line tool path modification, they observed that during the movement of component from CNC machine to coordinate measuring machine, distorted of reference coordinate for machining is occur and on machine measurement system was used for improvement in measurement accuracy and reduction of setup time.

Compensation methodology has been applied by Landon et al. (2003) for correction of tool path deformed due to action of cutting force on cutting tool, tool holder and spindle assembly. Detailed investigation on surface error profile generated due to tool deflection has be carried out by Despince and Hascoet (2006). They has proposed a technique to obtain optimized tool path trajectory that achieves specified tolerance on finish component.

Application of error compensation approach during machining of thin walled workpiece and highlighted complexities involved in the same has been introduced by Ratchev et al. (2004,2005). In this research reduction of workpiece deflection that induced surface error was mainly focused and not consider the combined deflections of cutter and workpiece.

Chen et al. (2009) investigated the error compensation effectiveness strategy in multilayer milling process for thin walled machining process. The main disadvantages of this technique are used long machining time to milling thin wall feature.

Bera et al. (2011) states that many researchers had made multipass machining in axial direction of workpiece in order to reduce surface error. There are two disadvantages of this approach, it is produce lower productivity of the component because the long time is used for the milling process due to multiple passes along axial direction of the cut. Second drawbacks of this approach are the machine tool is not utilized to its full potential.

Shyong and Liao (1999) used the finite element analysis to model the machining process to defined the surface error of the workpiece. In this investigation, the surface form error is predicted in the peripheral milling of a flexible plate in which the end mill and the workpiece are model. Milling forces are calculated with the flexible model which includes the effect of the tool and the workpiece deflections and the cutting force distribution is determined through iteration.

The drawbacks of this technique is it take a long time to use finite element software to predict the surface error at the thin wall surface and it required additional cost to prepare computer and the software of finite element. Other than that, it needs the well trained person to handle the software.

This study proposes tool path compensation strategy to mill the thin wall feature. In this study the error compensation that determine by the workpiece that be machine by nominal machining is used and determine the new tool path compensation to machine new thin wall with constant parameter of the milling machine. The surface error of the workpiece will be measured by coordinate measuring machine before new workpiece design with error is made to define the new tool path to machine thin wall feature.

2.4 Factor affecting deflection thin wall machining

In order to produce good product of milling operation, parameter of milling is played the important rules. The important parameter of milling process is cutting force that will affect the cutting depth and feed rate during the workpiece was cut to the required form. The force of cut will deflect the low rigidity part during the milling process and produce surface error to the component produce. The chosen of fault parameter of milling operation will reduce the efficiency and productivity of the product.

Liu et al. (2010) stated that the influential parameter of milling operation during the product machining is axial depth of cut and followed by feed per tooth. They stated that the cutting force is decreased as cutting speed is increased and cutting force