CUTTING PERFORMANCE OF DIFFERENT COATINGS DURING MINIMUM QUANTITY LUBRICANT MILLING OF AA6061T6

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ABSTRACT

This report presents an experimental investigation on the effects of output parameters which are surface roughness, tool wear and material removal rate during machining aluminum alloy 6061-T6 using minimum quantity lubricant (MQL) technique. The minimum quantity of lubrication technique was becoming increasingly more popular due to the safety of environment. The cutting speed, depth of cut, feed rate and MQL flow rate were selected input parameters in this study. This experiment was conducted based on central composite design (CCD) method. To develop a model of process optimization based on the response surface method. MQL parameters include nozzle direction in relation to feed direction, nozzle elevation angle, distance from the nozzle tip to the cutting zone, lubricant flow rate and air pressure. To achieve a maximum output parameters based on the optimized process parameters for coated carbide cutting tools (CTP 2235). The surface roughness was increased with decrease of cutting speed. The optimum cutting condition for MQL and flooded are obtained. For MQL, the feed rate, depth of cut, cutting speed and MQL flow rate are 379 (mm/tooth), 2 (mm), 5548.258 (rpm) and 0.333 (ml/min) respectively. For flooded, the feed rate, depth of cut, cutting speed and MQL flow rate are 379 (mm/tooth), 2 (mm) and 5563.299 (rpm) respectively. It was seen that a majority of coated carbide inserts had a long tool wear when exposed to high cutting speed, and feed rate leading to breakage of the inserts.

ABSTRAK

Laporan ini membentangkan siasatan ujikaji mengenai kesan parameter pengeluar iaitu kekasaran permukaan, pemakaian alat dan kadar penyingkiran bahan semasa pemesinan aloi aluminium 6061-T6 menggunakan minimum kuantiti pelincir (MQL) teknik. Teknik minimum kuantiti pelinciran menjadi semakin popular kerana keselamatan alam sekitar. Kelajuan pemotongan, kedalaman pemotongan, ‘*feed rate*’ dan kadar aliran MQL dipilih menjadi parameter kemasukan dalam kajian ini. Eksperimen ini telah dijalankan berdasarkan reka bentuk komposit pusat (CCD) kaedah. Untuk membentuk model pengoptimuman berdasarkan kaedah gerak balas permukaan. Parameter MQL termasuk arah muncung berhubung dengan makanan haiwan arah, sudut ketinggian jarak muncung dari hujung muncung ke zon pemotongan, kadar aliran pelincir dan tekanan udara. Untuk mencapai parameter pengeluar maksimum berdasarkan proses parameter dioptimumkan untuk bersalut alat pemotong karbida (CTP 2235). Kekasaran permukaan telah meningkat dengan penurunan kelajuan pemotongan. Keadaan pemotongan optimum untuk MQL dan ‘*flooded*’ diperolehi. Untuk MQL, ‘*feed rate*’, kedalaman potongan, kelajuan pemotongan dan kadar aliran MQL adalah 379 (mm / gigi), 2 (mm), 5548,258 (rpm) dan 0.333 (ml / min) masing-masing. Untuk ‘*flooded*’, ‘*feed rate*’, kedalaman potongan, kelajuan pemotongan dan kadar aliran MQL adalah 379 (mm / gigi), 2 (mm) dan 5563,299 (rpm) masing-masing. Ia dilihat bahawa majoriti ‘*insert*’ bersalut karbida mempunyai pemakaian alat yang lama apabila terdedah kepada kelajuan pemotongan yang tinggi, dan ‘*feed rate*’ yang membawa kepada kerosakan kepada ‘*inserts*’.

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RPM	Revolution per minute
v_c	cutting speed
f_r	feed rate in mm/rev
f_t	Feed rate in mm/tooth
n	Number of the teeth of cutter
R_a	Average surface roughness
L	Sampling length
CS	Cutting speed
mm^3/min	Millimetre cubic per minute
mm	Millimetre
μm	Micrometre
N	RPM of Cutter
W	Width of cut (may be full cutter or partial cutter)
t	Depth of cut
L	Length of pass or cut
f_m	Table (machine) Feed
D	Cutter Diameter in mm

LIST OF ABBREVIATIONS

MQL	Minimum quantity lubrication
RSM	Response surface method
CNC	Computer numerical control
TiC	Titanium carbide
TiCN	Titanium carbon nitride
TiN	Titanium nitride
PVD	Physical vapour deposition
CVD	Chemical vapor deposition
WOC	Width of cut
DOE	Design of Experiment
RPM	Revolution per minute
WC	Tungsten carbide
Ra	Average roughness
MRR	Material Removal Rate

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Manufacturing in general term is the use of machine, tools and labor to produce things for sale. In this field of expertise, the competition is indeed fierce and manufacturer have to produce new products in a very short time and with reduced costs, whereas customers require more and more quality and flexibility, as explained by Kebrat et al. (2010). Manufacturing usually occur in large scale that involve mass of production. Beside the manufacturers in the competitive marketplace because of the manufacturing environment, low costs, goals of high rates of production, and high quality. The minimization of cutting fluid also leads to economic benefits by way of saving lubricant costs and workpiece/tool/machine cleaning cycle time (Dhar et al., 2006). In order to improve the traditional manufacturing, many technologies are developed and it's cause many machine are created as well as tool itself. There are many types of machine and tool that are used to process the material in manufacturing process. Some of them may involve high cost to operate the process such as cost of machine, cost of maintained, energy consumption, labor and so on. Therefore, in mass production, there is important to consider the economic aspect due to make the industry profitable and growth. Many traditional techniques and hybrid methodologies are developed to make the manufacturing process more effective by many ways such as directly assess the machining performance (Jawahir et al., 2003).

An ultimate machine required ultimate tool to operate at full of performance. We can use high quality of material to created better tool for example by using TiN-coated carbide cutting tool as it can stand at high temperature, high cutting-speed and it was prove that can improve the tool life. The coated tools are used more than 40% in industry and perform more than 80% to all machining use (Cselle and Barimani, 1995). However, the performance of that cutting tool is depending on many variable of cutting condition.

This project focused the technique of minimum quantity lubrication performed for machining of AA6061T6 using coated carbide tool and CNC end milling machine. The mechanical properties for AA6061T6 depends on the greatly on the temper, or heat treatment, of the material. The aluminum offers advantages over other materials because of its relatively low density, high recyclability, design flexibility in mass production and economic benefit (Chu and Xu, 2004). Besides that, the aluminum with increasing concern of fuel economy and stringent government emission regulations, light weight materials, specifically aluminum, are being extensively adopted by design engineers for structural components. Surface finish is essential factor in evaluating the quality of products and surface roughness (R_a) most used index to determine the surface finish. The response surface method (RSM) as a statistical method that been used to optimize the surface responses. The RSM quantifies the relationship between response surfaces and input parameters. Fuh and Hwang (1997) constructed a model that can predict the milling force in end milling operations by using RSM method. They measured the speed of spindle rotation, feed per tooth and axial and radial depth of cut as the three major factors that affect in milling operation. The authors had made a comparison between the experimental data and the values predicted by this prediction model showed the model’s accuracy to be as high as 95%. In this experiment focuses on best usage of machining AA6061T6 and coated carbide in respect to the cutting force, tool life and surface roughness using the RSM approaches in the CNC milling machine as explained by Fuh and Hwang (1997).

1.2 PROBLEM STATEMENT

Performance of milling machine almost depending in how fast the machine can cut the work piece, meaning that even a slight change in machining element such as implementing a suitable coating on the cutting tool could improve the machinability of a material (Chattopadhyay et al., 2009). High productivity needed high rate of metal removal, so it will reduce manufacturing cost and operation time. The large amount of the cutting fluid contain potentially damaging or environmentally harmful possibly damaging chemical elements that can expose skin and lung disease to the operators plus air pollution (Sreejith (2008) . The minimal quantity lubrication (MQL) will be used in our experiment compare another cutting fluid. MQL in an end-milling process is very much effective regarding (Lopez de Lacalle et al., 2001) and they mentioned that MQL can reach the tool face more easily in milling operations compared with other cutting operations. AA6061-T6 is more suitable choice due to its cost-efficient element (MacMaster et al., 2000) and economical aspect has always been important when it came to mass production while there is more material such as aluminum alloy AA 6069 (Chu and Xu, 2004). Ghani et al (2004) investigated that the coating typically reduced the coefficient of friction between the cutting tool and reduce the tool wear. Eventually, sudden failure of cutting tools lead to loss of productivity, rejection of parts and consequential economic losses. The coated carbide tool is to be considered in this study to evaluate the performance of a machining process depends on tool wear or tool life.

1.3 OBJECTIVES OF THE PROJECT

The objectives of this project are as follows:

i. To experimentally investigate the machining characteristics of aluminum alloy in end mill processes for MQL techniques.
ii. To investigate of coated carbide cutting tool performance on surface finish by using MQL method.
iii. To study the tool wear and the material removal rate regarding the MQL technique.

1.4 SCOPE OF THE STUDY

i. Using CNC milling machine to operate the end milling on AA6061T6 by coated carbide using MQL.

ii. Determine optimum performance of coated carbide cutting tools in milling operation by vary machining parameter which is cutting speed, feed and depth of cut.
iii. Design of experiments and optimization model is prepared using MiniTab software.
iv. Mathematical model using Response Surface Method (RSM).

1.5 ORGANIZATION OF REPORT

There are five chapters including introduction chapter in this study. Chapter 2 presents the literature review of previous studies includes the end milling, process parameters, response parameters, prediction modelling. Meanwhile, Chapter 3 discusses the design of experiment, preparation of experimentation, mathematical modeling techniques and statistical methods. In Chapter 4, the important findings are presented in this chapter. Chapter 5 concludes the outcomes of this study and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides the review from previous research efforts related to milling process, CNC milling machine, cutting parameters in milling machine, and cutting tools. This chapter also involves a review some research studies like the statistical method and artificial neural network which are related to the mathematical modelling the present study. Substantial literature has been studied on machinability of aluminum alloys which is covers on surface roughness, tool life, tool wear cutting force and chip formation. This review has been well elaborate to cover different dimensions about the current content of the literature, the scope and the direction of current research. This study has been made in order to help identify proper parameters involved for this experiment. The review is fairly detailed so that the present research effort can be properly tailored to add to the current body of the literature as well as to justify the scope and direction of present.

2.2 END MILLING

Milling is the most common form of machining process used in the production of moulds/dies, due to the high tolerances and surface finishes by cutting away the unwanted material. A serious attention is given to accuracy and surface roughness of the product by the industry these days (Nagallapati et al., 2011). Surface finish has been one of the important considerations in determining the machinability of materials. In end milling process, the end-milling cutter are discretized into limited number of elements, and the forces exerted by each element regarded as oblique cutting are calculated (Wang et al., 2004) By summing up the cutting forces generated by elemental edges, the instantaneous cutting forces of end milling can be determined. Wang et al. (2004) also stated that the end-milling operation is an oblique cutting process. There have been a lot of important factors to predict machining performances of any machining operation, such as surface roughness and dimensional accuracy. Ibraheem et al. (2008) investigated the effect of cutting speed, feed, axial and radial depth of cut on cutting force in machining of modified AISI P20 tool steel in end milling process. They concluded that, higher the feed rates, larger the cutting forces. They also developed the genetic network model to predict the cutting forces. Abou-El-Hossein et al. (2007) developed the model for predicting the cutting forces in an end milling operation of modified AISI P20 tool steel using the response surface methodology. End milling has been the most versatile form of milling for quite and the fact that it can be used to machine slots, shoulders, die cavities, contours, and profiles is indeed magnificent. It is one of the most common processes in product manufacturing and is very commonly employed in a lot of machines (Li and Li, 2004). However numerical control machines are the kind of machine that had been employed for material removal operations. Li and Li (2004) later also added that the prediction of cutting forces in milling is of fundamental importance in order to establish optimization of the cutting processes. There were many force models developed for milling processes. However, despite the increased sophistication and usefulness of the models developed in recent years, the predictive capability of the force and surface error predictions rely on the empirically established milling force component coefficients for each cutter design. Usually there are a lot of other limitations can be prevented by modeling a milling force in a more scientific nature. Based on the research carried out by Wang et al. (2004), the precise metal cutting has become more and more important for productivity and reliability requirement for modern industry. There are a lot of sources when it comes to the causes the vibration in cutting process. Dynamic change in cutting force is one of the major sources causing the vibration in cutting process. The result of this phenomenon is that the machining accuracy will be deteriorated. Thus, accurate modeling of cutting forces is necessitated for the prediction of machining performance and to determine the mechanisms and machining parameters that affects the stability of machining operations. Referring to all the facts including the difficulty of measuring the length of shear line and to represent it as a function of measurable variables, the linear force model that is proportional to undeformed chip thickness has been widely used in analysis and simulation (Wang et al., 2004).

Figure 2.1 shows cutting force coefficients and cutting force models (Dang et al. 2010). Cutting force coefficients are determined directly from milling tests, using a specific cutter / work piece combination in this direct calibration method. The cutting forces were presumed to be directly proportional to the uncut chip thickness, which somehow explained that in other words, the cutting force coefficients were constants. The non-linear connection exists between the cutting forces coefficients and the prompt uncut chip thicknesses. The cutting force coefficient has the tendency to increase quickly as the instantaneous uncut chip thickness becomes smaller. This is the so-called size effect, which to put it simply is vice-versa, where the cutting force would be much weaker when the chip thickness where to be larger in size. The designated feed per tooth is large enough and the employed radial depth of cut is identical, the total cutting forces will be roughly in quantity to the flank instantaneous uncut chip thickness under the condition that only the first disc element of any edge is in cut at the prime phase of each tooth period. Sun et al. (2009) explained that the ball-end milling is widely used in machining parts with curved geometries such as die, mould, propellers and turbine blades. There are bound to be challenges and difficulties in whatever the system that has to work with and with that, regardless of the emergence of many advanced CAM systems, machining of complicated surfaces is still acknowledged as a challenge. All these little elements had no doubt contributes to high demand for tolerance, roughness and more often than not, it affects the machinability of difficult-to-cut materials. The cutting force modeling has become an essential step to understand the behavior of cutting process and it can serve as a stepping stone to further ensure the stability of machining system and the optimization of process parameters.

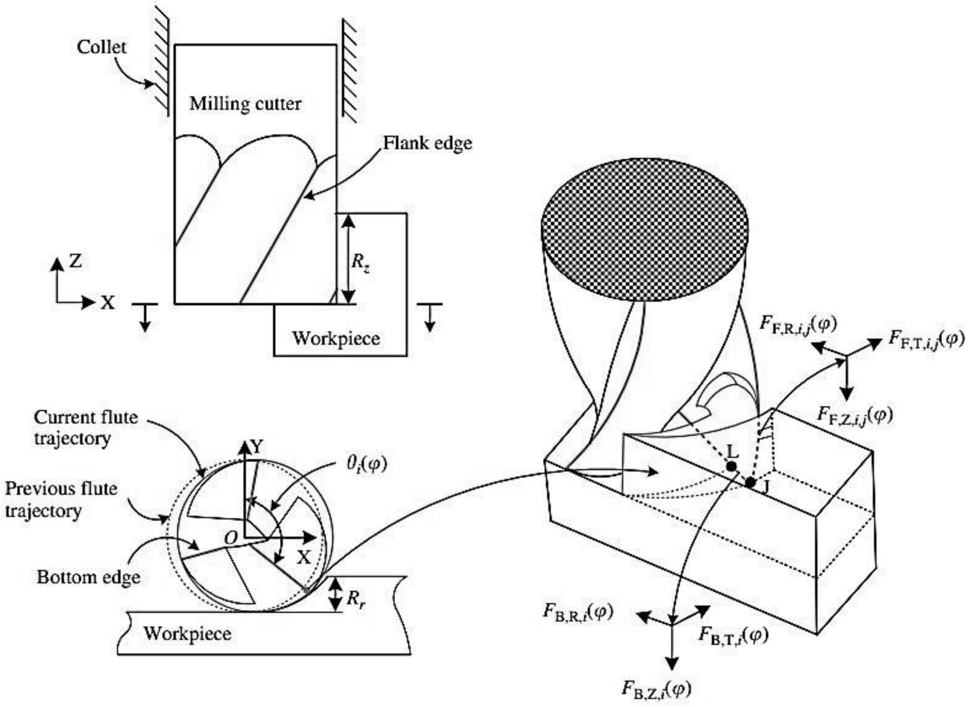

Figure 2.1: Modeling of flat end milling

Source: Dang et al. (2010)

Figure 2.2 shows a chip load distribution model in end milling where another investigation to reveal the relationship between the cutting force and cutting depth, the change of cutting force at the instant when a flute passes point *p* was examined. There are supposedly a lot of things to be considered in this issue. However, in this case, seven engagement cases were established within the range of cutting depths being considered. The behavior of chip loads for these cases were examined in a similar manner as described above. Based on this study, the initial conclusion is that the cutting force at the instant when a flute passes point *p* is at a maximum for most cutting conditions. Generally speaking, there are many factors and causes that may affect CNC machining result many aspects including the form error. The final deviation is the combined result of errors in CNC machine tool elements (geometry, orientation, and relative motion), errors in control (servo and NC program), errors from structural compliance (tool, machine tool, and fixture), and environmental effects (temperature). The form of error in ball milling has been dominated by tool deflection, particularly in the precision milling machining process. Li and Li (2004) also experimenting about the predictive force model for which oblique cutting can be established by using a machining theory in which the cutting forces can be calculated from the input data of workpiece material properties, tool geometry and cutting conditions. The study and analysis of the stress distribution and tool chip interface had always been the basis of the theory. The shear plane and the tool chip interface are estimated to be a direction of maximum shear stress and maximum shear strain rate. The end milling process where it's consists of a cylindrical cutter that has multiple cutting edges on both its periphery and tip, permitting end cutting and peripheral cutting. These cutting edges or flutes are usually made helical to reduce the impact that occurs when each flute engages the work piece.

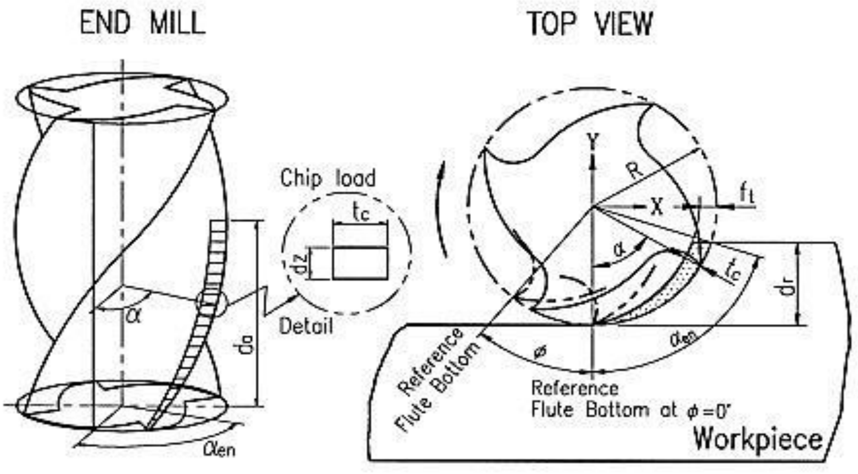

Figure 2.2: Chip load distribution model in end milling.

2.3 RESPONSE SURFACE METHOD

Many researchers have conducted studies on predicting cutting forces produced in machining operations using theoretical and analytical approaches. The response surface method is a powerful reliability method that approximates the limit state function with a polynomial expression using the values of the function at specific points, explained Allaix and Carbone 2011. The difficulties with these methods are that they are grounded on a big number of estimations that are not included in the analysis. This may reduce the reliability of the calculated cutting force values found by these methods. In addition, these approaches may be successfully applicable only for certain ranges of cutting conditions (Kadirgama et al. 2008). The authors had describe in detail regarding the present study regarding the effect of simultaneous variations of four cutting parameters (cutting speed, feed rate, radial depth of cut and axial depth of cut) on the behavior of cutting forces. The response surface methodology (RSM) is utilized. RSM is statistical techniques that are useful for modeling the relationship between the input parameters (cutting conditions) and the output variables, as elaborated by Kadirgama et al. (2008). RSM saves cost and time on conducting metal cutting experiments by reducing the overall number of required tests. In addition, RSM helps describe and identify, with a great accuracy, the effect of the interactions of different independent variables on the response when they are varied simultaneously. RSM has been extensively used in the prediction of responses such as tool life, surface roughness and cutting forces. As we all know, The RSM is used to build the relationship between the input parameters and output responses, and used as the fitness function to measure the fitness value of the genetic algorithm (GA) approach. The GA is later applied to find the optimal parameters for a milling process. The experimental results show that the integrated approach does indeed find the optimal parameters that result in very good output responses (Hou et al., 2007).

2.4 INPUT PARAMETERS

There are many input cutting parameters that need to be considered in end milling process such as nose radius, cutting speed, depth of cut, federate and many more. The range of these input parameters need to be carefully determine as it will directly affect the output parameters later on the experiment.

2.4.1 Cutting Force

According to Li and Liang (2006), the know-how of cutting forces is a requirement to cutting temperature estimation, tool life prediction, cutting process planning, and chatters analysis. Many researchers have conducted studies on predicting cutting forces produced in machining operations using theoretical and analytical approaches (Abou-El-Hossein et al., 2007). Cutting force is the acknowledged factor that influences the most on the milling operation performance. Thus, prediction of cutting forces before real machining can provide key guidelines to the planning and optimization of cutting process (Wei et al., 2011). It is crucial to create a set of predictive thermo-mechanical models in order to predicting the cutting forces as functions of near dry lubrication parameters and cutting conditions. The most documented studies on near dry machining were empirical and qualitative. Despite the fact that the evaporative heat transfer model is created for near dry machining, there is no experimental evidence was presented whatsoever. Since Yang and Park first developed a cutting force model for ball end milling, many contributions to modeling and/or predicting of the cutting force for ball end milling have been develop (Yang and Park, 1991). The shear angle and chip thickness do not vary considerably with tool wear. The cutting forces can also be calculated as the summation of the forces attributed to the sharp tool and the forces attributed to the tool flank wear. In near dry machining, in order to achieve the cooling effect, a moving heat source method is pursued to quantify the primary-zone shear deformation heating, the secondary-zone friction heating, and flank face air–oil mixture cooling (Li and Liang, 2006). There are a lot of other effects to be considered but these two had been specifically used to estimate cutting forces under the condition of sharp tools. The predicted variables of flow stress, contact length, and shear angle obtained from the model are used to predict the cutting forces due to the tool flank wear effect.

2.4.2 Depth of Cut

Depth of cut (DOC) is an input parameter to determine the values of cutting range on which the material wish to be cut. There are multiple types of depth of cut, radial and axial depth of cut, on which both are equally important in most cases. Azeem et al. (2004) had addressed his idea regarding depth of cut parameters where describe that the CNC machines have radically changed the machining operations, especially those having high variety and moderate batch sizes. For machining process, there are multiple input cutting parameters to be acknowledge including cutting speed (v), feed rate (f_r), radial depth of cut (d_r) and axial depth of cut. After the proper machine sequence and operation had been chosen, the cutting tools and the parameters for each of the operations have to be determined. The parameters will later then have a substantial impact on the cycle time, the tool life and the material removal rate as well as low surface roughness average and dimensional accuracy (Toussaint and Cheng, 2006). Abou-El-Hossein et al. (2006) were investigated that the significance of input parameters in the improvement of the output parameters such as surface roughness and tool life. It is due to the fact that it has been observed that the improvement in the output variables, such as tool life, cutting forces and surface roughness through the optimization of input parameters, such as feed rate, cutting speed and depth of cut, may result in a considerable economic performance of machining operations. The authors also addressed that one of these output variables that may have either direct or indirect indications on the performance of other variables such as tool wear rate, machined surface characteristics and machining cost, is cutting forces.

2.4.3 Feed Rate

Feed rate is an important aspect. By selecting a fixed feed rate based upon maximum force, which is obtained during full length of machining, the tool is saved but very often these results in extra machining time, which reduces productivity. By optimizing the feed rate, both the objectives of saving the tool (and hence more tool life) and also reducing machining time thereby increasing productivity are achieved (Salami et al., 2007). Feed rate is measured in the units of mm/rev. Sun and Wright (2005) focused on ball end milling presents strategies and algorithms for selecting cutting parameters such as width of cut (WOC) and spindle speed. However, the authors decided to pin point their research towards feed rate. When it came to algorithms and strategies of milling process, there are a lot of goals and objectives to be considered. One of the major goals is to minimize the overall machining time, but it was done within the constraints of the cutting tool limitations (such as the CNC machine tool capability and the tool strength) and the design specifications of the part being machined (such as the allowable surface finish, the accuracy of machined dimensions of prismatic pockets, and the faithfulness between the CAD specified free-form contours and the as machined free-form contours--usually referred to as allowable form error). This is a multiple-variable and multiple constraint optimization problems (Sun and Wright, 2005).