Faculty of Manufacturing Engineering

DEVELOPMENT OF CUTTER GEOMETRICAL FEATURE FOR MACHINING THIN WALL PART

Mohd Zulhairi bin Tajry

Master of Science in Manufacturing Engineering

2017

DEVELOPMENT OF CUTTER GEOMETRICAL FEATURE FOR MACHINING THIN WALL PART

MOHD ZULHAIRI BIN TAJRY

**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Manufacturing Engineering**

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this thesis entitled "Development of Cutter Geometrical Feature for Machining Thin Wall Part" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	MOHD ZULHAIRI BIN TAJRY
Date	:	....

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfilment of Master of Science in Manufacturing Engineering.

Signature : ....

Name : ASSOC. PROF. DR. RAJA IZAMSHAH BIN RAJA ABDULLAH

Date : ....

DEDICATION

To my beloved family

ABSTRACT

Demand for cost-effective aircrafts fabrication has motivated the aerospace industry to use non-traditional materials and new aircraft structural design. New aircrafts are designed with monolithic component to replace large number of assembled component. For manufacturers, high-performance cutting tool is essential as more than 80% of the material is removed to produce the monolithic component. Most of the monolithic components have thin-wall feature with low stiffness and deformation is more likely to occur in its machining process, resulting in dimensional surface errors. Most of the existing research on machining thin-wall component merely focused on the process planning and there was no scientific study on the effects of cutter geometric feature on component failure. Tool geometry has a direct influence on the cutting performance and should be taken into consideration. In this research, due to the importance of machining efficiency, development of new cutter design specifically for machining thin-wall components are studied. This study consists of both experimental and statistic techniques to evaluate the machining performance associated with the cutter geometry for different types of end mill, namely variable helix constant pitch (VHCP), variable helix variable pitch (VHVP) and tabular helix constant pitch (THCP). Based on the established relationship between cutter geometry feature and machining performances, the optimal cutter geometry is determined by using the non-parametric statistical ranking technique. From the experimental results, tool TD3 with $31^{o}/33^{o}/35^{o}$ helix angle and equal pitch angle of 90^{o} between teeth (THCP) is the most suitable design to be used for machining thin-wall workpiece. In addition, it shows that careful design of the pitch and helix angle combination can increase the machining performances of thin-wall part. The outcome from this research has potential benefits in providing new scientific knowledge on the selection of effective cutter geometry for machining low rigidity components.

ABSTRAK

Permintaan untuk pembuatan yang kos efektif telah mendorong industri aeroangkasa untuk menggunakan bahan-bahan bukan tradisional dan reka bentuk pesawat baru. Reka bentuk baru dengan sekeping komponen monolitik menggantikan dengan bilangan besar komponen pemasangan. Bagi pengilang, permintaan bagi alat pemotong yang berprestasi tinggi adalah penting kerana lebih daripada 80% daripada bahan dipotong untuk menghasilkan komponen monolitik. Oleh kerana dinding nipis tidak kukuh, deformasi lebih kerap berlaku dalam proses pemesinan yang menyebabkan kesilapan dimensi permukaan. Kebanyakan penyelidikan yang sedia ada pada pemesinan komponen dinding nipis hanya tertumpu kepada perancangan proses dan tidak ada kajian saintifik mengenai kesan daripada ciri geometri pemotong. Alat geometri mempunyai pengaruh langsung ke atas prestasi pemotongan dan tidak boleh diabaikan dalam pemesinan pertimbangan. Setiap satu daripada ciri-ciri geometri mempunyai fungsi tersendiri dan perlu dikaji untuk aplikasi pemesinan tertentu. Dalam kajian ini, oleh kerana pentingnya kecekapan pemesinan, reka bentuk pemotong baru khusus untuk pemesinan komponen dinding nipis telah diberikan perhatian. Didorong oleh keperluan untuk sentiasa meningkatkan kecekapan pemesinan dan bahagian ketepatan ini kajian penyelidikan mengenai kesan pemotong ciri geometri kegagalan komponen. Berdasarkan hasil kajian yang diperolehi, pemotongan optimum geometri ditentukan dengan menggunakan teknik peringkat statistik bukan parametrik. Kajian ini mempunyai potensi dalam memberikan manfaat untuk menyediakan pengetahuan saintifik baru untuk mengoptimumkan ciri pemotong geometri khusus untuk yang efektif untuk proses pembuatan komponen dengan tahap kekukuhan yang rendah.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Allah the Almighty for blessing me to complete my master by research project. I want to take this opportunity to record my utmost and sincere gratitude to my supervisor, Dr. Raja Izamshah Bin Raja Abdullah. Without him, I can never start work on my project and to proceed until this point. He has shown me guidance, important advice, and inspiration throughout my research.

I would like to express my gratitude to Mr. Mohd Hanafiah Bin Mohd Isa, Mr. Muhammad Azwan Bin Abdul Kadir, and all other assistant engineers as well as technicians from Faculty of Manufacturing Engineering for their assistance and support in laboratory works.

To my beloved family, I would like to forward my obliged to them for their continuous support during my study period, their patience and benevolence. Last but not least, I would like to thank everyone who has contributed during my research studied, your kindness and cooperation of my paperwork is much appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

CHCP	-	Constant Helix Constant Pitch
VHCP	-	Variable Helix Constant Pitch
VHVP	-	Variable Helix Variable Pitch
THCP	-	Tabular Helix Constant Pitch
ANOVA	-	Analysis of Variance
CAD	-	Computer Aided Design
PCD	-	Polycrystalline Diamond
FEM	-	Finite Element Method
S/N	-	Signal to Noise Ratio
CNC	-	Computer Numerical Control
ISO	-	International Organization for Standardization
RMS	-	Vibration Measurement Test
TB1~TB4	-	VHCP cutting tool
TC1~TC4	-	VHVP cutting tool
TD1~TD2	-	THCP cutting tool
CMM	-	Coordinate Measuring Machine (CMM)
TMM	-	Tool Maker Microscope
CT	-	Computer Tomography
CAM	-	Computer Aided Manufacturing
RSM	-	Response Surface Methodology
DOE	-	Design of Experiments

LIST OF SYMBOLS

hrs	-	Hours
kg	-	Kilogram
h	-	Plate thickness
p	-	Shorter length of two edges in the plate
δ	-	deformation of elastic's wall
T	-	Permitted machining standard limitation
$\geq$	-	more than or equal
β	-	Helix Angle
θ	-	Pitch Angle
dFtj	-	differential force in the tangential direction
dFrj	-	differential force in the radial direction
jth	-	Flute Element
Ktc, Krc	-	specific cutting force coefficients for tangential and radial direction
Kte, Kre-		specific edge cutting force coefficients for tangential and radial direction
ϕ	-	tool's immersion angle start from positive y-axis
$z_{jl}(\phi)$	-	lower axial engagement limits of the in cut portion of the flute *j*
$z_{ju}(\phi)$	-	upper axial engagement limits of the in cut portion of the flute *j*
Al	-	Aluminum
Zn	-	Zink
Cu	-	Copper

Fe	-	Ferus
Cr	-	Chromium
Mn	-	Manganese
Ti	-	Titanium
Si	-	Silicon
RPM	-	Revolution per min
mm	-	millimeters
µm	-	micro meter
g/cm^3	-	gramme per centimeter cube
kgf-m/ cm^3	-	kilogramme force meter per centimeter cube
mm/min	-	millimeter per minute
o	-	Degree
µm	-	micro meter
µm	-	micro meter
°, ° C	-	degree, degree Celcius
mK	-	meter kelvin
g/ cm^3	-	gram per centimetre cube
kg / m^3	-	kilogram per meter cube
mm/ tooth	-	millimetre per tooth
mm/min	-	millimetre per min
mm/rev	-	millimetre per revolution
rpm	-	revolution per minute
%	-	percent
L_c	-	tool-chip contact length
Ra	-	arimethic roughness

LIST OF PUBLICATIONS

1. R.Izamshah, M. Zulhairi, M.Shahir, M. Hadzley, M. Amran, M. Amri, Sivarao, "Cutter Path Strategies for Shoulder Milling of Thin Deflecting Walls", Advanced Materials Research, Vol. 903, pp. 175-180, 2014

CHAPTER 1

INTRODUCTION

1.1 Background

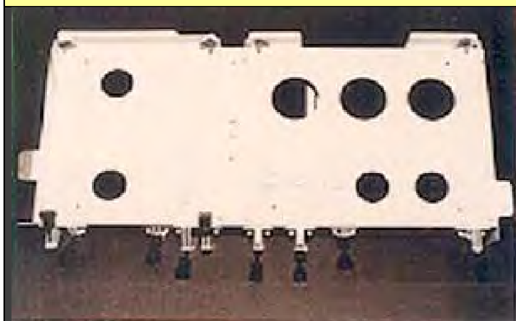
Demand for the cost effective and high performance aircrafts has forced the aerospace manufacturer to change to a new aircraft structural design (Izamshah et al., 2011). Modern aircraft are designed with one piece flow of monolithic component that can replace large number of assembled part for the same component. These new monolithic structural component contains hundreds of unitized monolithic feature which consists of thinner ribs (i.e. walls) and webs (i.e. floors). In addition, from the business perspective, the monolithic structural components able to reduce the manufacturing times that are related to inventory and Just-In-Time (JIT) manufacturing. Table 1.1 demonstrates some of the advantages of monolithic component compared to conventional aircraft component.

Nevertheless, due to the poor stiffness of thin-wall feature, deformation is more likely to occur in the machining process which resulting in dimensional surface errors. The cutting forces were the major cause of the part deflection and are directly related to the cutting tool. During the milling process of this component, the part suffers from deflection with the risk of instability and tolerance violation. The relative vibrations between flexible end mill and workpiece are the source of most of the problems that occur during manufacturing of thin wall. Intermittent engagement of cutter and workpiece excites a wide range of structural natural frequencies that result as unstable chatter vibrations and stable forced vibrations. Chatter is caused by variations in the instantaneous chip thickness caused when the vibration of the tooth currently engaged in the cut is out of phase with the vibration of the previous tooth.

For manufacturer, demand for the high-performance cutting tools is pre-requisite as more than 80% of the material is cut away to produce the monolithic component. In addition, this structure necessitates high quality surface profile that poses some degree of machining technique to achieve the tight dimensional tolerance of aerospace component. Tool geometry has a direct influence on the cutting performance and should not be neglected in the machining consideration. Factors such as cutting forces, vibration, and quality of machined surface and shapes accuracy are closely reflected with the tool geometry. The geometric parameter of end mills includes the number of flute, edge shape, rake angle, relief angle, helix angle, pitch angle and clearance angle. Among the tool geometric features, helix angle and pitch angle were the most dominant factors that affect the machining performances i.e. surface error, vibration, surface roughness magnitude and therefore should be methodically investigated for the case of machining thin-wall part.

Previous published literatures shows that by manipulating the design of pitch and helix angles for each tooth led to the interruption of the dynamic regeneration mechanism in which disordered the tooth passing frequency between the adjacent tooth periods as a result of different chip loads (Yusoff and Sims, 2011). It demonstrates that, by manipulating the cutter design can interrupt the feedback mechanism for the tool vibrations, thus altering the stability of the machining condition. However, the boundary between stable and unstable machining condition are a function between workpiece condition and the cutter geometry, a matter that will be explored in this thesis.

Table 1.1: Comparison between monolithic and conventional aircraft component (Tongyue et al., 2010).

Conventional Part		**Monolithic Part**	
			
Number of Pieces	= 44	Number of Pieces	= 6
Number of Tools	= 53	Number of Tools	= 5
Design & Manufacturing Time (hrs)	= 965	Design & Manufacturing Time (hrs)	= 30
Machining Time (hrs)	= 13	Machining Time (hrs)	= 8.6
Assembly Man-hours	= 50	Assembly Man-hours	= 5.3
Weight (kg)	= 3.77	Weight (kg)	= 3.37
Overall manufacturing Cost (units)	= 100	Overall manufacturing Cost (units)	= 37

Driven by the need to constantly increase the machining efficiency and part accuracy, this thesis aim to develop an optimum end mill cutter geometry that can effectively reduce the surface error, vibration magnitude and producing smooth surface finish on machining thin wall low rigidity component. The development involves experimental investigation of different type of cutter geometry namely Constant Helix Constant Pitch (CHCP), Variable Helix Constant Pitch (VHCP), Variable Helix Variable Pitch (VHVP) and Tabular Helix Constant Pitch (THCP) on milling thin-wall low rigidity part. The workpiece material is aerospace grade Aluminum alloy 7075-T6 for all of the components. The expected outcomes from this research include the increase in process stability and elimination of finishing operations.

1.2 Problem Statement

The so-called 'right first time' machined component is continuously manufactured by manufacturers in order to improvise their product quality and remain competitive in manufacturing industry. Manufacturers have to encounter a challenging process, especially in machining thin-walled component, due to the tight dimensional tolerance of aerospace component. Based on the literatures review, it shows that there were three main problems that associated with the machining of thin wall component namely dimensional surface errors, poor surface quality and low productivity (Izamshah et al., 2011). Figure 1.1 depicts the summarization of the problems associated with the machining of thin wall component based on my research.

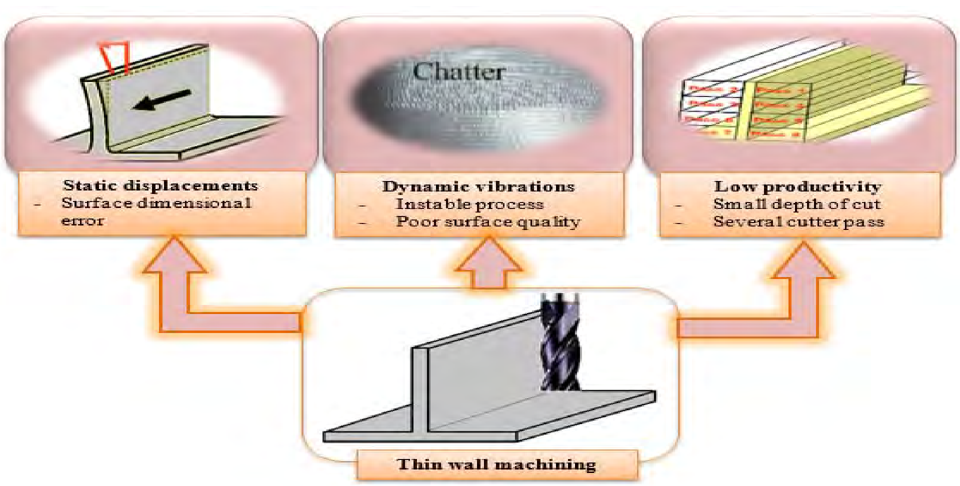
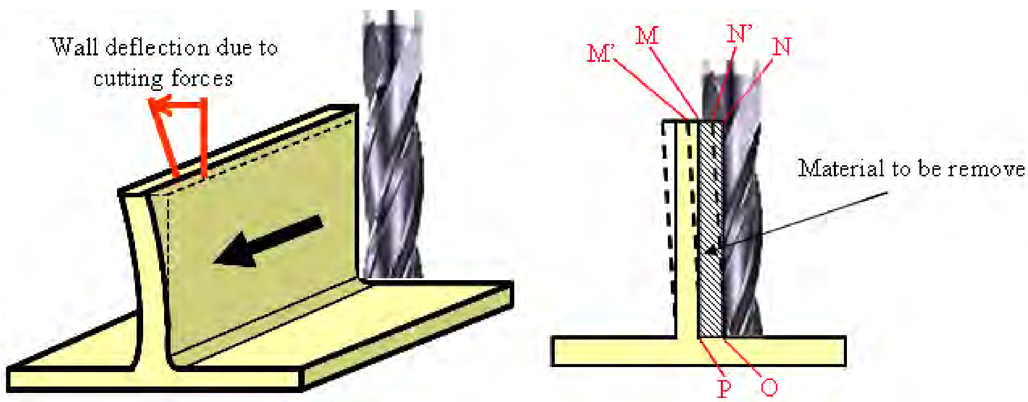


Figure 1.1: Summary of challenges in machining thin wall component (Izamshah et al., 2011)

1.2.1 Dimensional Surface Errors

Deformation can easily happen during machining of thin-wall areas due to the lack of stiffness at those areas, in which, causing dimensional surface errors (Arnaud et al., 2011). Figure 1.2 shows the dimensional surface errors produce in machining thin-wall feature. Materials in the shaded areas MNOP as depicted in Figure 1.2 (b) are to be removed ideally. However, due to the milling force the wall is deflected which shifted point *M* to point *M′* as well as point *N* to point *N′*. As a result of the wall deflection, only material *MN'OP* is removed resulting a dimensional surface errors in *NON'* areas (Izamshah et al., 2011).

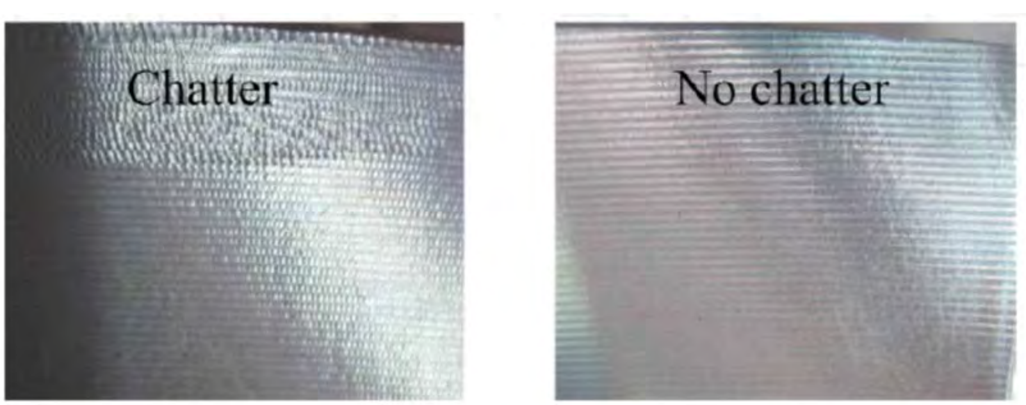


(a) (b)

Figure 1.2: Dimensional surface errors produce in machining thin-wall feature.
(a) Deflection of wall resulting from cutting force , (b) Machining sketch of thin-wall component (Izamshah et al., 2011).

1.2.2 Poor Surface Quality

In addition, according to Bolsunovskiy et al. (2013) the problems that emerge due to high flexibility of the cutting tool-workpiece machining condition are the chatter regeneration that limits the productivity. The Intermittent engagement of cutter and workpiece excites a wide range of structural natural frequencies that result as unstable chatter vibrations and stable forced vibrations. Powell, (2008) said chatter is caused by variations in the instantaneous chip thickness caused when the vibration of the tooth currently engaged in the cut is out of phase with the vibration of the previous tooth. Chatter can produce large cutting force amplitudes that lead to increased tool wear, and degradation of the machined surface or regeneration of waviness. Regeneration of waviness refers to the variation in chip thickness which results from the interference between the wavy surface left by the vibrating tool and workpiece on the previous pass and the vibrating tool and workpiece on the current pass. If the vibrations of the current pass are in phase with the vibrations from the previous pass, the chip thickness remains fairly constant, as does the cutting force resulting in a stable cut. If the vibrations of the current pass are out-of-phase with the vibrations from the previous pass, the chip thickness can vary greatly; the variation in chip thickness leads to variation in cutting force which can result in rough machined surface (Lacerda et al., 2004).



(a) (b)

Figure 1.3: Occurrence of chatter in machining thin wall component.
(a) Chattered surface. (b) Non chattered surface. (Lacerda et al., 2004).