THE EFFECT OF PRIMARY RELIEF ANGLE TO THE DIMENSIONAL SURFACE ERROR OF THIN-WALL COMPONENTS

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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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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:

………………………………

(Project Supervisor)

ABSTRAK

Pengisaran sisi untuk komponen yang sangat fleksibel adalah proses pembuatan yang biasa digunakan dalam industri angkasa lepas. Banyak komponen yang digunakan dalam industri angkasa lepas biasanya berstruktur dinding nipis yang sangat fleksible. Struktur yang berdinding nipis adalah tidak kukuh menyebabkan ia mudah terpesong disebabkan oleh daya pemotongan semasa operasi pengisaran sisi. Pemesongan mata alat dan bahan kerja membawa kepada kesilapan dimensi permukaan yang sangat tidak diingini. Biasanya, terdapat perbezaan yang sangat ketara antara profil perancangan dan hasil mesinan yang menyebabkan hasil mesinan tidak dapat melakukan fungsi asal yang telah ditetapkan. Geometri mata alat adalah salah satu faktor yang perlu diambil kira untuk mendapatkan hasil kisaran sisi yang berkualiti tinggi. Sudut relif primer merupakan antara geometri mata alat yang mesti diambil kira untuk mendapatkan prestasi pemotongan yang tinggi. Projek ini mengkaji tentang sudut relif primer terhadap kesilapan dimensi permukaan struktur berdinding nipis dalam pengisaran sisi. Di samping itu, daya pemotongan dan kekasaran permukaan yang telah dikisar juga turut dikaji. Hasil kajian menunjukkan sudut relif primer memberi kesan yang ketara kepada kesilapan dimensi permukaan bagi komponen yang berdinding nipis di mana sudut relief primer yang lebih kecil memhasilkan kesilapan dimensi yang lebih rendah.

ABSTRACT

Peripheral milling of very flexible components is a common manufacturing process in the aerospace industry. Many components used in the aerospace industry are usually thin-walled structures which is very flexible. Thin-walled structures are not rigid hence easily deflect due to cutting force during peripheral milling operation. The tool-workpiece deflection results in significant dimensional surface error which is highly undesirable. There is usually a significant deviation between the planned and machined part profiles that the machined parts may no longer be able to serve its original designated functionality. The geometry of cutting tool is one of the factors that must be considered in obtaining high quality milling. Primary relief angle is one of significant tool geometry that must be considered to obtain high cutting performance. This research studies on the effects of primary relief angle of endmill on the dimensional surface error of peripheral milling of thin-walled structure. Besides, the cutting force and surface roughness of the milled thin wall also investigated. The results obtained show that primary relief angle has significant effect to the dimensional surface error of thin-wall components where smaller primary relief angle has lower surface error.

DEDICATION

This thesis is dedicated to all the people who never stop believing in me

my beloved parents

my brothers

my friends

and all those who believe in the richness of learning.

ACKNOWLEDGEMENT

First and foremost I would like to thank God for giving me the power to complete this report. I could never have done this without Your help. I love You.

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LIST OF ABBREVIATION, SYMBOLS AND NOMENCLATURE

Al	-	Aluminium
Ra	-	Average Roughness
a_p	-	Axial depth of Cut
Cr	-	Chromium
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
CNC	-	Computer Numerical Control
CMM	-	Coordinate Measuring Machine
Cu	-	Copper
v_c	-	Cutting Speed
^{o}	-	Degree
D0	-	Diameter
f_z	-	Feed per tooth
v_f	-	Feed Rate
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
LD	-	Flute length
αH	-	Helix angle
HSS	-	High Speed Steel
Mg	-	Magnesium
MPa	-	MegaPascal
mm	-	milimeter
LT	-	Overall length
LF	-	Overhang length
α1	-	Primary Relief Angle
PSM	-	Project Sarjana Muda
a_e	-	Radial Width of cut
rpm	-	Revolution per minute

N	-	Rotational speed
α2	-	Secondary Relief Angle
N	-	Teeth number
3D	-	3 Dimensional
EY	-	Young Modulus

CHAPTER 1
INTRODUCTION

This section introduces the background of the peripheral milling of thin-wall workpiece, the problem statement of the research, the research objectives and the research scope.

1.1 Background

Thin-wall milling is important in machining of aerospace components. Machining a complex part with many thin sections from a single, monolithic workpiece can be dramatically less expensive than building up the part via traditional fabrication techniques. Thin-wall machining can be a way to increase both productivity and profitability compared with fabricating thin walls. Subjected to the forces generated by metal removal, a thin-wall's relatively delicate structure will move relative to the tool, making it difficult to maintain dimensional accuracy and impart the specified surface finish (Kennedy, 2007).

Nowadays, many thin-wall structure parts, which traditionally were assembled from simpler parts, are being machined from a unique starting raw block material to their final shape. For this purpose, it is necessary to remove up to 95 percent of the material, resulting in airframe parts known as monolithic structure parts. These parts present enhanced homogeneity and physical properties. However, removing large amount of materials usually results in large warping or distortion due to the re-establishment of equilibrium in the retained part along with the relief of the initial residual stresses in the removed part. In many cases, these warping or distortions can be so large that the machined parts may no longer be able to serve its original designated functionality.

Most open literatures studying on monolithic component deformations focused on the prediction of surface dimensional errors induced by machining loads and clamping forces. This kind of machining error belongs to local elastic deformation. Controlling the local elastic deformation can improve the machining precision of local features, such as marginal plate and web plate. However, even if the surface dimensional error meets the design criterion, the monolithic component will inevitably be discarded for the large overall warping or distortion (Bai *et.al.*, 2010).

1.2 Problem Statement

Many components used in the aerospace industry are usually thin-wall structures. Because of their poor stiffness, thin-wall workpieces are very easy to deform under the acting of cutting force in the process of cutting. Even in CNC milling, in which the tools are controlled exactly according to the contour of the thin-wall component, the wall will be thicker at the top and thinner at the root (refer to Figure 1.1). The most commonly used method in factories is to cut the wall several times without feed in depth after the finishing cutting. However, this will increase working time and surface roughness, and will need locksmith's finishing. (He *et. al.*, 2003). Thin-wall structures are not rigid hence easily deflect due to cutting force during peripheral milling operation. This deflection results in significant dimensional surface error which is highly undesirable. There is usually a significant deviation between the planned and machined part profiles. Geometry of cutting tool surfaces is one of the crucial parameters affecting the quality of the milling process. Relief angle is one of the significant tool geometry to be considered in fabrication of endmill. This research will study on the effects of primary relief angle of endmill on the surface dimensional error, cutting force and surface roughness of peripheral milling of thin-wall structure. This study is an attempt to investigate the effect and consequently help in improving the reduction of dimensional surface error due to deflection in thin-wall structures by optimizing the suitable relief angle in endmill.

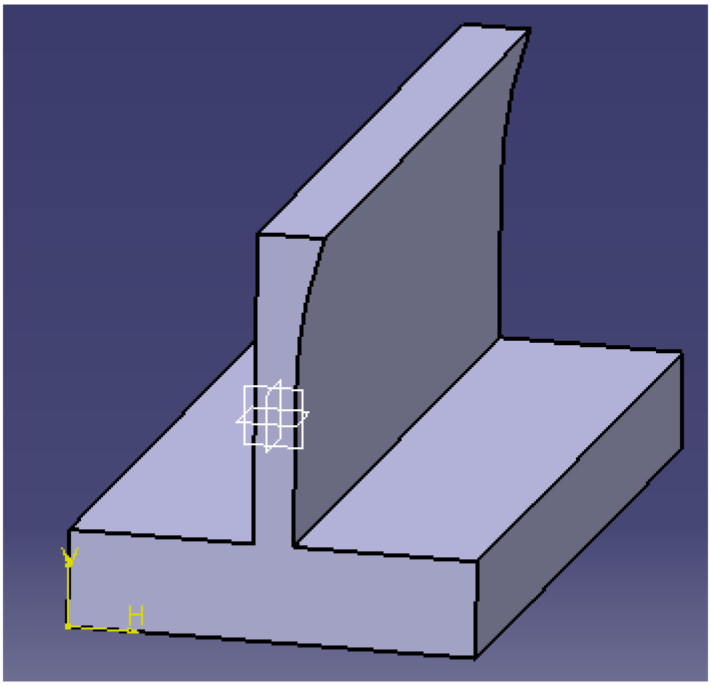

Figure 1.1: Surface Dimensional Error in Thin-wall

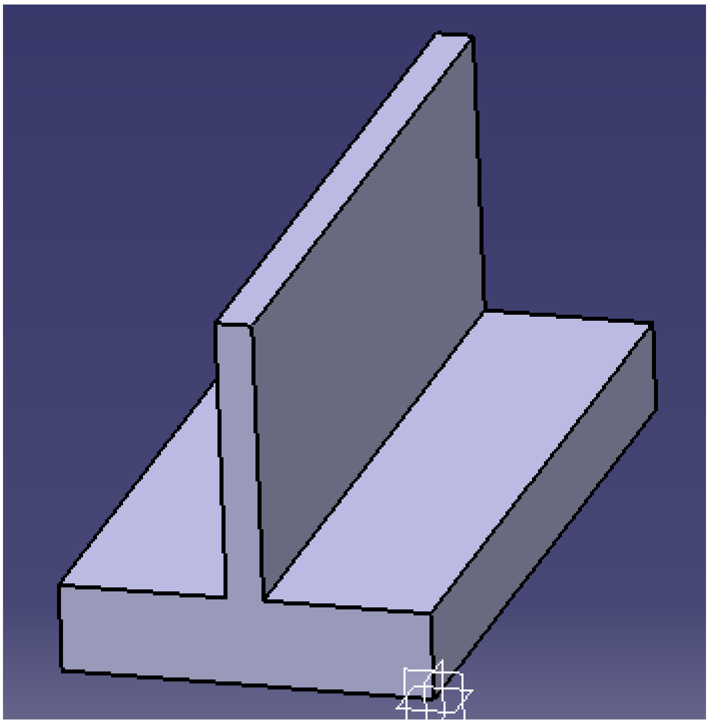

Figure 1.2: The Desired Surface Finish

1.3 Research Objectives

Most of the existing research on machining thin-wall component concentrated on the process planning, little attention is emphasized on the effect of cutting tool on the occurrence of the surface error and surface roughness. Driven by the need to constantly increase the machining efficiency and part accuracy, the objectives of this project are:

a) to investigate the effect of primary relief angle on the dimensional surface error when milling thin-wall workpiece.
b) to investigate the effect of primary relief angle on the cutting force when milling thin-wall workpiece
c) to investigate the effect of primary relief angle on the surface roughness when milling thin-wall workpiece.

1.4 Research Scope

This project focuses on investigating the effects of primary relief angle of endmill to the dimensional surface error, cutting force and surface roughness in peripheral milling of thin-walled workpiece. Five carbide endmill tools with different primary relief angle values are fabricated using CNC tool grinding machine. Then, a side-milling experiment is conducted on aluminum thin-wall workpiece to analyse the effects on primary relief angle of endmill to the dimensional surface error, cutting force and surface roughness. The dimensional surface error is measured by CMM machine, cutting force by dynamometer and surface roughness by surface roughness tester.

CHAPTER 2
LITERATURE REVIEW

This section discusses about the reviews from previous literatures and researches regarding the surface dimensional error in thin-wall milling. This section also include the cutting tool parameter especially the relief angle, the force that cause deflection in thin wall and the peripheral milling of thin-wall aluminium alloy.

2.1 Peripheral Milling of Thin-wall

In peripheral milling, the milled surface is generated by teeth located on the periphery of the cutter body. The axis of cutter (endmill) rotation is parallel to the workpiece surface (Kalpakjian, 2006). Peripheral milling of very flexible components is a common manufacturing process in the aerospace industry. Very flexible components are considered to have a wall thickness thinner than 5 mm and an axial depth of cut larger than 30 mm. The wall thickness of the component is reduced further by peripheral milling operation using a long, helical slender end mill. A typical example for the process is peripheral milling of jet engine impellers and rotor discs on five axis CNC machining centers (Budak and Altintas, 1995).

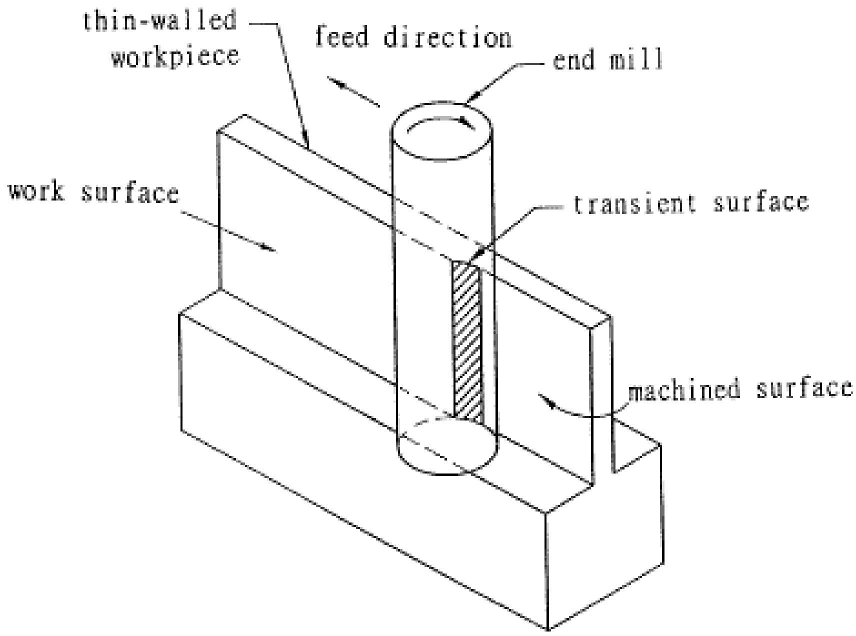

Figure 2.1: The Peripheral Down Milling of Thin-wall Workpiece
(Budak and Altintas, 1995)

(a) (b)

Figure 2.2: (a) Conventional-“Up” Milling and (b) Climb-“Down” Milling
(Source: Kalpakjian, 2006)

In this research, down milling is used. Climb milling or down milling is the process when feed movement and tool rotation are in same direction. Vice versa, conventional milling or up milling is the process when feed movement is opposite to tool rotation. Conventional milling is preferred when milling castings or forgings with very rough surfaces while climb milling is preferred when milling heat treated alloys and stainless steel to reduce work hardening.

2.2 Force-induced Deflection in Peripheral Milling of Thin-wall

The peripheral milling of thin-wall is complicated, where periodically varying milling forces excite the flexible cutter and plate structures both statically and dynamically. Static deflections produce dimensional form errors, and dynamic displacements produce poor surface finish in milling (Budak and Atlantis, 1995). Very flexible plates are considered to have a large span ratio of height to thickness. The part to be machined discussed in this paper is only limited to the small deformations of thin-walled plates. In peripheral milling of the thin-walled plates, the radial forces can be looked as the linear loads (see Figure 2.3). The thin-walled plates in Figure 2.3 can be considered as the cantilever plate, which is also the boundary condition for the plate. For simplification, it applies the following assumptions for the calculation of small deformations of thin-walled plates:

a) The displacement of every point on the plates does not change along the thickness, which is equal to the deformations of the plate middle plane.
b) Straight normal line hypothesis: the normal line is still straight and vertical to the middle plane both pre deformations and after deformations.
c) The normal stress applied on the plane that is parallel to the middle plane is very small. It thus can be ignored.

(Tang and Liu, 2008)

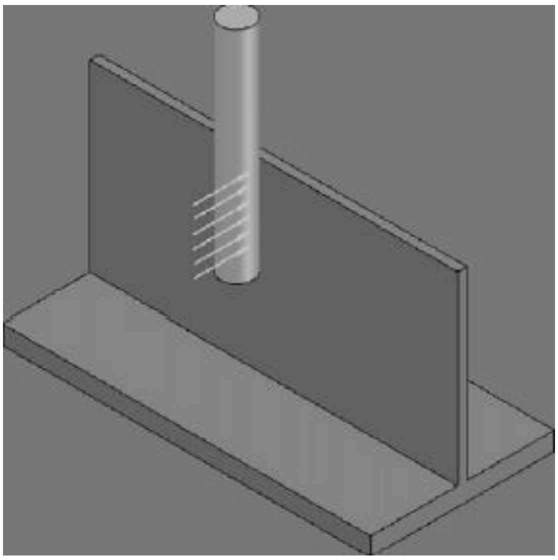

Figure 2.3: Linear Loads Acting on Thin-wall Plates.

2.3 Current Research on Milling of Thin-wall

Most of the studies and researches have been made are more on the prediction of surface dimensional error in the thin-wall milling. There is still no research on the study of cutting tool geometry in reducing the surface dimensional error in thin-wall milling especially the study on the relief angle on the dimensional error. Many researches use FEA method to simulate the thin-wall milling which is complicated and time-consuming.

In Bai *et. al.* (2010) study, a finite element analysis (FEA) based milling process simulation system was developed to predict machining deformation of aerospace thin-walled monolithic structures. Some key factors such as initial residual stress, cutting loads, cutting sequence and tool path were introduced synthetically into the simulation system. The geometry of workpiece that Bai *et. al* studied is shown in Figure 2.4. All the thicknesses of the side wall, rib plate and web plate are equal to 2mm.

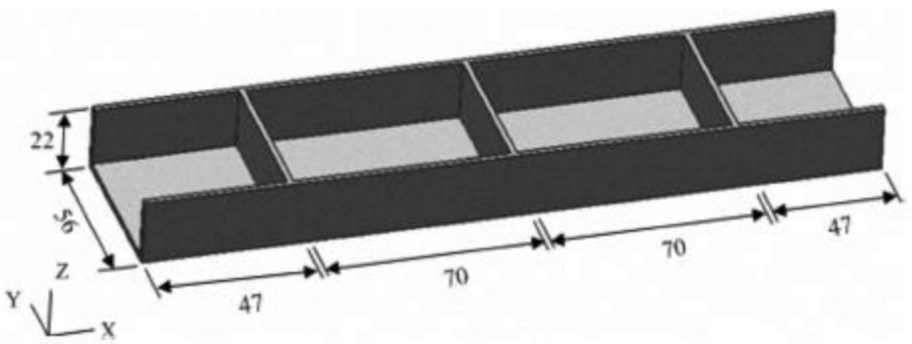

Figure 2.4: The Thin-walled Structure Studied by Bai *et. al.* (2010)

Peterka *et. al.* (2008) studied the deformation measuring of thin-walled parts by measuring systems ARAMIS and TRITOP. The ARAMIS is a system for optical 3D deformation analysis for static or dynamically loaded specimens and components. The TRITOP is a system for optical deformation for static loaded components. In the first stage there was monitor and measurement dynamic deformation of thin-wall during milling. In the second stage there was measurement static deformation of thin-wall.