

DEVELOPMENT OF 1ST AND 2ND ORDER TOOL LIFE MODEL WHEN
MACHINING MODIFIED AISI P20 TOOL STEEL

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We certify that the project entitled “Development of 1st and 2nd order tool life model when machining modified AISI P20 tool steel” is written by Afiq Zainorul Bin Zainal. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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To my Beloved Family

NORLAILA BINTI MOHAMED

ZAINAL BIN AHMAD

NURHAMIM BIN ZAINAL

MOHD. HAZIQ BIN ZAINAL

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ABSTRACT

This thesis deals with tool life durability when performing end-milling operation on modified AISI P20 tool steel using TiN coated inserts. The objectives of this thesis is to develop the 1st and 2nd order tool life model when machining modified AISI P20 tool steel and to investigate the relationship between cutting parameters; cutting speed, feedrate, axial depth, radial depth with tool life. This prediction model was then compared with the results obtained experimentally. By using Response Surface Method (RSM) of experiment, first and second order models were developed with 95% confidence level. The 1st order and 2nd order tool life prediction model was developed with the aid of MINITAB software. Modified AISI P20 tool steel were selected as the material in this thesis which commonly used to make plastic injection mold, zinc die-casting, extrusion dies, blow molds, and other structural components. From the results, it is observed that the 2nd order tool life model gives less error percentage compared to the 1st order. Comparing with the 1st order model, 2nd order model gives more accurate value because the average error % shows it has smaller value, which is 0.59%. From both generated regression equation, the relationship between the four cutting parameters with tool life for 1st and 2nd order model are, the tool life increase with reduction of cutting speed, feedrate, and radial depth excluding the axial depth. For end-milling of P20 tool steel, the optimum conditions that is required to maximize the coated carbide tool life are as follow: cutting speed of 140 m/s, feedrate of 0.1 mm/rev, axial depth of 1.5 mm and radial depth of 2 mm. Using these parameters, a tool life of 39.46 min was obtained. This value for tool life was obtained from the 2nd order model. Tool life optimization can help to overcome the cutting tool's costs and production time problem.

ABSTRAK

Tesis ini membentangkan mengenai ketahanan jangka hayat mata alat apabila melakukan operasi “end-milling” terhadap besi AISI P20 yang di ubah suai. Objektif tesis ini adalah untuk meberbitkan persamaan urutan pertama dan urutan kedua jangka hayat mata alat apabila memesis besi AISI P20 yang telah di ubah suai dan mengkaji kaitan di antara parameter-parameter pemotongan iaitu, kelajuan memotong, kadar suapan, kedalaman berpaksi, dan kedalaman jejari dengan jangka hayat mata alat. Model ramalan kemudian dibandingkan dengan nilai yang diperoleh dalam eksperimen. Dengan menggunakan eksperimen “Response Surface Methodology (RSM)”, model urutan pertama dan urutan kedua diterbitkan dengan tahap keyakinan 95%. Model-model tersebut diterbitkan dengan bantuan perisian MINITAB. Besi AISI P20 yang di ubah suai yang dipilih sebagai material di dalam eksperimen ini lazimnya digunakan untuk membuat acuan suntikan plastik, acuan tuangan zink, tuangan penonjolan, acuan tiupan, dan komponen-komponen struktur yang lain. Daripada hasil yang diperoleh, diperhatikan bahawa model jangka hayat urutan kedua member lebih sedikit peratus kesilapan berbanding model jangka hayat urutan pertama. Berbanding dengan model jangka hayat urutan pertama, model jangka hayat urutan kedua member bacaan yang lebih menghampiri ketepatan kerana peratus kesilapan nya yang kecil iaitu, 0.59%. Daripada kedua-dua persamaan regresi, kaitan diantara parameter-parameter pemotongan dengan jangka hayat mata alat ialah, jangka hayat mata alat meningkat dengan penurunan nilai kelajuan pemotongan, kadar suapan, dan kedalaman jejari kecuali kedalaman berpaksi. Untuk proses “end-milling” besi AISI P20 yang telah diubah suai, keadaan optimum yang diperlukan untuk memaksimumkan jangka hayat mata alat adalah seperti berikut; kelajuan pemotongan pada 140 m/s, kadar suapan 0.1 mm/rev, kedalaman berpaksi 1.5 mm, dan kedalaman jejari pada 2 mm. Menggunakan parameter-parameter tersebut jangka hayat mata alat selama 39.46 min diperoleh. Nilai ini di peroleh daripada model urutan kedua. Peningkatan jangka hayat mata alat dapat membantu mengatasi masalah kos mata alat dan masa produksi.

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LIST OF SYMBOLS/ ABBREVIATIONS

R_a	Finest surface finish
TiN	Titanium Nitride
t	Tool life
V_c	Cutting speed
f	Feedrate
a_a	Axial depth
a_r	Radial depth
y	Tool life experimental value
\hat{y}	Tool life predicted value
$\beta_0, \beta_1, \beta_2, \beta_3$ and β_4	Model parameter
ε	Experimental error
x_0	Dummy variable
x_1, x_2, x_3 and x_4	Cutting speed, feed rate, axial depth of cut and radial depth of cut substitute in tool life model.
AISI	American Iron Steel Institute
ANOVA	Analysis of Variance
3-D	Three Dimensions
2-D	Two Dimension
MQL	Minimum Quantity of Lubrication
CNC	Computer Numerical Control
FKM	Fakulti Kejuruteraan Mekanikal
CVD	Chemical Vapor Deposition
PVD	Physical Vapor Deposition
RSM	Response Surface Methodology
EDM	Electrical Discharge Machine
UMP	Universiti Malaysia Pahang
ISO	International Standardization for Organization

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Machining is very important in manufacturing process. Manufacturing companies were often facing problem in settling the machining tools. It took times when changing a tool that have lost its effectiveness to replace it with a new tool. If the company changing their tool frequently it will cost the company a lost in production time when the machine has to stop running. Companies also have to spend money for the machining tools. If the changing of the machining tools can be reduced, it can help in saving the machining tools cost and the time lost when changing the new tools. Tool life affects production costs and therefore competitiveness of the process and may as well have a considerable impact on tool supply, stability of production and last but not least delivery performance. Since tool failure is unavoidable, tool life must be properly taken into account for the calculation of tooling cost and planning of tool supply for production. In daily practice this or a similar situation would call for immediate short term actions of tool life improvement in order to stabilize production or for long term activities of tool life optimization and cost reduction. [1]. This project is going to find a solution to optimize the tool life by investigating the relationship between selected cutting parameters and develop the first and second order tool life model when machining modified AISI P20 tool steel thus helping to solve the cutting tools cost and production time problem.

1.2 PROBLEM STATEMENT

The main problem to define the major reason for tool failure is the large number of process parameters and their possible interactions affecting tool life [1]. The life of cutting tool depends upon many factors, such as the microstructure of the material being cut, metal removal rate, the rigidity of the setup and effects of cutting fluid [2].

During machining process, the cutting tool ability will degrades with time; in other word it became dull. Until a certain time, the tool can no longer cut through the material. If the condition is not suitable with the tool, it will shorten the tool life faster. Low tool life may endanger tool supply and therefore production output and tooling cost may even exceed the calculated manufacturing costs of the entire product [1].

To overcome this problem, cutting tools users need to have a prediction model to help them predict the tool life by calculation. Therefore the cutting tool users can mix and match the suitable parameters for the cutting process. In this way, the cutting tools can be prevented from being damage for a short period of time.

1.3 OBJECTIVE

1. The objective of this study is to predict tool life in end-milling operation of modified AISI P20 tool steel by developing the first and second order mathematical model for tool life.
2. To investigate the relationship between cutting parameters; cutting speed, feedrate, axial depth, radial depth with tool life.

1.4 SCOPE / LIMITATION

In this project, the developed tool life models were limited to the certain range of parameters. There are four selected cutting parameters, cutting speed, feedrate, axial depth, and radial depth. The range of cutting speed is from 100 to 180 m/min, the feedrate is from 0.1 to 0.2 mm/rev, the axial depth is from 1 to 2mm, and the radial depth is from 2 to 5mm.

1.5 THESIS OUTLINE

This thesis consists of five chapters. Chapter 1 gives the introduction of this project. In the introduction, there will be brief explanations about the background of this study, the problem statement, the objective of this study, and the scope/limitation in this project.

Chapter 2 shows the literature review of this study. The literature review will discuss on the selected points such as, the machining process, CNC milling process, cutting tools, modified AISI P20 tool steel, and response surface methodology. In the cutting tool part, there will be a more deep discussion about the tool life.

Chapter 3 presents the methodology of this project. It gives information about the equipment used, the preparation of the work piece, experiment process, and response surface methodology.

Chapter 4 discuss's about the analysis of the experiments in this project. From this analysis, the mathematical models for the tool life, the first and second order will be developed. The accuracy of both mathematical models will be analyzed. Thus this chapter will achieve the objective of this project.

Chapter 5 provides the conclusion and recommendation to this project. The conclusion was made after all the experiment in this project performed and the result has been analyzed. Recommendation for further experiment was made based on the experience during running the experiment.

CHAPTER 2

LITERATURE REVIEW

2.1 MACHINING PROCESS

In machining process, there are two types of cutting, orthogonal cutting and oblique cutting. The orthogonal and oblique cutting processes have then been related to each practical operation such as turning and milling [3]. Turning process is an example of orthogonal cutting. It is recognized that deformation in orthogonal cutting is confined to a narrow shear zone when the chip starts sliding up the face of the cutting tool [4]. According to the orthogonal model, the specific cutting energy is the energy consumed per unit volume of the material removed and it is independent of the cutting speed, therefore it also equals the cutting force divided by the cross sectional area of the uncut chip [5].

Oblique cutting is a 3-D type of cutting. It can be seen in milling process. Referred to the similar definition in the orthogonal cutting model, the specific cutting energy in this oblique cutting model is obtained [6]. The traditional model for oblique cutting has two shortcomings, one being that it involves only one machining case where the tool major cutting edge angle is limited to be 90° , i.e. the undeformed chip thickness is equal to the feed of the tool; whilst the other is that it takes no account of the influence of the tool feed velocity on the resultant cutting velocity. Great attention has been paid to oblique cutting by a number of researchers all around the world, because many practical machining processes are actually examples of oblique cutting, and numerous research papers have been published. Orthogonal cutting is a 2-D type of cutting [7]. Figure 2.1 shows the orthogonal and oblique cutting process [8].

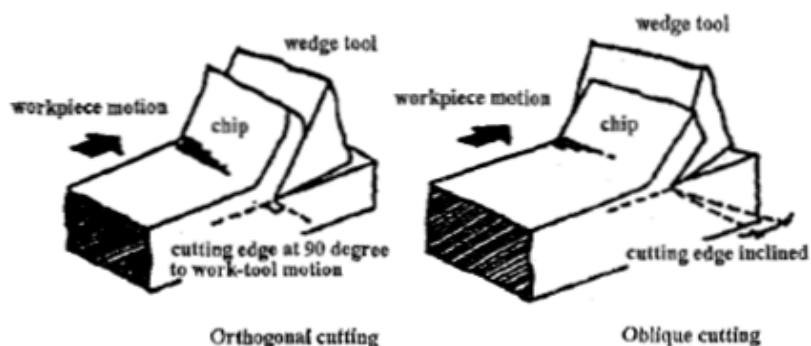


Figure 2.1: Orthogonal and oblique cutting process [8].

Source: Karri and Talhami (1995)

The machining process use coolant. Coolant emulsion rapidly affects the temperature of the chips and can sometimes favorably influence chip breaking, particularly when large cross section chips are formed [9, 10, 11]. In general, most turning and other machining applications use water based coolant emulsions. These contain a microscopic dispersion of the concentrate in water. The microscopic oil globules are homogeneously dispersed throughout the coolant. The basic ingredients of these emulsions are water, oil, and wetting agents [12].

There are many types of cutting fluid available today in the marketplace. The cutting fluid used in the underlying research was water based emulsion. It is mixed with water at a concentration of 10%. Its properties are listed in Tables 2.1 and 2.2 [13].

Table 2.1: The properties of cutting fluid [13].

The properties of cutting fluid	
Appearance-concentrate	Amber liquid
Appearance-dilution	Opaque amber-white
Odor	Bland
Residual film	Soft, fluid
pH at 20:1 (5%)	9.1 ± 0.5
Specific gravity at 60 (F)	0.93 ± 0.03
Lbs/gallon	7.7±0.1
Flash point, PMCC (F)	222

Table 2.2: Concentration and refractometer for coolant % [13].

Concentration	Refractometer reading
4% (1:25)	4.6
5% (1:20)	5.7
6% (1:17)	6.8
7% (1:14)	8.0
8% (1:12)	9.1
9% (1:11)	10.3
10% (1:10)	11.4

Source: Jaw Lin, Agrawal, and Fang (2008)

Machining with minimum quantity of lubrication (MQL) can cut down cost and improve both tool life and surface finish [14]. MQL is the name given to the process in which very small amount of oil (less than 30 ml/h) is pulverized into the flow of compressed air [15]. MQL helps in reducing cutting temperature and also averts thermal shocks, experienced by flood coolant. The air/oil aerosol mixture is then fed to the cutting area through the ducts (normally two in number) [16].

2.2 CNC MILLING

This project is going to apply the oblique cutting based on the experiment that required a CNC milling process. Figure 2.2 shows the HAAS CNC machine in FKM laboratory.



Figure 2.2: HAAS CNC machine.

In a CNC (Computerized Numerical Control) machine, the tool is controlled by a computer and is programmed with a machine code system that enables it to be operated with minimal supervision and with a great deal of repeatability. The same principles used in operating a manual machine are used in programming a CNC machine. The main difference is that instead of cranking handles to position a slide to a certain point, the dimension is stored in the memory of the machine control once. The control will then move the machine to these positions each time the program is run. In order to operate and program a CNC controlled machine, a basic understanding of machining practices and a working knowledge of math is necessary. It is also important to become familiar with the control console and the placement of the keys, switches, displays, etc., that are pertinent to the operation of the machine [19]. In three-axis computer numerically controlled (CNC) machining of sculptured surface parts, the tool path pattern is crucial to surface quality and

machining time [20]. Because tool path patterns determine how the cutting tool machines the surfaces, well-planned paths can both increase machining efficiency and ensure surface quality [20].

The machine illustration shows three directions of travel available on a vertical machine center. To carry the number line idea a little further, imagine such a line placed along each axis of the machine. It shows the three directions to position the coordinates around a point origin, which is where these number lines intersect on a vertical machining center with the X, Y, and Z axis lines [19]. Figure 2.4 shows the axis line in HAAS CNC machine.

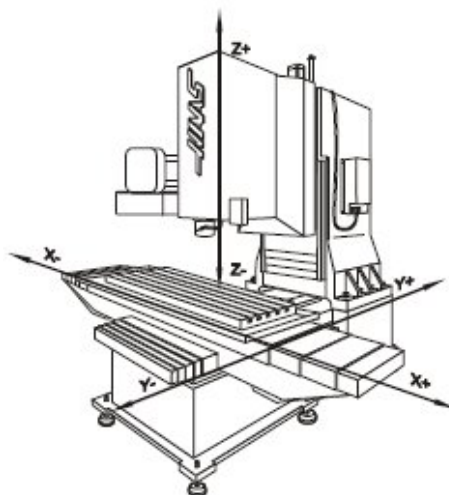


Figure 2.4: Axis lines in HAAS CNC machine [19].

Source: HAAS Automation Inc. Programming Workbook (2002)

2.3 CUTTING TOOL

The insert tool used in this experiment is TiN coated type. It was stated that in terms of the tool life coated inserts performed better than uncoated inserts [13]. Coating increases the lubricity and reduces the affinity to the work piece material. This allows the coated inserts to perform much better than the uncoated inserts, especially at higher cutting speeds

[13]. The coating provides a better thermal barrier so the temperature is reduced [21]. The speed attained after coating was double compared to that of the uncoated insert. The improvements achieved as a result of coating were extending tool life, attaining higher cutting speeds, and reducing production costs [13]. Application of coated cutting tools in the modern machining practices today is very common and extensive. A suitable coating on a cutting tool improves the machinability of a material and enhances the tool life as well [22].

Such beneficial effects of coating are achieved through remarkable improvement of wear resistance and anti-friction properties. In addition, the coating material is intended to offer chemical inertness to the work material at cutting temperature, especially for the sticky work materials. Otherwise, formation of built up edge on the rake surface is unavoidable, which leads to fluctuation of cutting force, deterioration in surface finish, drastic reduction in tool life etc. [22]. Indexable coated carbide inserts are widely used in modern manufacturing industry. These inserts have one or more thin layers of wear resistance CVD or PVD coating such as TiC, TiN, Al₂O₃, ZrN, CrC or diamond, which can improve machinability significantly [23].

Today, “coated carbide grades for roughing and cermets for finishing” is a well established trend [24]. For the coated carbide insert in the milling cutter, although the multiple coating layers can improve wear resistance significantly, it is still hard to bear the high load impacts and high temperature. Actually the coated layer cannot stand for long before it is worn. This will result in severe tool wear and short tool life. In the up milling operations, the cutter encounters minimum chip thickness as it enters the workpiece. This approximating rubbing at the beginning of the cut will cause an excessively work hardened layer in the workpiece, therefore higher cutting forces, higher tool wear rate and shorter tool life than those in down milling were observed. It is recommended that down milling operations be used as far as possible [23].

2.3.1 TOOL LIFE

The life of a tool is important in metal cutting since considerable time is lost whenever a tool is replaced or reset [25]. Tool life plays a critical role in an estimation of the productivity level expected for specific cutting conditions in manufacturing. It becomes extremely important both economically and for good quality that a tool insert should be chosen in such a way that it wears out in a progressive manner rather than being unpredictable for its working life due to its uncertain machining capability [13]. An ability to predict the tool life during machining is necessary not only for the design of cutting tools but also for the determination of cutting conditions, appropriate tools, etc. for a particular operation [27].

This study will predict the tool life on three-dimensional oblique process. CNC machine will be used to do the milling work. For a practical machining situation, since no machining theory is available to predict the tool life, one is compelled to rely on empirical equations such as those proposed by F.W. Taylor early in this century. A number of researchers have attempted to tackle the problem more fundamentally by relating tool wear and hence tool life to the machining conditions in terms of machining theory [27]. For tool life, workpiece material was found as the most influential parameter followed by the rotational speed of tool. High values of tool's rotational speed proved unfavorable for tool life but favorable for surface finish. The effect of feed on tool life is much more pronounced than the effect of speed. An increase in the speed, the feed, and the axial depth of cut decreased the tool life [28]. In addition, the effects of workpiece inclination angle and radial depth of cut were analyzed upon effective cutting speed and cusp height and, subsequently, upon surface roughness.

Lot of research work has been and is being done in order to find the optimal combination of tooling, cutting, and environment parameters for enhancement of tool life, without compromising the high values of material [16]. Different observations have been reported regarding effects of workpiece's inclination angle upon performance measures. It has been reported that tool life in the case in which workpiece surface was inclined at 30° was about three times more than that obtained when workpiece surface was kept normal to axis of cutter [29]. Moreover, the tool failure in the first case was caused by chipping on the

rake face while it was caused in the second case because of generation of extremely rough surface. In other paper, the authors reported the contrary observation, i.e., longer tool life values could be achieved when operating with cutter axis oriented normal to the workpiece surface rather than oblique one [30]. By the end of this project, there will be two mathematical models developed, the 1st order and the 2nd order. The 1st order model or the linear model is for the relationship between the machining responses and machining independent variables. The 2nd order model or the quadratic model is for the interaction between the variables [25].

2.4 MODIFIED AISI P20 TOOL STEEL

In this project, the material that is going to be machined is modified AISI P20 tool steel. Generally, AISI P20 is a chromium-molybdenum alloyed steel which is considered as a high speed steel used to build moulds for plastic injection and zinc die-casting, extrusion dies, blow moulds, forming tools and other structural components. The modified form of AISI P20 is distinguished from normal P20 steel by the balanced sulphur content (0.015%) which gives the steel better machinability and more uniform hardness in all dimensions. Modified AISI P20 possesses a tensile strength of 1044MPa at room temperature and a hardness ranging from 280 to 320 HB. The workpiece used in this study was prehardened and tempered to a minimum hardness of 300HB and was provided by ASSAB (Sweden). Some of the product made from this type of material is plastic injection mold using end-milling process.

2.5 RESPONSE SURFACE METODOLOGY (RSM)

Design of experiment technique, response surface methodology (RSM); have been used to accomplish the objective of the experimental study. RSM is a combination of mathematical and statistical techniques used in an empirical study of relationships and optimization, where several independent variables influence a dependent variable or response. In RSM, the relationship between the responses and the variables investigated is commonly approximated by polynomial functions, whilst the model parameters are

obtained by a small number of experiments utilizing a design of experiment. In this study, primary machining variables such as cutting speed, feed rate and axial depth of cut, which are easily controllable, are considered in building the models [28].

In order to reduce the total number of cutting tests and allows simultaneous variation of the three independent factors, a well-designed experimental procedure has to be followed. In machining research, the Box-Behnken design has found a broad application compared to other experiment designs used for RSM. The Box-Behnken design is based on the combination of the factorial with incomplete block designs. It does not require a large number of tests as it considers only three levels (-1, 0, 1) of each independent parameter (Box and Behnken, 1960) [49]. The Box-Behnken design is normally used for non-sequential experimentation, when a test is conducted only once. It allows an efficient evaluation of the parameters in the first and second order models. Using statistical software the cutting conditions of 15 experiments are generated and the experiments are conducted randomly to minimise errors. Minitab has employed as the statistical software. In order to calculate the experimental error, the 15 experiments consider five times repeating of central point of the cutting conditions [25].