UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MODELLING EFFECT OF CUTTER GEOMETRICAL FEATURE FOR SHOULDER MILLING OF THIN DEFLECTING WALL

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

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BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

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

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Dr. Raja Izamshah Bin Raja Abdullah

Project Supervisor

ABSTRAK

Pemesinan komponen struktur aeroangkasa melibatkan beberapa bahagian dinding nipis. Bahagian dinding nipis ini ditentukan oleh pertimbangan reka bentuk untuk mencapai kekuatan yang dikehendaki dan kekangan berat. Komponen-komponen tersebut dibentuk atau dibuang kepada bentuk anggaran akhir dan proses larik akhir yang digunakan untuk menyiapkan bahagian-bahagian atau komponen pemesinan dari blok pepejal bahan akhir pengisaran dengan kelicinan dan menamatkan potongan. Semasa pemesinan, daya pemotongan menyebabkan pesongan pada bahagian dinding nipis, membawa kepada ketidaksamaan bentuk dimensi yang menyebabkan kesilapan spefikasi. Pemotong geometri seperti sudut helik dan bilangan pemotong memainkan peranan penting untuk prestasi pemesinan dan perlu dianalisis langkah demi langkah. Bagi pengisaran dinding nipis, pengetahuan mengenai kesan geometri pemotong adalah penting kerana ia akan membantu untuk mengawal kuasa-kuasa lain. Oleh itu, projek ini bertujuan untuk meramalkan kesan daripada ciri-ciri geometri pemotong semasa pemesinan komponen dinding nipis dengan analisis berangka. Model yang dibangunkan mengambil kira geometri alat pada proses penyingkiran bahan semasa proses pemesinan. Nilai ramalan yang telah disahkan oleh ujian pemesinan ke atas bahagian-bahagian aloi titanium akan menunjukkan perjanjian baik antara model simulasi dan data ujikaji yang mengesahkan kesahihan model. Data dijana daripada model yang kemudian digunakan sebagai input untuk statistik analisis bagi menilai kesan-kesan geometri pemotong pada ralat permukaan. Analisis statistik menunjukkan bahawa kurang bilangan pemotongan dan tahap yang tinggi dari sudut helix memberikan anjakan minimum bagi komponen dinding nipis.

ABSTRACT

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. During machining, the cutting forces cause deflection of the thin-wall section, leading to dimensional form errors that cause the finished part to be out of specification. Cutter geometry such as helix angle and number of flute play an important roles on the machining performance and should be methodically analyzed. For the thin wall milling, the knowledge on the effect of cutter geometry is vital since it will help to control the cutting forces. Thus, this project aims to predict the effect of cutter geometrical feature when machining thin-wall component by numerical analysis. The model is developed to take into account the tool geometries on material removal process during machining process. The prediction values have been validated by machining tests on titanium alloys parts and show good agreement between simulation model and experimental data which confirmed the model validity. The data generate from the model are then used as an input for statistical analysis to evaluate the effects of cutter geometry on surface error. From the statistical analysis it showed that less number of flutes and high degree of helix angle gives minimum displacement to the thin-wall component.

ACKNOWLEDGEMENT

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AMG	-	Automatic Mesh Generator
ANOVA	-	Analysis of Variance
CAD	-	Computer Aided Design
CMM	-	Coordinate Measuring Machine
CNC	-	Computer Numerical Control
D	-	Diameter
DOE	-	Design of Experiment
DW	-	Inscribed Circle Diameter
FEA	-	Finite Element Analysis
HSM	-	High Speed Machining
JIT	-	Just-in-Time
N	-	Number of Flute
RSM	-	Response Surface Method
Ti6Al4V	-	Titanium Alloy
WC	-	Tungsten Carbide
%	-	Percent
°	-	Degree
h_e	-	Helix Angle
γ	-	Rake Angle
η	-	Number of Flute

CHAPTER 1

INTRODUCTION

1.1 Research Background

Demand for the next generation to produce high performance and cost effective aircraft, has motivated the aerospace industry to use new aircraft structural design and non-traditional materials (Izamshah et al. 2011). To replace the large number of assembled component, aircraft structure are designed with one piece flow of monolithic component. Sridhar & Babu P. (2013) found that monolithic thin-wall components are one piece, with high strength to weight ratios, lighter, less expensive and more accurate components which are machined approximately up to 95% of material from prismatic blanks. Machining of monolithic components involves several thin-wall flange and rib sections as shown in Figure 1.1. According to Ding et al. (2011), thin-wall machining of monolithic structural components allows for higher quality and reduce the manufacturing times which impact organization issues including Just-In-Time (JIT) manufacturing and inventory.

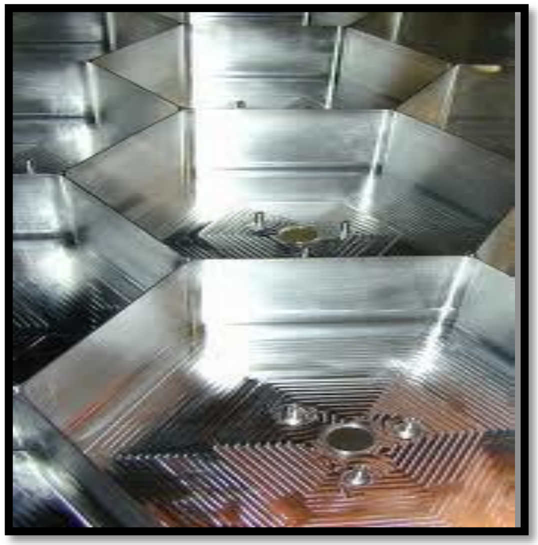

Figure 1.1: Aerospace monolithic component. Retrieved from *http://www.autindustries.com*

Tongyue et al. (2010) demonstrated, deformation is occur in the machining of thin-wall part which resulting a dimensional surface error, due to the poor stiffness of thin-wall feature. The dimensional surface error is caused generally by the deflection of the thin-wall workpiece and the end mill tool during milling, which results in variation of the tool radius immersion.

According to Izamshah et al. (2013), end mill geometrical features effect on the cutting performance such as the cutting forces, quality of machined surfaces, shape accuracy, cutting edge wear and tool life. Peterka et al. (2010) have added that the deflection and chatter vibration of the workpiece in milling a thin-walled structure is due to low stiffness, had a negative effect on the geometric accuracy and surface integrity. Therefore, it is necessary to select optimal cutter features when considering those effects. The geometrical feature of end mills includes the helix angle, number of flutes, rake angle and clearance angle. Each of the geometric features has their own specific function and need to be modelled and simulate using the finite element analysis method to effectively predict the machining surface errors.

Finite element analysis (FEA) has been largely implemented in simulation of the machining process. In this project FEA based simulation is used to predict the machining performance based on the cutter helix angle and number of flutes when milling of thin-wall component.

1.2 Problem Statement/ Current Technique in Machining Thin-Wall

Manufacturer poses a great challenge especially on machining aerospace component that contains a thin-wall feature due to the tight dimensional tolerance. One of the challenges faced is the dimensional errors caused by the cutting forces. The machining force caused the part deflection to deflect and away from the cutting tool. Figure 1.2 shows the surface dimensional errors produce in machining thin-wall feature. Material in the shaded areas MNOP as depicted in Figure 1.2 (b) is to be removed. However, due to the milling force the wall is deflected which make point M moves to point M′ as well as point N to point N′. As a result, only material MN′OP is removed and produce dimensional surface errors in NON' areas. (Panadian P, 2013)

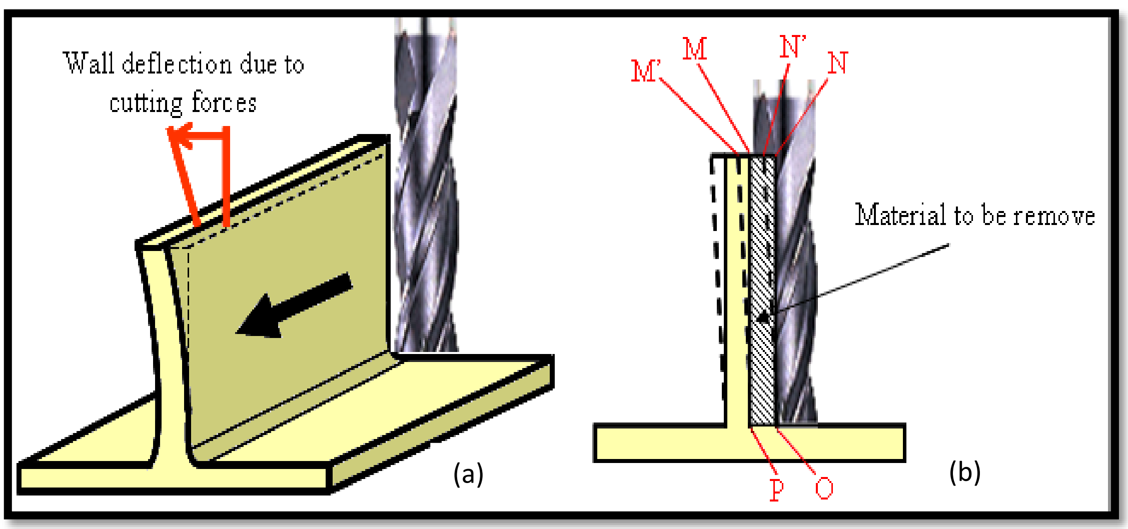

Figure 1.2: Dimensional surface errors produce in machining thin-wall feature
(a) Deflection of the wall resulting from cutting force (b) Machining sketch of thin-wall component

Tool geometrical feature has a direct influence on the cutting performances. Each of the geometric feature has their own specific function and need to be investigate. However, the conventional trial and error approach to investigate the effects of cutter geometrical feature on part deflection are often very costly, labour intensive and time consuming.

In addition, most of the related work on predicting surface error are concentrated on machining parameter and the chatter vibration of the workpiece. To the best of author knowledge, none of the past research work, study the effect of cutter geometrical feature on surface error. Thus the proposed research will benefit in providing new scientific knowledge on optimizing the tool geometric design for machining thin-wall component.

1.3 Objectives

Based on the difficulty and the time-consuming analysis process for machining thin-wall monolithic component initiated this project. Driven by the need to constantly increase the machining efficiency and part accuracy, the objectives of this project are to:

1. Modelling the effect of cutter geometrical feature (helix angle and number of flutes) for shoulder milling on surface error.

2. Validate the simulation model with experiment for an identical set of test components.

3. Once the model is validate, a set of database will be generate to analyse the effect of cutter geometrical feature namely helix angle and number of flutes on part deflection using statistical analysis.

4. To optimize the cutter geometrical feature for effectively machining thin-wall component.

1.4 Scope of Project

This project focuses on the finite element modeling of machining simulation of shoulder milling of thin deflecting wall part. A cutter geometrical feature of end mill tool such as number of flute and helix angle with constant rake angle and clearance angle will be designed and modelled. Then the effects of number of flute and helix angle of end mill tool on the deflection of the thin-wall part is predicted by finite element analysis (FEA). Its only focus on shoulder milling in straight line with water based coolant as a cutting medium. The result of the FEA will be validated with shop floor trials. Titanium alloy (Ti6Al4V) is used as a thin-wall workpiece material and tungsten carbide (WC) is used as end mill tool material. A set of database from the simulation will be generate for statistical analysis input.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, all related topics on modelling and milling of thin-wall are reviewed. This chapter will discuss mainly about cutting tool used for machining thin wall part. Apart from that, reviews on related work in machining thin-wall component also been discussed. Finally, finite element analysis is also included in this chapter for the purpose of discussing on prediction occurs during simulation of the thin wall part. The purpose of studying these topics is to collect a theoretical based for this project.

In the literatures, it shows that most of the research works done only focusing on the prediction of surface error and process planning which are difficult to control and expensive. None of the researcher investigated the effect of cutter geometrical feature on part failure for machining thin deflecting wall aerospace component.

2.2 Thin Wall Machining

To remain competitive, manufacturer continually seeks to increase their product quality by producing ‘right first time’ machined component. Manufacturer poses a great challenge especially for machining an aerospace component that contains a thin-wall feature due to the tight dimensional tolerance as has been shown (Tongyue et al., 2010).

Peterka et al. (2010) have added that thin-wall can be explained as a workpiece containing of very thin plates. Thin plate shall be deformed even a minimum cutting force acting on the surface resulted the local thickness in critical place is different. In a simple words, thin-wall component contains of walls, which is small thickness compared with other dimensions such as wall length and wall height.

According to Godoy (1996) thin-walled structures are used as structures or structural components in many engineering applications, including civil, naval, aeronautical, mechanical, chemical, and nuclear engineering. In aeronautical engineering, thin-walled is a monolithic structural component consists of several thin-wall rib and flange sections that need to be machined.

Pandian P et al. (2013) found a new approach to that to machine thin-wall component, which is use high speed machining, but it needs a high speed-milling machine. Because of that factor, high speed machining technique has been adopted for machining thin ribs. High Speed Machining (HSM) is machining of materials with 4 to 6 times the cutting speed used in conventional machining.

Apart from that, Grzesik (2008) has stated that HSM allowing machining of thin-walled parts with relatively high precision and can reduce cutting forces and heat transfer into the workpiece. Currently, the HSM of monolithic component is widely used in the aerospace industry, replacing assembled sheet metal components.

2.2.1 Shoulder Milling

Shoulder milling requires face milling in combination with peripheral milling which generates two faces simultaneously. Obtaining a precise parallel shoulder, is one of the most important requirements on the process. Shoulder milling can be performed by using end milling cutters and also, by traditional square shoulder cutters, long side and face milling cutters and edge cutters. Due to numerous options of cutters, it is important to consider the operational requirements carefully before make an optimal choice. (Mills & Persson, 2013)

According to Smith (2008), in combination of face milling with peripheral milling to produce shoulder milling, face milling is operation combined cutting action by the inserts, in the main on the tool's periphery and, to a lesser extent by insert edges on the cutter's face. In face milling, the cutter rotates at 90° to that of the direction of radial feed against the workpiece.

Apart from that, Smith (2008) posited that peripheral milling utilises peripherally with cutting edges that are situated in a milling cutter body which is horizontally spindle mounted. The cutter rotates around a horizontal axis, this axis being parallel to the tangential feeding direction. Peripheral milling has a depth of cut in a radial direction that will determine how deep the cutter diameter will penetrate into the workpiece. There are two peripheral milling strategies that can be used with these horizontally-mounted cutters, these are either 'Up-cut', or 'Down-cut' milling operations. This project only focus on 'up-cut' milling operations.

2.2.2 Milling Thin-Walls

According to Smith (2008), for the machining of thin-walls, such as when milling rib-sections on aerospace components, the machining strategy will vary, depending upon the respective height and wall thickness. In every case of thin-walled machining, the number of passes are determined by the component's wall dimensions and axial depth of cut, within the following manner which is height-to-thickness ratios of <15:1, height-to-thickness ratios of <30:1, and height-to-thickness ratios of >30:1. This project only focus on height-to-thickness ratios of <30:1. There are two basic milling techniques that are typically apply, which is:

a) ‘Waterline milling’ (Figure 2.1) – this is where either side of the thin-wall feature is milled to set depths, in non-overlapping passes. (Smith, 2008)

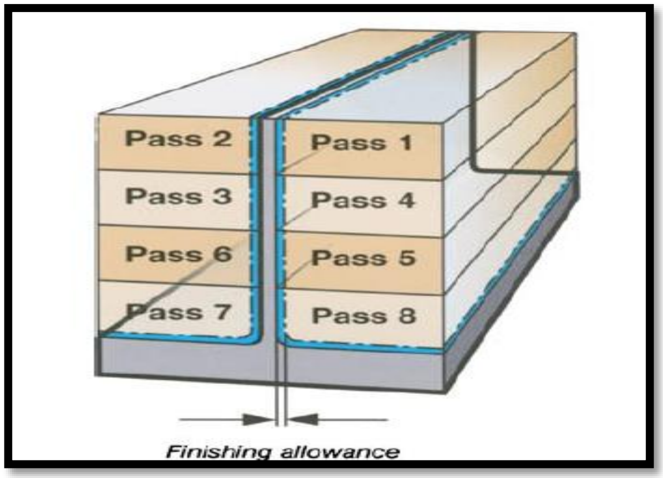

Figure 2.1: Waterline milling (Smith, 2008)

b) ‘Step-support milling’ (Figure 2.2) – this technique utilizes a similar approach to the previous method, but in this case, there is an overlap between passes on opposite sides of the wall. This strategy gives more support at the vicinity where machining occurs and the cutting forces are less likely to distort the wall as its height increases. (Smith, 2008)

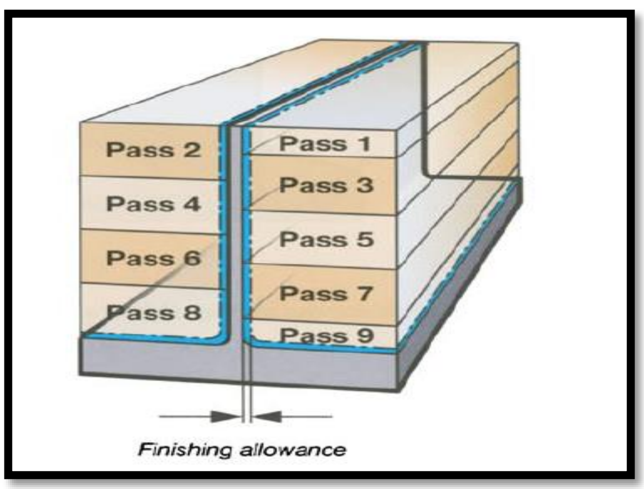

Figure 2.2: Step-support milling (Smith, 2008)