



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**FEEDRATES OPTIMIZATION IN BALL END MILLING OF
ALLUMINUM ALLOY**

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

by

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2010



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

JUDUL: FEEDRATES OPTIMIZATION IN BALL END MILLING OF ALUMINUM ALLOY

SESI PENGAJIAN : 2009/2010 Semester 2

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APPROVAL

This PSM submitted to the senate of UTeM and has been as 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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ABSTRACT

The ball end milling is the most frequent in the machining of mechanical workpiece with complex surface such as those in molds and dies. The ball end mill is designed is that it can handle very high feed rates, meaning it can mill the material very quickly and at the same time it can gives a high productivity. The quality and the efficiency in ball end milling machining is effect by generated scallop height. During this project, the optimization of feedrate in ball end milling process will be study by optimum the quality and improving the machining efficiency for minimize the scallop height after done the isoparametric process. The purpose in this project has been aiming at achieving conflicting objective. This has led to the determination of optimal intervals between successive feedrate to optimize the conflicting objective. The basic concept of feedrate optimization “ $f = p$ ” machining and the calculation for any given scallop height is used to determine the optimal feedrate. The optimal feedrate can be determined as the feed interval scallop height is equal to the path interval height. Full factorial techniques will be applied in this project to measures the response of every possible combination of factors and factor levels. In this project, the best feedrate is not the main target but would like to see the trend of the result that been effect of the scallop height. Upon what is obtained, if the angle, feed and the stepover increase, the value of scallop height also increase. This means that all factors are directly proportional to the scallop height. The scallop heights that will be produce by ball end milling machining are depends on the way to enhance the efficiency in the ball end milling machining. In the other hand, the quality in ball end milling machining is effect by generated scallop height.

ABSTRAK

Pengisar bebola adalah proses yang sering digunakan dalam pemesinan benda kerja yang rumit dan kompleks seperti dalam pembuatan acuan dan die. Pengisar bebola direka supaya boleh mengendalikan kadar suapan yang tinggi untuk mengisar bahan dengan cepat dan pada masa yang sama dapat memberikan produktiviti yang tinggi. Kualiti dan kecekapan mesin pengisar bebola adalah kesan dari pembentukan ketinggian gelombang. Sepanjang projek ini dijalankan, pengoptimuman kadar suapan dalam proses pengisaran bebola akan dikaji dengan mengoptimimkan kualiti dan meningkatkan kadar kecekapan bagi meminimumkan ketinggian gelombang selepas proses “isoparametric” dalam pegisaran bebola. Tujuan projek ini dijalankan adalah untuk mencapai target yang bertentangan. Hal ini mengakibatkan penentuan jeda antara kadar suapan berturut suapan jeda sama dengan ketinggian laluan jeda. Konsep dasar optimasi “ $f = p$ ” dan pengiraan untuk setiap ketinggian gelombang digunakan untuk menentukan kadar suapan yang optimum. Kadar suapan yang optimum dapat ditentukan sebagai ketinggian gelombang bagi menentukan dan sekaligus menyelesaikan persamaan. Teknik factorial lengkap digunakan dalam project ini bagi mengukur tanggapan dari setiap kemungkinan kombinasi faktor dan tahap faktor. Dalam projek ini, kadar suapan terbaik bukan sasaran utama tetapi ingin melihat kecenderungan keputusan yang memberi kesan terhadap ketinggian gelombang. Setelah apa yang diperolehi, jika sudut, suapan dan jurang langkah adalah tinggi, nilai ketinggian gelombang juga akan tinggi. Ini bermakna, semua parameter adalah berkadaran terus dengan ketinggian gelombang. Ketinggian gelombang yang dihasilkan oleh pemesinan penggilingan bola bergantung pada cara untuk meningkatkan kecekapan pada mesin penggilingan bola. Dengan kata lain, kualiti pemesinan penggilingan bola adalah bergantung kepada kualiti dari ketinggian gelombang yang terhasil.

DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENTS

All praise to almighty Allah S.W.T. I am thankful for the strength and patience He has given within me to complete this Bachelor Degree Project as a part of program Manufacturing Engineering. First and foremost, I would like to thank to my supervisor of this project, Encik Mohamad Ridzuan b. Jamli for the valuable guidance and advice. He inspired me greatly to work in this project. His willingness to motivate me contributed tremendously to my project. I also would like to thank his for showing me some example that related to the topic of my project.

Besides, I would like to thank the authority of Universiti Teknikal Mlaysia Melaka (UTeM) for providing me with a good environment and facilities to complete this project. Also, I would like to take this opportunity to thank to the Faculty of Manufacturing Engineering (FKP) of UTeM for offering this subject, Project Sarjana Muda (PSM). It gave me an opportunity to participate and learn about the operation of milling process.

An honorable mention goes to my families for their understandings and supports on me in completing this project. To all lecturers and staff of Faculty of Manufacturing Engineering, I am particularly indebted for your help and academic guidance throughout my study. Also to my friends, especially student under same supervisor Noor Haznil Ikmal and Nor Hanani and coursemates who also give contribution and support all the time. Finally, I would like to wish thank you a lot to anybody who has given all the support and contribution to me in this project. Without helps of the particular that mentioned above, I would face many difficulties while doing this project.

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LIST OF ABBREVIATIONS

DOE	-	Design of Experiment
DE	-	Design Expert
°	-	Degree
µm	-	micron meter
mm	-	millimeter
rpm	-	round per minutes
PSM	-	Project Sarjana Muda
Eq.	-	Equation
Mpa	-	Mega pascal
HSS	-	High Speed Steel
CS	-	Cutting Speed
EP	-	Extreme Pressure
RPM	-	round per minutes

CHAPTER 1

INTRODUCTION

1.1 Background of Project

A ball end mill is a type of end mill using ball end mill tool (**Figure 1.1**) that is especially suited to machining three dimensional contoured shapes, such as those in molds and dies. It has a rounded tip which is designed to give an improved surface finish to the material being cut. The ball end milling is the most frequent in the machining of mechanical workpiece with complex surface. The machining of these workpieces presents several difficulties such as the complex geometry of certain parts, very hard materials or the great precision. This is because the cutting edge is determined on spherical surface and the tip of tool is moving in a linear motion and the cutting speed is zero.



Figure 1.1: Ball End Mill cutter

A ball end mill is well suited to milling many types of materials, from plastics to steel alloys and titanium. The toughness and durability of the cutting edge is very high in ball end mills because of the rounded edge design. This fact is actually just a by product of the rounded cutting edge. Originally it was rounded for

a specialized purpose, namely for milling grooves with a semi-circular cross section. This type of groove is an important part of the metal bearings used in many machines. Another benefit of the way, the ball end mill is designed is that it can handle very high feedrates, meaning it can mill the material very quickly. This gives it great productivity for use in today's milling machines. The smooth geometry of the cutting tip also translates into lower cutting forces, giving the cutter added strength under pressure. Since it is less likely to break under normal forces, the ball end mill is also highly cost-effective for the applications to which it is suited.

Ball nose end mills are used in many metal working applications including mold making where the inherent strength and milling advantages of a fully radiuses cutting edge for the copy milling of a mold cavity is best demonstrated. Its ball shape allows the end mill to attack the mold cavity from any angle or direction. The cutting edge when generated through the end of the ball mill becomes helical with rotation. This promotes shearing of the metal to be cut in an efficient manner.

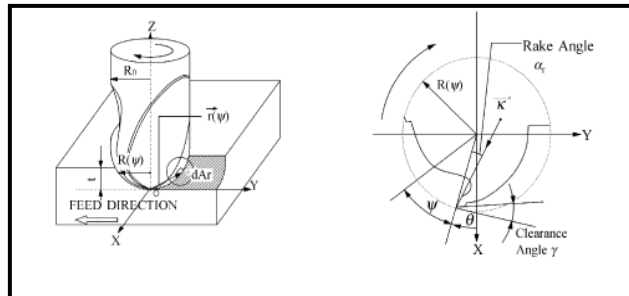


Figure 1.2: A model of cutting with a ball end mill (K, Yoshihiro, et al, 2001)

For the high-speed machining where the high feed or pick ratio is used, the feed-interval scallop must be taken into account. The scallop height represents the distance between the scallop curve and the design surface. For constant scallop height machining, the scallop curve are on an offset surface of the design surface with the scallop height as the offset distance (**Figure 1.3**). Two offset surfaces of the design surface, the scallop surface and the tool center surface, are employed to successively establish scallop curves on the scallop surface and cutter location tool

paths for the design surface. To satisfy surface finish quality, tool paths are generated and scallop height formed by two adjacent tool paths is controlled within a predefined machining tolerance. The path interval should be small enough, and consequently, the machining efficiency is limited. To achieve a significant improvement in machining efficiency, the scallop height is kept at a constant which is equal to the predefined machining tolerance. To improve the machining accuracy of constant scallop height machining, an iterative approach for tool path generation is using a thorough understanding of the machining geometry.

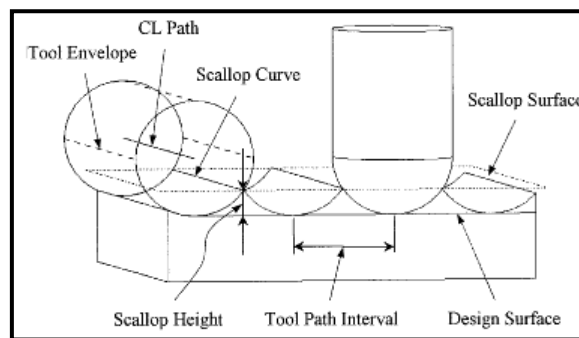


Figure 1.3: Geometric element of a machined surface (Feng, H. Y, Li, H, 2001)

The effectiveness of the present approach is demonstrated through the machining of a typical sculptured surface. The path interval is particularly important since it affects the efficiency of the tool path planning. It also derives the cutting depth for machining a sculptured object. The previous works show that the feedrate optimization of the high speed ball-nosed milling must take into account the feed-interval scallop effect due to the dynamical and periodical change of the cutting edge orientation also had established a model that can predict both the feed interval and path interval scallop heights at any given tool radius, tool profile, feed, pick and tool-axis inclination. It was found that the tooth feed must be kept within one third of the path pick in order to keep the feed-interval scallop height not over the path-interval scallop height. It was found a notch-cut on the center of the ball-end cutter reduced the feed interval cusp height. If the parameters of the notch cut profile can be optimized, it is believed that the feedrate can be further increased.

This project optimizes the feedrate in the ball end milling process to optimum the quality and improves the efficiency of this process because the one of factor that affects the feed-interval scallop due to the dynamical and the periodical change of the cutting edge orientation. The parameters in ball end milling that will be considered in this project are depth of cut, feedrate, spindle speed, angle, step over, lubrication, material and tool material. The concept “ $f = p$ ” by Chen, J. S., et al (2005) is used that refer to the path and pick interval scallop produced after machining.

1.1 Problem Statement

Die and mold machining is to produce highly quailed surface using the high speed hard machining with the ball end cutter. The ball end milling is however less efficiency than the flat end milling. It is important to optimize the feedrate that gives the maximum material removal rate constrained by an allowable surface roughness in order to improve the machining efficiency of the ball end milling. The scallop heights that will be produce by ball end milling machining are depends on the way to enhance the efficiency in the ball end milling machining. In the other hand, the quality in ball end milling machining is effect by generated scallop height. In this project, the optimization of the feedrate by considering the generated scallop effect of the ball end cutter will be study. The isoparametric process in ball end mill will be use to see the result and the surface generated.

1.2 Objective

- a) To study the optimization of feedrate in the ball end milling process
- b) To minimize the scallop height after done the isoparametric process in the ball end milling process
- c) To optimum quality in order to improve the machining efficiency of the ball end milling process

1.3 Scope

Project on optimal feedrate has been aiming at achieving conflicting objective. The feedrate optimization of the high speed ball nose milling must take into account the feed interval scallop effect due to the dynamical and periodical change of the cutting edge orientation. Basic concept of feedrate optimization “ $f = p$ ” machining will be used in this project. This concept involving the calculation for any given scallop height to determine the optimal feedrate.. It is basically assumed that the feed interval and pick interval scallop are produce by the same generating mechanism. Modeling with CATIA is using along finish this project by using basic advance machining. Analysis in this project is using Design of Experiment (DOE). One of DOE techniques Full Factorial will be apply in this project to measures the response of every possible combination of factors and factor levels. These responses are analyzed to provide information about every main effect and every interaction effect.

1.5

Flow chart

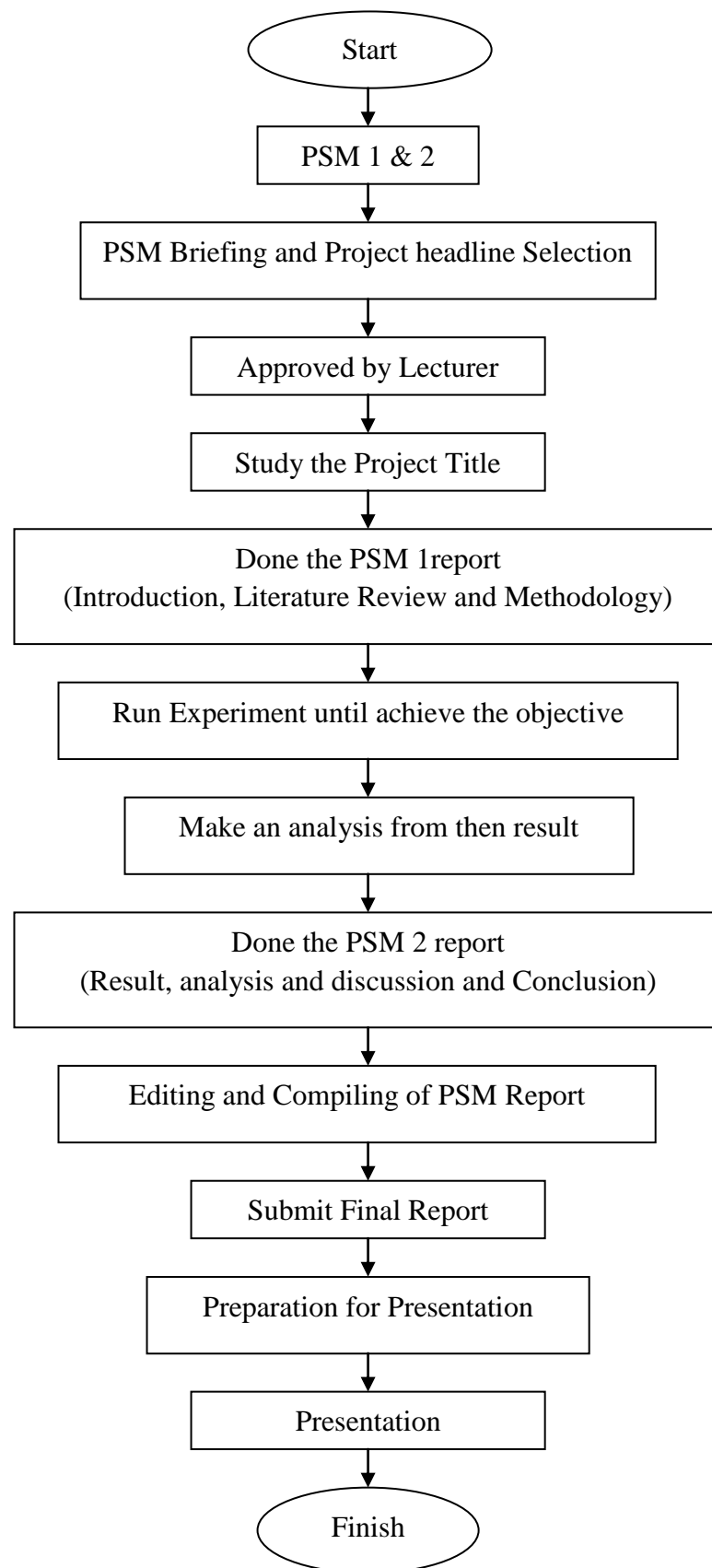


Figure 1.4: Flow chart for PSM 1 and 2

CHAPTER 2

LITERATURE REVIEW

A literature review is an account of what has been published on a topic by accredited scholars and researchers. The topic that been discuss should be narrow and only present ideas on studies that are closely related to topic. Ideas that be presented must economically and the flow within and among paragraphs be a smooth, logical progression from one idea to the next. In this chapter, not trying to list all the material published but to synthesize and evaluate it according to the guiding concept of own thesis or research question.

2.1 Pick Interval and Feed Interval Scallop (Chen, J.S; et al, 2005)

In the milling process, the cutting edges of the cutter are in a motion of combined translation and rotation. The periodical variation of the cutting edge orientation during spindle rotation results in two kinds of scallops generated on the machined surface: the pick-interval scallop and the feed interval scallop. For the high-speed machining where the high feed and pick ratio is used, the feed interval scallop must be taken into account. Parameters such as the tool radius feed or pick ratio, initial cutting edge entrance angle and tool-axis inclination angles have been highlight and verified.

Surface finish and distortion of a machined workpiece after the high-speed machining are much superior to the conventional milling process. It is the goal that

the secondary benching can be kept to minimum or even eliminated. Sculptured surface machining process requires the construction of successive cutting paths separated by an offset distance (called the path pick). Along each cutting path direction, the orientation of the cutting edge is periodically changed during the spindle rotation. Because of the geometric shape and the dynamical change of the ball end cutting edges, path-interval scallop and feed-interval scallop are generated on the machined surface. The path interval scallop is generated by the finite pick offset between the successive cutting paths, while the feed interval cusp is generated by the finite increment between the successive tooth feeds. For the ball end milling, the machining process consists of successive parallel cutting paths separated by an offset distance where as the offset between the successive paths is called the pick. Due to the spherical geometry, a path interval scallop can be observed between successive paths. The path interval scallop is simply formed by the stationary geometry of the ball end cutter. Note that the path-interval scallop formation is assumed that the ball end cutter is in pure translation to the workpiece.

In order to achieve high qualified surfaces, the scallop generation mechanism must be well controlled. The generating mechanism of the rotation ball nose end milling is much complicated because the orientation of the cutting edge is dynamically and periodically changed during the spindle rotation. Scallops are not only generated between the successive cutting paths but also found between the successive feeds of the cutting teeth. The cutting speed at the center of a ball end cutter is equal to zero. So, unfavorable cutting condition leads to poor workpiece surface qualities and tool wear. By introducing an inclination of the tool-axis to the surface normal, the zero cutting speed condition can be avoided. The surface roughness at the high speed machining is particularly sensitive to the tooth feed and tool-axis inclination in the ball end milling operation.

The shape and generating mechanism of the feed interval scallop looks exactly same as the path interval scallop (**Figure 2.1** (a) and (b)). However, the pick interval scallop is simply defined by the static geometric shape of the ball end cutter in the pure translation motion but in **Figure 2.1** (b) the cutting tool is rotating.

Therefore, the dynamical translation and rotation motions of the cutting edge must be taken into account in analyzing the feed-interval scallop. However, note that the pick-interval scallop is simply defined by the static geometric shape of the ball end cutter in the pure translation motion. But in **Figure 2** (b), the cutting tool is rotating. Therefore, the dynamical translation and rotation motions of the cutting edge must be taken into account in analyzing the feed interval scallop.

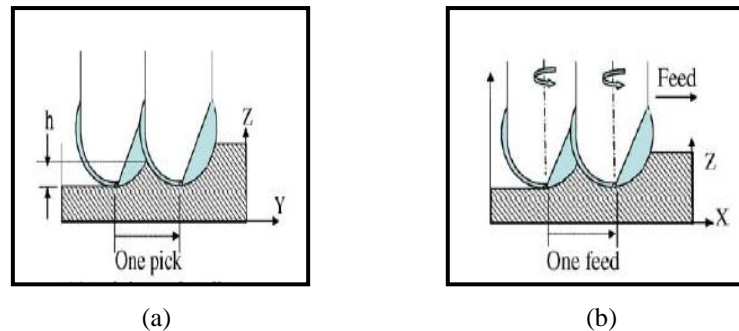


Figure 2.1: (a) The Path Interval (b) Feed Interval Scallops of Ball End Milling (Chen, J.S; et al, 2005)

In most conventional operation, the feed to pick ratio is usually below one third. The use of high speed milling makes it possible to increase the number of tool paths thus reduce the pick between the successive paths and therefore to reduce the path interval scallop height without increasing machining time. The feed interval scallop is generated by the dynamic motion and intersection of the multiple sweeping cutting edges. The feed interval scallops play a more important role to the surface roughness than the pick interval scallops. The feed interval scallop height is about three times of the pick interval scallop height. The peak height of the feed interval scallop happened at a location that the pick interval scallop height is almost at a minimum value.