A STUDY ON TOOL DEFLECTION DURING DEEP POCKETING CYCLE

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We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree Bachelor of Manufacturing Engineering.

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STUDENT'S DECLARATION

I, Zikrulhakim bin Muhd Zahid declared that this dissertation entitled *"An Experimental Study On Tool Deflection During Deep Pocketing Cycle"* is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not currently submitted in candidature of any other degree.

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To my beloved family
Muhd Zahid bin Ismail
Natarah bt Junoh
Brothers and sisters

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ABSTRACT

Tool deflection during deep pocketing cycle will cause tapper in mould and die. This problem can cause defect on final product and also increases cost and time wasting in manufacturing process. This study basically shows a detailed study to overcome tapper problem in deep pocket. Dimensional accuracy due to tapper problem was analyzed in order to obtain optimum cutting parameters. The pocket part was drawn by using CATIA software. The data collected during experiment was analyzed using signal to noise ratio through Minitab software. From the analysis, it was found that depth of cut has gives the most effect on tapper problem, followed by feed rate and spindle speed. From the result, it is shown that level 1 of depth of cut which is 0.3mm, level 1 of feed rate which is 64mm and level 2 of spindle speed which is 1280rpm was the best cutting parameter. Hence, from these cutting parameters, the tapper problem cause by tool deflection during deep pocketing cycle can be overcome.

ABSTRAK

Pembiasan alat semasa pusingan pempoketan dalam akan menyebabkan ketidakrataan di dalam acuan. Masalah ini akan menyebabkan kecacatan pada produk akhir yang akan meningkatkan kos dan pembaziran masa ketika proses penghasilan. Kajian ini pada asasnya menunjukkan kajian terperinci untuk menangani masalah ketidakrataan di dalam poket. Ketepatan ukuran pada masalah ketidakrataan akan dianalisis untuk mendapatkan rujukan pemotongan paling optimum. Bahagian poket dilukis dengan menggunakan perisian CATIA. Data yang diambil semasa eksperimen telah dianalisis menggunakan nisbah *signal* kepada *noise* melalui perisian Minitab. Daripada analisis, ia telah mendapati bahawa kedalaman potongan telah member kesan yang paling tinggi terhadap masalah ketidakrataan, diikuti oleh kadar memotong dan kelajuan mata. Daripada keputusan analisis, ia telah menunjukkan bahawa kedalaman potongan pada tahap 1 iaitu 0.3mm, kadar memotong pada tahap1 iaitu 64mm/min dan kelajuan mata pada tahap 2 iaitu 1280rpm adalah rujukan pemotongan terbaik. Maka, daripada rujukan pemotongan ini, masalah ketidakrataan yang disebabkan oleh pembiasan alat semasa pusingan pempoketan boleh diselesaikan.

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CHAPTER 1

INTRODUCTION

1.0 Project Title

A study of tool deflection during deep pocketing cycle.

1.1 Project Objectives

- To overcome tool deflection during deep pocketing cycle
- Come out with best cutting parameter

1.2 Project Scopes

In order to achieve the project objective, this project needs a proper plan. The project scopes as shown below.

i. Study on cutting tools in milling process for pocketing.
ii. Initial study about cutting parameters in milling.
iii. Study on tool path during pocketing process.

1.3 Project Background

Pocketing process is widely used in producing mould and die. The advance of modern technology and a new generation of manufacturing equipment, particularly computer numerical control (CNC) machine, have brought enormous changes to the manufacturing sector. Generally, the handbook or human experience is used to select convenient machine parameters in manufacturing industry. In process planning of pocketing process, selecting reasonable milling parameters is necessary to satisfy requirements involving machining economics, quality and safety.

In every machining process, defects on final product always occur either surface roughness or dimensional accuracy. Meanwhile in pocketing process, tool deflection will occur during the process and will affect dimensional accuracy of final product. Hence, this study is to overcome the tool deflection problem and come out with the best machining parameters at the end of this project.

The machining parameters in milling operations consists of cutting speed, depth of cut, feed rate and number of passes. These machining parameters significantly impact on the cost, productivity and quality of machining parts. The effective optimizations of these parameters affect dramatically the cost and production time of machined components as well as the quality of final products.

1.4 Problem Statement

One of the milling processes is pocketing. It is usually to machined mould and die. But it is always comes with tool deflection problem (Figure 1.1 and Figure 1.2). This problem logically can affect entire product that being produce. The defect on products can be costly for manufacturers and its need the best solution to overcome the tool deflection problem. Establishment of efficient machining parameters has been a problem that has confronted manufacturing industries for nearly a century, and is still the subject of many studies. Optimum machining parameters are of great concern in manufacturing environments, where economy of machining operation plays a key role in competitiveness in the market.

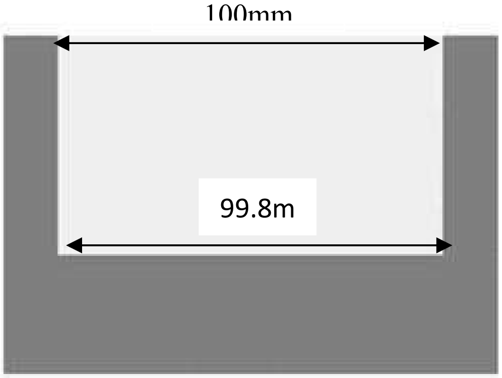


Figure 1.1: Dimensional different between upper part and lower part

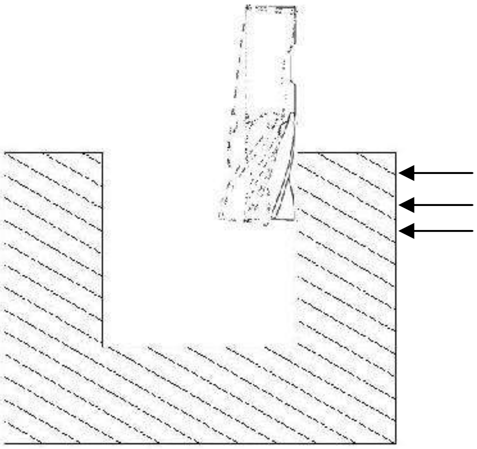


Figure 1.2: Tool deflection during deep pocketing cycle

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Milling is a process to remove material on work piece. There are several type of milling process such as pocketing, drilling, and face milling. Pocketing clears an area bounded by specified entities such as lines, arc, and free form curves, which constitute outer periphery with or without island. There are rectangular shape, circular shape and inclined shape of pocketing. During deep pocketing, tool deflection occurs and causes the different in measurement between inner and outer part.

2.1 Milling Machine

Milling is the process of machining flat, curved, or irregular surfaces by feeding the work piece against a rotating cutter containing a number of cutting edges. The usual mill consists basically of a motor driven spindle, which mounts and revolves the milling cutter, and a reciprocating adjustable worktable, which mounts and feeds the work piece.

Milling machines are basically classified as vertical or horizontal. These machines are also classified as knee-type, ram-type, manufacturing or bed type, and planer type. Most milling machines have self-contained electric drive motors, coolant systems, variable spindle speeds, and power-operated table feeds. [1]

A milling machine is a machine tool that cuts metal with a multiple-tooth cutting tool called a milling cutter. The work piece is fastened to the milling machine table and is fed against the revolving milling cutter. The milling cutters can have cutting teeth on the periphery or sides or both.

Milling machines can be classified under three main headings:

(i) General Purpose machines - these are mainly the column and knee type (horizontal & vertical machines).

(ii) High Production types with fixed beds- (horizontal types).

(iii) Special Purpose machines such as duplicating, profiling, rise and fall, rotary table, planetary and double end types.

Milling attachments can also be fitted to other machine tools including lathes planning machines and drill bench presses can be used with milling cutters. Milling machine is one of the most versatile conventional machine tools with a wide range of metal cutting capability. Many complicated operations such as indexing, gang milling, and straddle milling can be carried out on a milling machine. [2]

2.2 Milling Parameter

Optimum machining parameters are of great concern in manufacturing environments, where economy of machining operation plays a key role in competitiveness in the market. Due to high capital and machining costs of the NC machines, there is an economic need to operate NC machine as efficiently as possible in order to obtain the required pay back**.** The success of the machining operation will depend on the selection of machining parameters. A human process planner selects the proper machining parameters using his own experience or from the handbooks on the part geometry, technological requirement, machine tool, a cutting tool and the part material. These parameters do not give optimal result. The effective optimizations of these parameters dramatically minimize the cost and production time of machined components as well as the increase the quality of the final product. [3,4]

2.2.1 Feed Rate

Feed rate is the velocity at which the cutter is fed, that is, advanced against the work piece. It can be expressed thus for milling also, but it is often expressed in units of distance per time for milling (millimeters per minute), with considerations of how many teeth (or flutes) the cutter has then determining what that means for each tooth.

Feed rate is dependent on the:

- Type of tool
- Surface finish desired
- Power available at the spindle
- Rigidity of the machine and tooling setup
- Strength of the work piece
- Characteristic of the material being cut, chip flow depends on material type and feed rate. The ideal chip shape is small and breaks free early, carrying heat away from the tool.

This formula can be used to figure out the feed rate that the cutter travels into or around the work. This would apply to cutter on a milling machine (Table 2.1). [2]

$$FR = RPM \times T \times CL \tag{1}$$

Where:

- FR = the calculated feed rate in inches per minute or mm per minute.
- RPM = is the calculated speed for the cutter
- T = number of teeth on the cutter
- CL = the chip load or feed per tooth. This is the size of chip that each tooth of the cutter takes.

Table 2.1: Recommended feed rate

Type of milling	**Feed rate (mm/min)**
Face milling	50 – 400
Corner milling	50 – 500
Pocket milling	50 – 500
Slot milling 1	50 – 500
Slot milling 2	50 – 500

(Source: Courtesy of N.Baskar, P. Asokan, R. Saravanan , G. Prabhaharan (2006). Selection of optimal machining parameters for multi-tool milling operations using a memetic algorithm.)

2.2.2 Cutting Speed

Cutting speed may be defined as the rate (or speed) that the material moves past the cutting edge of the tool, irrespective of the machining operation used – the surface speed. A cutting speed for mild steel is 100ft/min (30meters/min). The hardness of the cutting tool material has a great deal to with the recommended cutting speed. The harder the cutting tool, the faster the cutting speed. The softer the cutting tool material, the slower the recommended cutting speed. For a given material there will be an optimum cutting speed for a certain set of machining conditions, and from this speed the spindle speed (RPM) can be calculated.

Factors affecting the calculation of cutting speed are:

- The material being machined
- The material the cutter is made from.
- The economical life of the cutter.

Cutting speeds are calculated on the assumption that optimum cutting condition exist (Table 2.2), these include:

- Metal removal rate
- Full and constant flow of cutting fluid
- Rigidity of the machine and tooling setup
- Continuity of cut
- Condition of material

Table 1.2: Recommended cutting speed

Type of milling	**Cutting speed (m/min)**
Face milling	60 – 120
Corner milling	40 – 70
Pocket milling	40 – 70
Slot milling 1	30 – 50
Slot milling 2	30 – 50

(Source: Courtesy of N.Baskar, P. Asokan, R. Saravanan , G. Prabhaharan (2006). Selection of optimal machining parameters for multi-tool milling operations using a memetic algorithm.)

2.3 Tool Path

Milling is one of the most widely used metal removal processes. Pocket milling clears an area bounded by a set of specified entities such as lines, arcs, and free-form curves, which constitute outer periphery with or without islands. The machining sequence may be either in the order of entities selected or in reverse order. Types of pockets include rectangular, circular, and inclined.

Based on the contour shapes and machining methods, pocketing tool paths are classified into spiraling and zigzag types. Although there are many possible ways of planning a tool path in pocket-milling operation, traditionally contour augmentation (spiral) and zigzag (or staircase) milling, have been the two standard procedures practiced. Zigzag or staircase milling involves the movement of the tool in a number of parallel passes to cover an entire area of the polygon to be machined.[3]

2.3.1 Spiral Tool Path

To generate spiral tool path, the boundary profile are streaked inwards while the island profiles outwards using the appropriate steps. In spiral-out option, the tool paths track from the centre of pocket to the outer boundary of the pocket, whereas in spiral-in option, the tool-path track from the outer boundary of the pocket towards the centre inwardly, as in Figure 2.1. Contour augmentation (spiral) milling method requires a relatively larger tool overlap between successive passes to avoid the undercut projections on the surface of the polygon. This results in an increased length of the tool path, and consequently, machining time. [5]

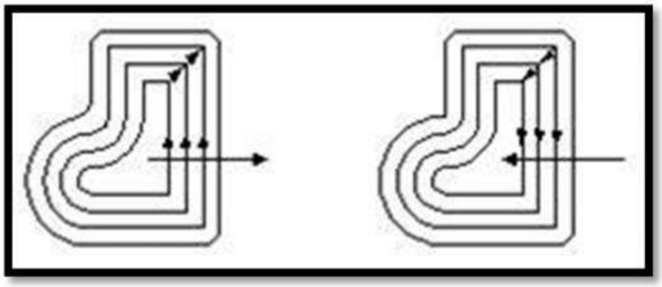


Figure 2.1: Spiral in and spiral out

2.3.2 Zigzag Tool Path

In the zigzag method of pocketing, the tool paths generated are parallel to a predefined vector direction and the tool moves back and forth. This method is used when a machine tool has a preferred direction of cut, like along the major axis of machine or the grain direction of the material calls for a particular direction of machining. One way machining, the tool always cuts the material in one way, along or against the spindle direction in the entire process as in Figure 2.2. The offset chains of pocket entities are intersected with a sequence of equidistant parallel lines, curves and arcs, which are oriented along the selected direction of cut. In successive zigzag method, machining takes place bidirectional parallel to a selected axis. In bidirectional milling, the cutting edge changes alternatively left and right sided, up milling and climb milling. Zigzag (staircase) milling requires more number of stops and turns, requiring more machining time. [5, 6]

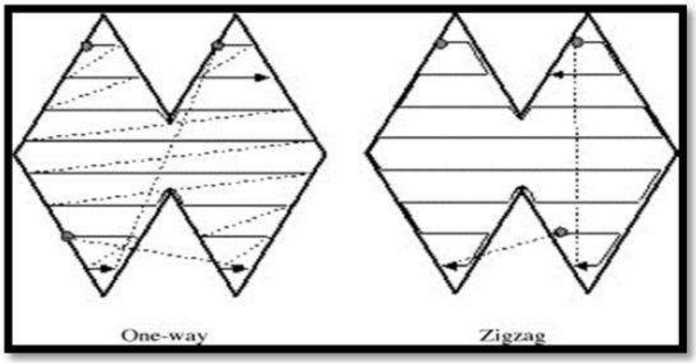


Figure 2.2: One-way and Zigzag

2.3.3 Zigzag Tool Path Requirement

Generally accepted user requirements of a zigzag machining include efficient machining using minimum machining time, fine surface quality without tool marks, and no gouge against boundary curves. Considering the above functional requirements, tool-path generation algorithm developed in this study includes the following [5]:

(i) *Minimization of tool retractions.*

- Tool retractions cause non-cutting tool motions in the air and tool marks on the machined surface. These types of motions have to be minimized.

(ii) Minimization of tool-path elements

- At the end of tool path elements, the feed rate should be slowed to avoid machining error caused by rapid change of feed direction. Minimizing the number of tool-path elements improves both productivity and quality of machined parts.

(iii) Maximization of average tool-path length

- Tool-path elements having longer length allow constant feed rate and direction, which in turn improves surface quality.

(iv) Technological requirements

- The tool-path planning system should be able to adapt to the various technological requirements or constraints such as one way milling or zigzag milling and up or down milling.

(v) Motion along boundary curve

- Linear tool motion between tool-path elements may cause gouging at the sharp vertices of boundary curves and which has to be checked.

2.4 Machining Strategy

Most computer aided manufacturing (CAM) systems have predefined pocketing routines which require selection of axial and radial depth of cut, and the starting point and directions of the tool path for each layer of cut. Tool paths may start from the center of the pocket towards walls with zigzag and lace paths which are all based on the geometric relationship between the cutter and pocket features.

The material removal rate is defined by the product of depth and width of cut, spindle speed and feed, which are presently selected based on trials and past experience. Some researchers manipulated the feed rate to increase the material removal rate while respecting cutting force and power limits along the tool path. However, incorrect spindle speed, axial and radial depths of cut cause chatter vibrations and leaves poor surface finish. [7]

2.4.1 Pocketing strategy

The pocketing requires identification of cutting conditions (radial and axial depth of cut, spindle speed and feed) and tool path strategy to be used by the CAM system. The objective is to determine the most time optimal strategy with highest material removal rate (MRR) without violating the chatter, torque and power limit of the machine tool. Although the pocket geometries vary significantly depending on the part and die/mold features, two basic pocket shapes are considered here to develop a general pocketing strategy [7].

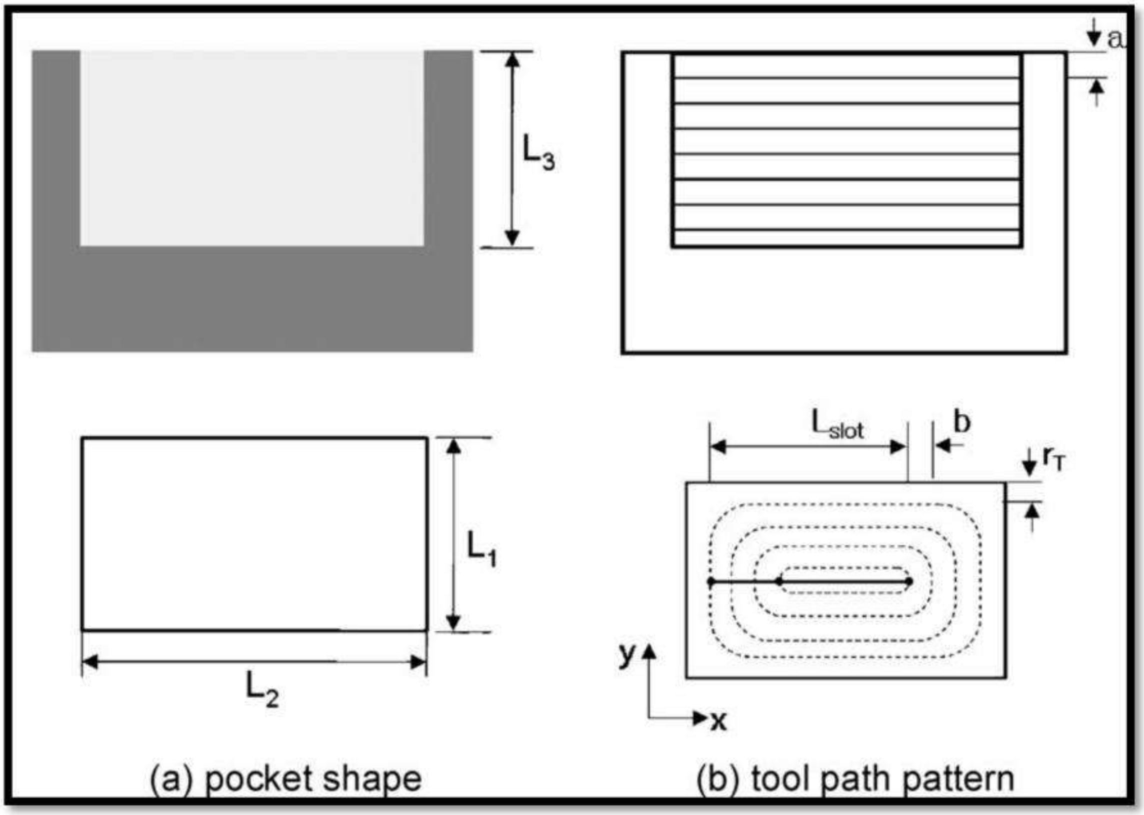


Figure 2.3: Pocket shape and tool path pattern

Rectangular, simple pockets like in figure 2.3 are commonly used in aerospace frames. The path can start from outside towards inside or vice versa, and the pocket is machined layer by layer. Uniform wall pockets; have curved walls with circular cross-sections (Figure 2.4).

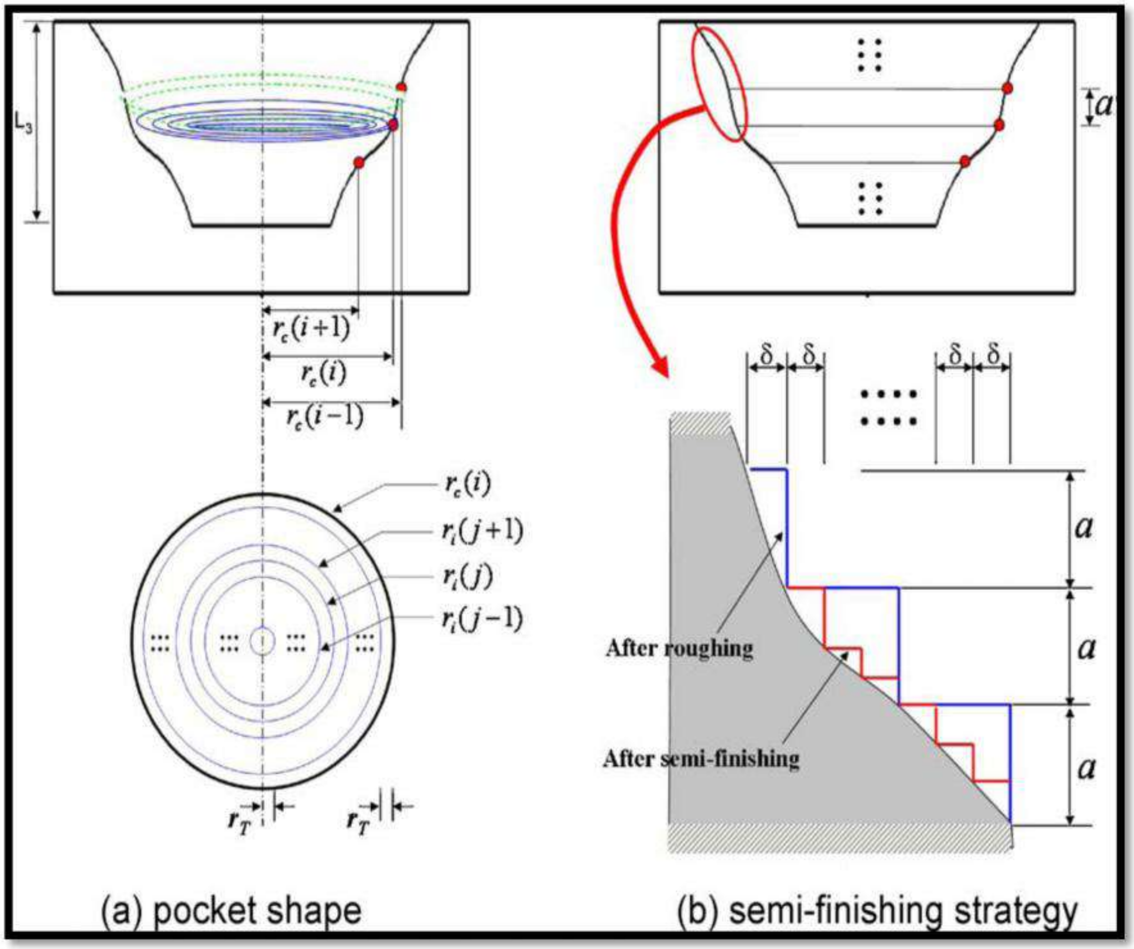


Figure 2.4: Pocket shape and semi-finishing strategy

2.4.2 Process planning

The act of prepare detailed operations instructions for turning and engineering design into an end product is called process planning. This action means to change the design specifications of a part into required manufacturing operation and it allows obtaining the final part state from raw material. There is a great deal of manufacturing data involved in process planning such as the identification of machines, tools, features, parameters and operation. All this data has to be evaluated in order to select the sequence of operation that will make up route sheet. The sequence is generally obtained to conform with particular objectives, such as the shortest time and minimum cost.[7]

2.5 Cutting Tools

The selection of cutting tool materials for a particular application is among the most important factors in machining operations, as is the selection of mold and die material for forming and shaping process. The cutting tool is subjected to high temperatures, high contact stress, and rubbing along the tool chip interface and along the machined surface. Consequently, the cutting tool material must possess the following characteristic like hot hardness, toughness and impact strength, thermal shock resistance, wear resistance, and chemical stability and inertness.

2.5.1 Uncoated carbides

To meet challenge for increase higher cutting speeds, carbides (also known as cemented or sintered carbides) were introduced in the 1930s. Because of their high hardness over a wide range of temperature, high elastic modulus, high thermal conductivity, and low thermal expansion, carbide are among the most important, versatile, and cost effective tool and die materials for a wide range of application. The two types of major carbide used for machining are tungsten carbide and titanium carbide. This two also referred to as uncoated carbide.

Tungsten carbide (WC) typically consists of tungsten carbide particles bonded together in a cobalt matrix. The tools are manufactured using powder metallurgy technique (hence the term sintered carbide and cemented carbide). The tungsten carbide particles are first combined with cobalt in a mixer, resulting in a composite material with a cobalt matrix surrounding the carbide particles. These particles, which are 1 to 5 μm in size, are then pressed and sintered into the desires, insert shapes. Tungsten carbides frequently are compounded with titanium carbide and niobium carbide to impart special properties to the material.

The amount of cobalt present, ranging typically from 6 to 16%, significantly affects the properties of tungsten carbide tools. As the cobalt increases, the strength, hardness, and wear resistance of WC decrease whiles its toughness increase because of the higher toughness of cobalt. Tungsten carbide tools generally are used for cutting steel, casts iron, and abrasives nonferrous material and largely have replace HSS tools because of their better performance.

2.5.2 Coated carbides

These materials have high strength and toughness but generally abrasive and chemically reactive with tool materials. The difficulty of machining these material efficiently and the need for improving the performance in machining the more common engineering material have led to important development in coated tools. Coating have unique properties, such as lower friction, higher adhesion, higher resistance to wear and cracking, acting as diffusion barrier and higher hot hardness and impact resistance.

Coated tools can have tool lives 10 times longer than those of uncoated tools, allowing for high cutting speeds and thus reducing both the time required for machining operation and production costs. This improvement had a major impact on the economics of machining operation in conjunction with continued improvement in the design and construction of modern machine tools and their computer controls. As a result, coated tools now are used in 40 to 80% of all machining operation, particularly in turning, milling and drilling.

Commonly used coating materials are titanium nitride (TiN), titanium aluminium nitride (TiAIN), Titanium carbonitride (TiCN) and aluminum oxide. These coating, generally in the thickness range of 2 to 15µm, applied on cutting tools and inserts by two techniques, chemical vapor deposition(CVD) and physical vapor deposition(PVD). Titanium carbide coatings on tungsten carbide insert have high flank wear resistance in machining abrasive material.

2.6 Mild Steel

Mild steel, also called plain-carbon steel, is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.29% carbon; making it malleable and ductile, but it cannot be hardened by heat treatment. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing.

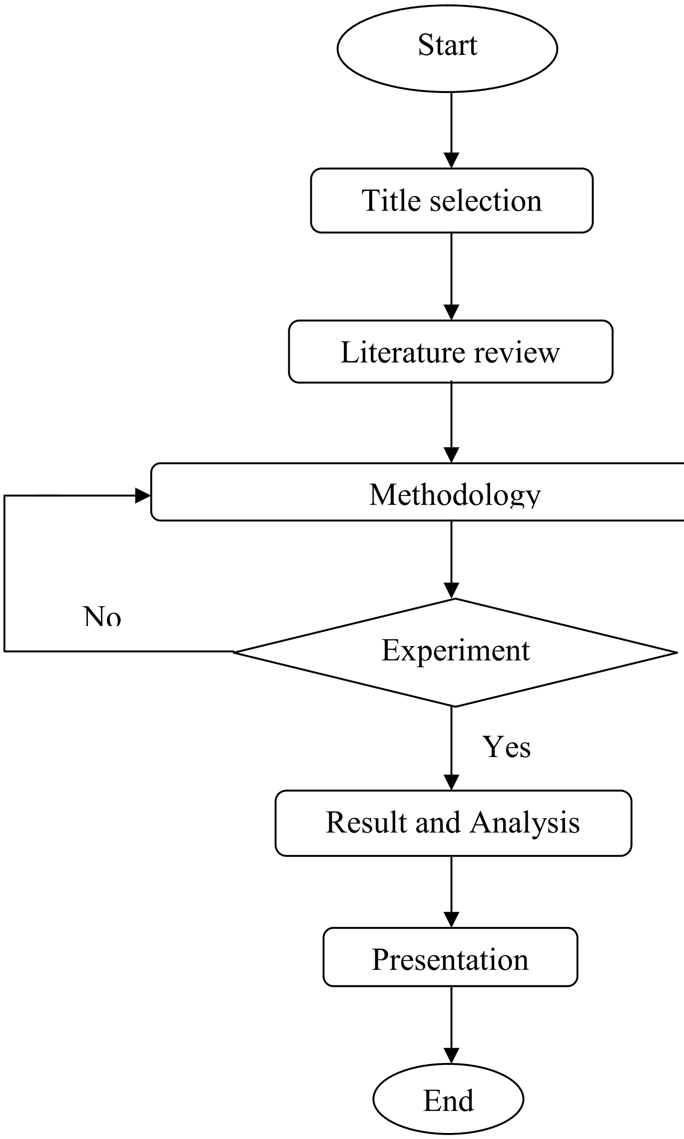
It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm^3 (7850 kg/m^3 or 0.284 lb/in^3) and the Young's modulus is 210 GPa (30,000,000 psi).

Low carbon steels suffer from yield-point run out where the material has two yield points. The first yield point (or upper yield point) is higher than the second and the yield drops dramatically after the upper yield point. If low carbon steel is only stressed to some point between the upper and lower yield point then the surface may develop Luder bands. Low carbon steels contain less carbon than other steels and are easier to cold-form, making them easier to handle.

CHAPTER 3

METHODOLOGY

3.1 Flow Chart



3.2 Selection of Cutting Parameters

Surface quality and dimensional accuracy are the two important aspects of a product in any machining operation. Several factors influence the final dimensional accuracy in a CNC milling operation. Generally it depends on many parameters such as tool material, work material, machine-tool rigidity and various cutting conditions including feed rate, depth of cut and cutting speed.

However, factors such as tool wear, chip loads and chip formations, or material properties of both tool and work piece are uncontrollable during actual machining. The presence of chatter or vibration of the machine tool, defects in the surface of work material, wear in the tool or irregularities of chip formation contribute to the surface damage in practice during actual machining operations.

In any experimental study, it is difficult to consider all these factors that affect the dimensional accuracy in pocketing process. Available literature reveals that depth of cut, spindle speed and feed rate are the three primary machining parameters and thus these are considered as design factors in the present study.

3.2.1 Calculation

The recommended cutting speed shown in previous chapter is to calculate the spindle speed (RPM) for the cutter. Using 2 flutes 10mm diameter end mill and recommended cutting speed (40m/min), hence, the spindle speed for the cutter was obtain from this formula (Equation 2):

$$Spindle\ speed(\text{rpm}) = \frac{Cutting\ Speed \times 320}{Tool\ Diameter} \qquad (2)$$

The spindle speed obtains from formula is the recommended value. The value then increase by 50% to obtain higher value for spindle speed. The lower value of spindle speed obtains by decreasing 50% from recommended value.

For the feed rates, it is given feed per tooth of 0.05mm/tooth as it recommended value.

$$Feed\ rates(\text{mm/min}) = Spindle\ speed \times number\ of\ teeth \times feed\ per\ tooth \qquad (3)$$

The feed rates obtain from the Equation 3 then increased by 50% and decreased by 50% to obtain the higher and lower value of feed rates respectively.

3.3 Work Piece Material Used

This study was carried out with mild steel. The chemical composition and mechanical properties of the work piece materials was describe in previous chapter. All the specimens were in the form of 100mm × 100mm × 75mm blocks as shown in Figure 3.1.

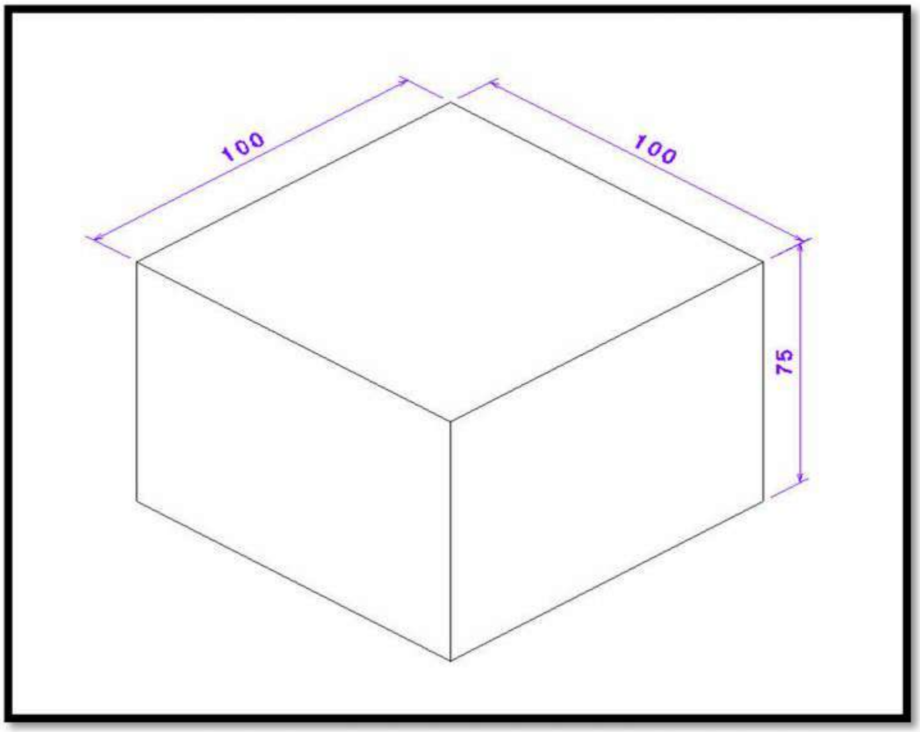


Figure 3.1: Dimension for raw material

3.4 Cutting Tool Used

Coated carbide tools have been found to perform better than uncoated carbide tools. In this study, 10mm diameter of 2 flutes TiAiN (titanium aluminium nitride) will be used. It is commonly used in milling process. This type of coated carbide end mill actually forms a hard aluminum oxide layer in hot (> 800ºC), dry machining applications (Table 3.1).

This further reflects the heat back into the chip and away from the tool and work piece. Greater ductility makes it a good choice for interrupted cuts. Increased production levels at higher feeds and speeds and longer tool life in high heat applications are the primary benefits. It can be apply in milling of high strength steel, hard die steel and high temperature alloy.

Table 3.1: TiAIN end mill properties

Hardness	2800 (85 Rc)
Oxidation temperature	800°C
Friction coefficient	0.70
Thickness	2-4 microns
Surface roughness($Ra\mu m$)	0.40

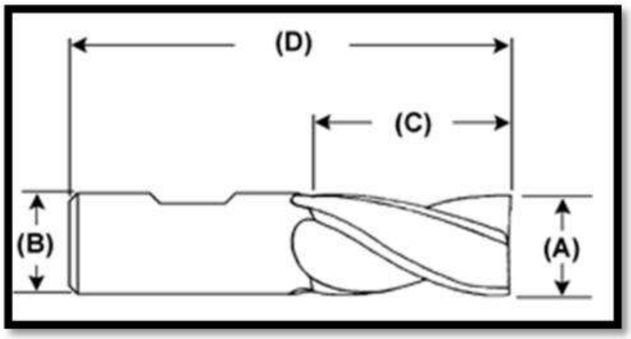


Figure 3.2: Design of an end mill where (A) is cutting diameter, (B) is shank diameter, (C) is flute length and (D) is overall length.

Based on dimension of depth of the pocket, the end mill (Figure 3.2) will be used must have flute length higher than 50mm. This is to avoid spindle of milling machine from colliding with work piece. It is also to ensure 50mm of pocket depth can be cut off.

3.5 Design of Experiment (DOE)

The design of experiments technique permits us to carry out the modeling and analysis of the influence of process variables (design factors) on the response variables. In the present study depth of cut (*d*, mm), spindle speed (*N*, rpm) and feed rate (*f,* mm/min) have been selected as design factors.

The process variables (design factors) with their values on different levels are listed in Table 3.2. The selection of the values of the variables is limited by the capacity of the machine used in the experimentation as well as the recommended specifications for different work piece and tool material combinations.

Table 3.2 show the value of each variable that need to be carried out in experiment. Three experimental process will be done as each experimental will take a cutting speed as it control variable. Other variables such depth of cut and feed rate are going to be as moving variables. Cutting speed as recommended (40m/min) is calculated to obtain spindle speed as it is to adapt on milling machine.

Depth of cut is taken from recommended value for pocket milling (0.5mm). In this study, three different value of depth of cut will be recorded. The recommended value, the lower value, and the higher value of depth of cut will be done during experiment.

Another variable is feed rate. The value of the feed rate also will be conducted on three different values. The recommended (0.05mm/tooth) is calculated to obtain the actual feed rate, the lower value of feed rate (-50%) and higher value of feed rate (+50%) will be conducted on three different cutting speed (recommended and 50% higher and lower).

Table 3.2: Experiment Variables

NO.	VARIABLES		
	SPINDLE SPEED (RPM)	DEPTH OF CUT (MM)	FEED RATE (MM/MIN)
1	640	0.3	64
2			128
3			192
4		0.5	64
5			128
6			192
7		0.8	64
8			128
9			192
10	1280	0.3	64
11			128
12			192
13		0.5	64
14			128
15			192
16		0.8	64
17			128
18			192
19	1920	0.3	64
20			128
21			192
22		0.5	64
23			128
24			192
25		0.8	64
26			128
27			192

From all variables, this study also will consider tool path as it variable. Contour and zigzag tool path. This type of tool path will be generated from FANUC software. Both tool paths will give different result as contour milling requires a relatively larger tool overlap between successive passes to avoid the undercut projections resulting in increasing of tool path length. Meanwhile zigzag requires more number of stops and turns, requiring more machining time.

Based on the variables and experimental set up, this study will be experimenting on total of 54 similar work pieces. 27 work pieces for contour tool path and another 27 work pieces for zigzag tool path.

3.5.1 Experimental procedure

The experiment starts with process planning on pocketing process. It is including part drawing using CATIA software. It is to simulate the machining process on milling machine. Then, by using FANUC through CATIA software, coding was generating for Makino KE55 milling machine for pocketing process.

Cutting test was carried out on Makino KE55 milling machine under dry condition. A pre-cut with a 1 mm depth of cut was performed on each work piece prior to actual milling. This was done in order to remove the rust layer or hardened top layer from the outside surface and to minimize any effect of in homogeneity on the experimental results. After that, deep pocketing process with measurement of 50mm x 50mm x 50mm was done. It is done according to the variables that have been set.

The upper measurement and lower measurement of the pocket was recorded using Mitutoyo internal micrometer. This is to analyze the change in measurement of upper part and lower part. The process was repeated for each variable according to table 2.

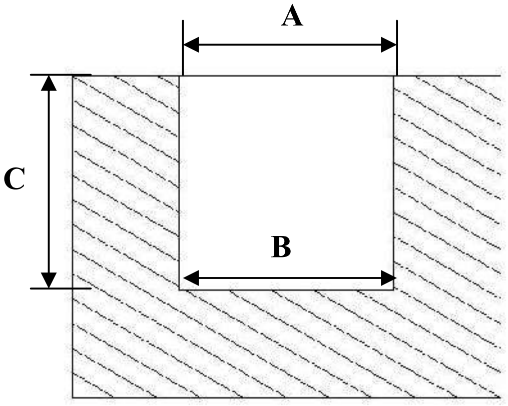


Figure 3.3: Cross section of the pocket

The data will be recorded as dimension of the part A in Figure 3.3 was be measured. This is for upper part for pocket wall. Then, the dimension of part B that is lower part of pocket wall was be measured. Part C is to ensure that dimension of depth of the pocket is exactly 50mm deep.

The recorded data then being analyze by using analysis of variance (ANOVA) method. This method is to compare means among the variables. It is can also be known as factorial experiments. This approach allows using sample data to see if the values of the variables population means are likely to be different.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, the data gained from all 27 runs of experiment was analyzed in order to obtain the optimum cutting parameter for deep pocketing process. All the data were analyze using analysis of variance (ANOVA), means, and signal to noise ratio. The result will be interpreted through table of analysis and chart.

4.2 Data Analysis

In this project, the data collected was analyzed by using signal to noise ratio (SN ratio) to determine the optimum cutting parameters. Surface plot graph based on spindle speed, depth of cut and feed rate was drawn to show the parameters effect on dimensional accuracy.

4.2.1 Measuring process

The experiments have gone through certain process before data can be collected and analyzed. The specimen in form of 100mm × 100mm × 75mm blocks has been machined using milling machine to achieved deep pocket part as shown in Figure 4.1. 10mm diameter end mill coated carbide was used in this experiment.

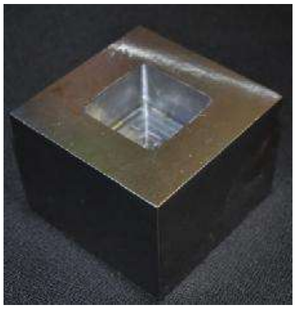


Figure 4.1: Deep pocket part

Figure 4.1 shows the final part that has been machined according to controlled parameters. All 27 specimens were machined and the parameters were controlled by programming generated by CATIA V5.

Table 4.1: Domain of the experiment

Factor	**Symbol**	**Unit**	**levels**		
			1	**2**	**3**
Spindle Speed	A	rpm	640	1280	1920
Depth of Cut	B	mm	0.3	0.5	0.8
Feed Rate	C	mm/min	64	128	192

Table 4.1 shows the domain of experiment for this project. Spindle speed, depth of cut and feed rate are the controlled parameters with three levels for each factor. All specimens that have been machined will undergo another process where all specimens were measured using die indicator to obtain the measurement of tapper at the inner part of the pocket.

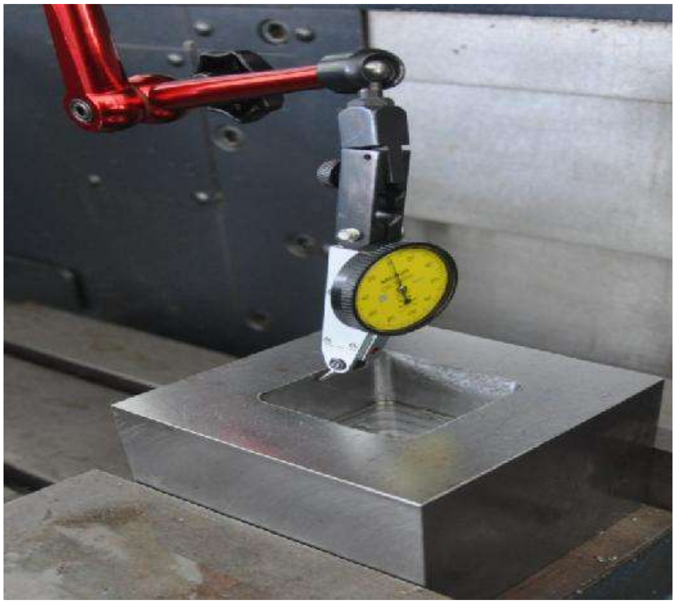


Figure 4.2: Upper part measurement

Figure 4.2 shows the measuring process for upper part of the pocket. This process was repeated two times to get the average reading.

Figure 4.3: Lower part measurement

Figure 4.3 shows the measuring process for the lower part of the pocket. The process was repeated two times to obtain the average reading. The die indicator can detects slightest change at the wall of the pocket to 2μm. Hence, slightest tapper of the deep pocket can be measured. For each specimen, the measuring process is taken by clamping the specimen to the Milling machine. The die indicator is lock at the spindle.

The change of the wall measurement is recorded from upper part to lower part by attaching the indicator to the upper part of the wall. Z-axis of the machine is moved down slowly until reached the lower part of the wall. The initial reading (upper part) and final reading (lower part) are recorded for both side of the wall. In order to get the wall to wall measurement, the differences of initial and final reading are calculated.

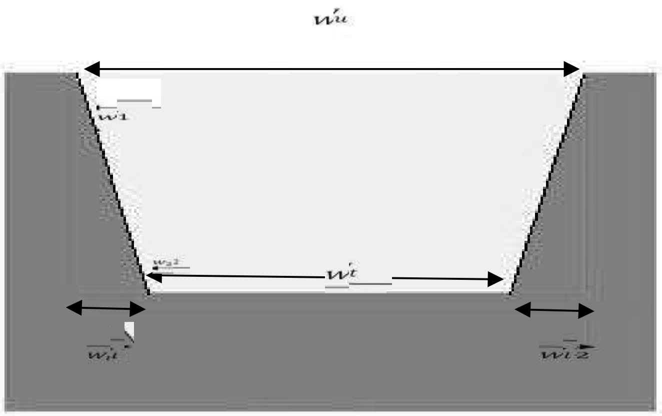


Figure 4.4: Wall measurement

Figure 4.4 shows the wall measurement for the pocket to obtain the tapper wall measurement. The differences between w_1 and w_2 can give the measurement of tapper wall, W_l. From tapper wall dimension, the total dimension for lower part of the pocket can be obtain by subtracting upper wall measurement, W_u, to tapper wall measurement, W_l. The equation for this measuring process can be expressed as equation (4).

$$w_1 - w_2 = W_l \tag{4}$$

Where w_1 and w_2 is upper wall reading and lower wall reading respectively. W_l is tapper wall measurement.

$$W_t = W_u - (W_l1 + W_l2) \tag{5}$$

Where W_t is total measurement and W_u and W_l is upper wall measurement and lower wall measurement respectively.

4.2.2 Collecting data

The data for this project was collected and recorded after all specimens were measured and calculated. The data was recorded in Table 4.2.

Table 4.2: Table of result

NO.	VARIABLES			WALL MEASUREMENT		
	SPINDLE SPEED (RPM)	DEPTH OF CUT (MM)	FEED RATE (MM/MIN)	1st (MM)	2nd (MM)	Ave (MM)
1	640	0.3	64	50.000	50.000	50.000
2			128	50.000	50.000	50.000
3			192	50.000	50.000	50.000
4		0.5	64	50.000	50.000	50.000
5			128	49.998	49.998	49.998
6			192	49.996	49.998	49.997
7		0.8	64	49.996	49.994	49.995
8			128	49.990	49.988	49.989
9			192	49.988	49.986	49.987
10	1280	0.3	64	50.000	50.000	50.000
11			128	50.000	50.000	50.000
12			192	50.000	49.998	49.999
13		0.5	64	50.000	50.000	50.000
14			128	50.000	50.000	50.000
15			192	49.998	49.998	49.998
16		0.8	64	50.000	50.000	50.000
17			128	49.996	49.998	49.997
18			192	49.994	49.996	49.995
19	1920	0.3	64	50.000	50.000	50.000
20			128	50.000	50.000	50.000
21			192	49.998	50.000	49.999
22		0.5	64	50.000	50.000	50.000
23			128	50.000	49.998	49.999
24			192	49.996	49.998	49.997
25		0.8	64	50.000	50.000	50.000
26			128	49.998	49.996	49.997
27			192	49.994	49.996	49.995

Table 4.2 shows the full table of experiment where the first measurement and second measurement was calculated. The average dimension was calculated from both first measurement and second measurement. This average dimension is needed for data analysis.

4.2.3 Data analysis

Based on data collected, the data was analyzed according to signal to noise ratio (SN ratio). This SN ratio is to determine the influence parameter on the dimensional accuracy. Referring to design of experiment, each parameter, spindle speed (A), depth of cut (B) and feed rate (C), consists of three levels. Each level will be calculated by using signal to noise equation with larger is better condition. The equation can be expressed as below.

$$S_T = -10 \log 10 \left(\sum_{y=i}^{n} [(\tfrac{1}{y^2}) / n\right) \quad (6)$$

Where y is the dimensions and n is number of experiment.

This equation is to calculate each of the dimensions for each level. Larger is better condition is to set the highest dimension to be consider as the most accurate dimension. All the calculation of signal to noise ratio for dimension was calculated and simplify into Table 4.3.

Table 4.3: SN ratio of dimension

Level	**A**	**B**	**C**
1	33.9787	33.9794	33.9793
2	33.9792	33.9792	33.9790
3	33.9791	33.9785	33.9788
Delta	0.0005	0.0009	0.0005

Table 4.3 shows the full result for SN ratio of the dimension. It shows that result for each parameter on each level. From the Table 4.3, delta shows the difference between highest SN ratio and lowest SN ratio for each parameter. It shows that factor B that is depth of cut (0.009) shows the most influence factor for the dimension. From Table 4.3, a graph can be tabulated.

4.2.3.1 Spindle speed

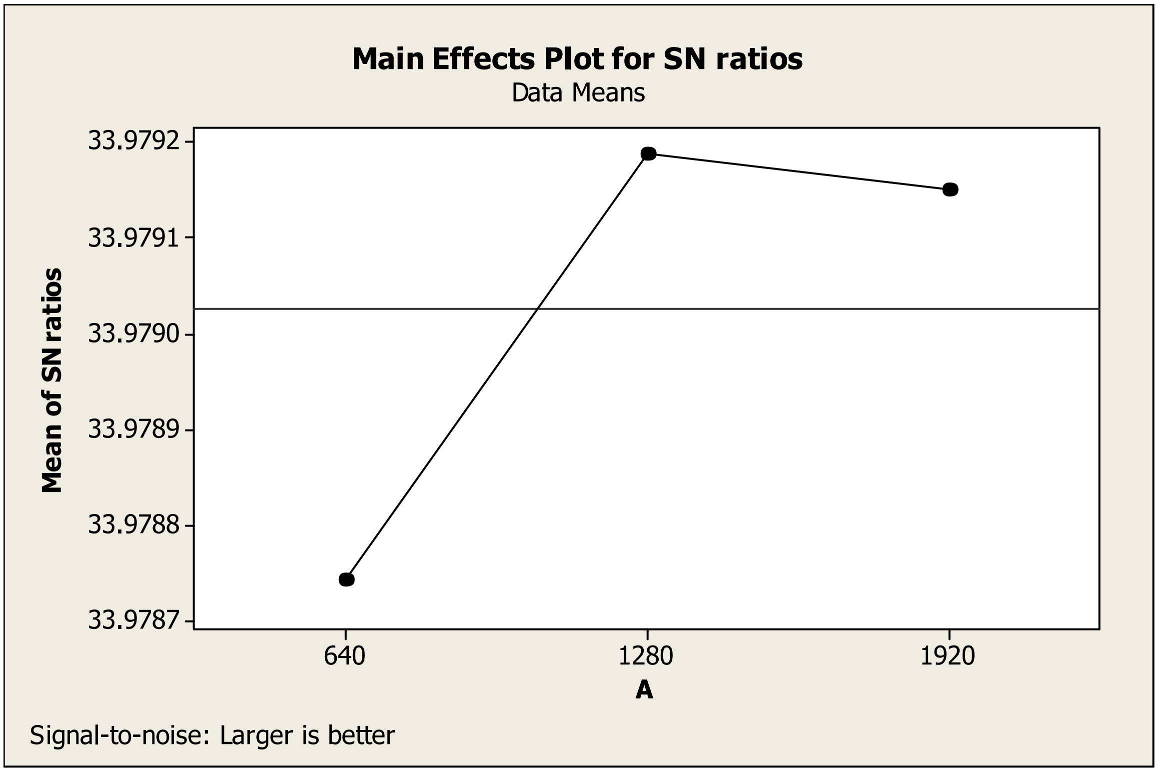


Figure 4.5: SN ratio graph for spindle speed (A)

Figure 4.5 shows the graph of main effect plot for SN ratio for spindle speed (A). Based on larger is better condition, the highest SN ratio gives the most the desired value of the factor. Optimal testing conditions of this parameter could be very easily determined from the response graph. Therefore, from the graph, the optimum value for spindle speed is at level 2 (1280rpm).

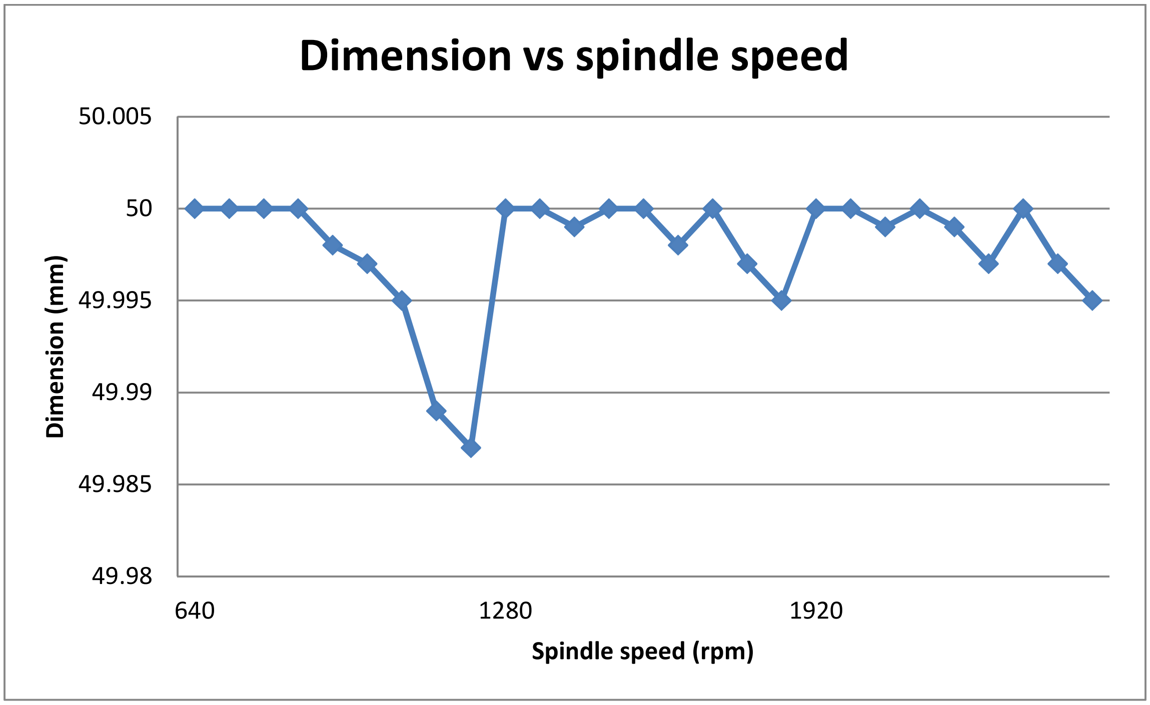


Figure 4.6: Line graph for dimension against spindle speed

Figure 4.6 shows the graph of dimension against spindle speed for all level. It shows that on the lowest spindle speed (640rpm), accurate dimension (50mm) can be obtained consistently at first four experiments but most of the experiments in second level (1280rpm) can achieve dimensional accuracy. The most inaccurate dimension (49.987mm) was at the last experiment with spindle speed of 640rpm. The dimension inaccuracy was obtained for every last of experiments at each speed. This can prove that spindle speed was the least influence factor for tapper problem.

4.2.3.2 Depth of cut

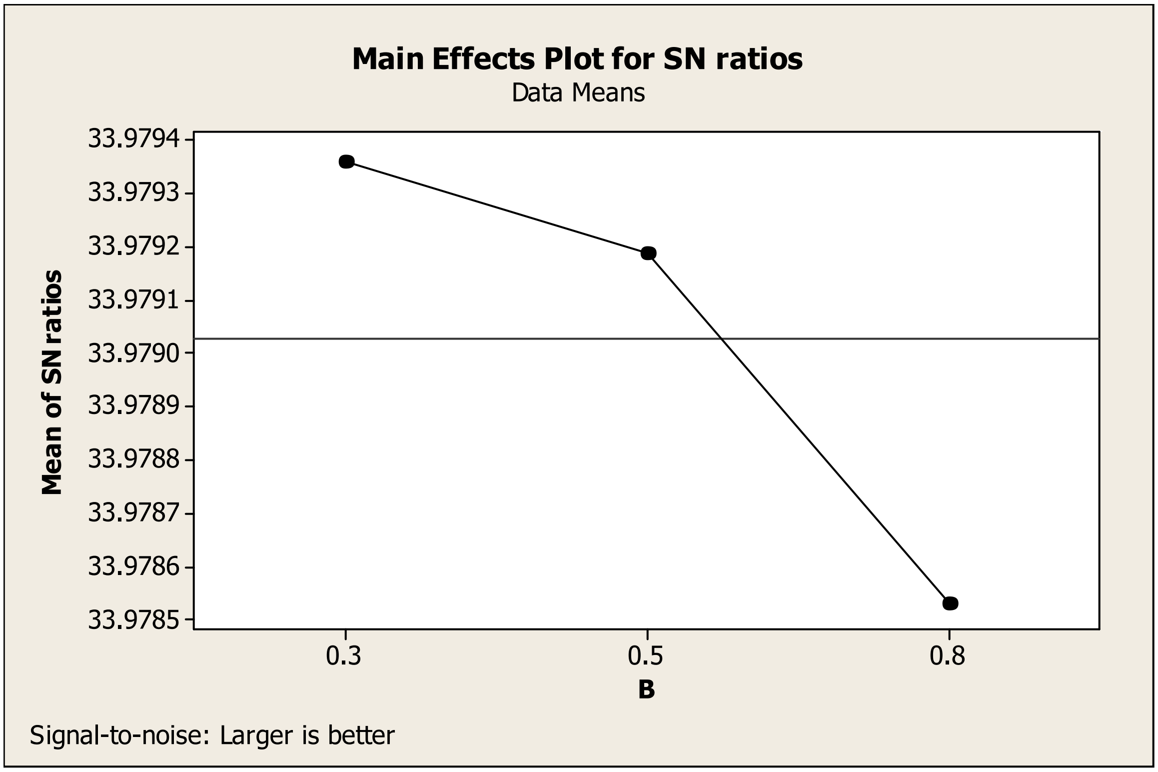


Figure 4.7: SN ratio graph for depth of cut (B)

Figure 4.7 shows the graph of main effect plot for SN ratio for depth of cut (B). Based on larger is better condition, the highest SN ratio gives the most the desired value of the factor. Optimal testing conditions of this parameter could be very easily determined from the response graph. Therefore, from the graph, the optimum value for depth of cut is at level 1 (0.3mm).

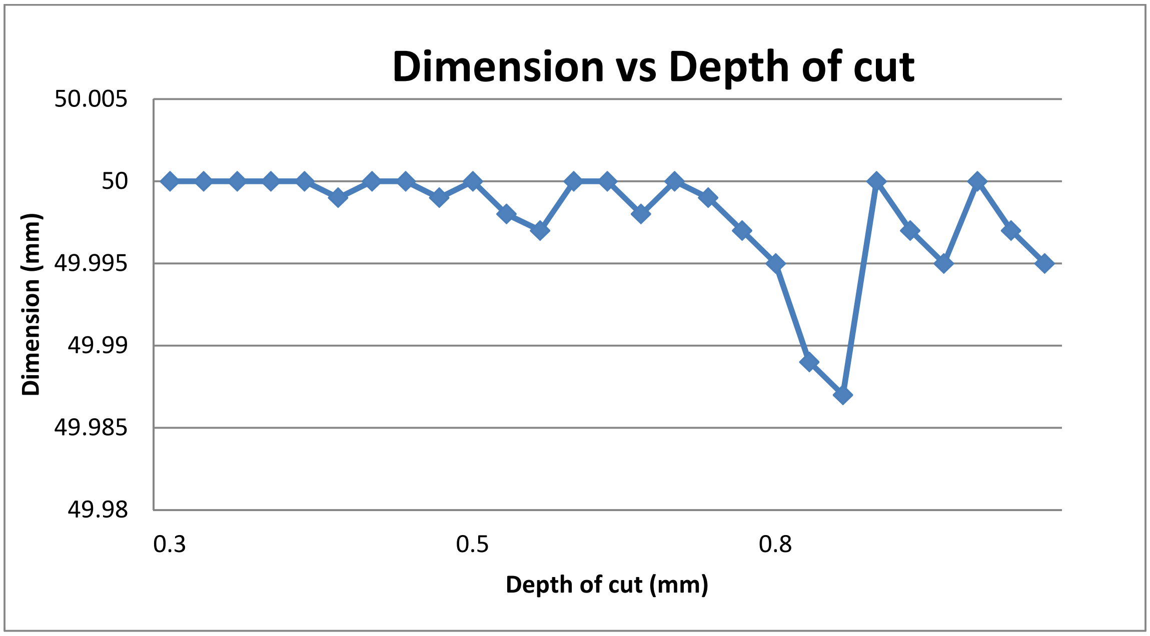


Figure 4.8: Line graph for dimension against depth of cut

Line graph for dimension against depth of cut in Figure 4.8 shows the consistency in obtaining dimensional accuracy (50mm) at the lowest depth of cut (0.3mm). Meanwhile, at middle depth of cut (0.5mm) and highest depth of cut (0.8mm) shows that dimensional accuracy can be obtained inconsistently with the most inaccurate dimension of 49.987mm. This proved to be that depth of cut only effective at the lowest depth of cut (0.3mm).

4.2.3.3 Feed rate

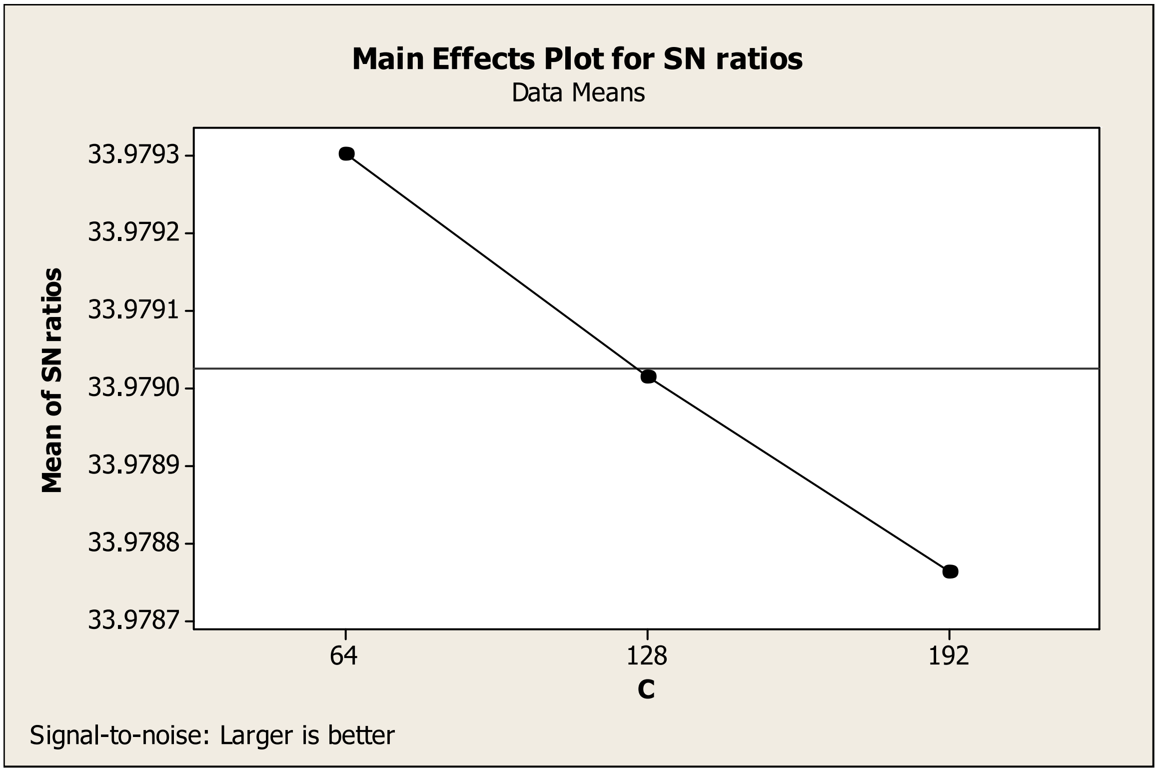


Figure 4.9: SN ratio graph for feed rate (C)

Figure 4.9 shows the graph of main effect plot for SN ratio for feed rate (C). Based on larger is better condition, the highest SN ratio gives the most the desired value of the factor. Optimal testing conditions of this parameter could be very easily determined from the response graph. Therefore, from the graph, the optimum value for depth of cut is at level 1 (64mm/min).

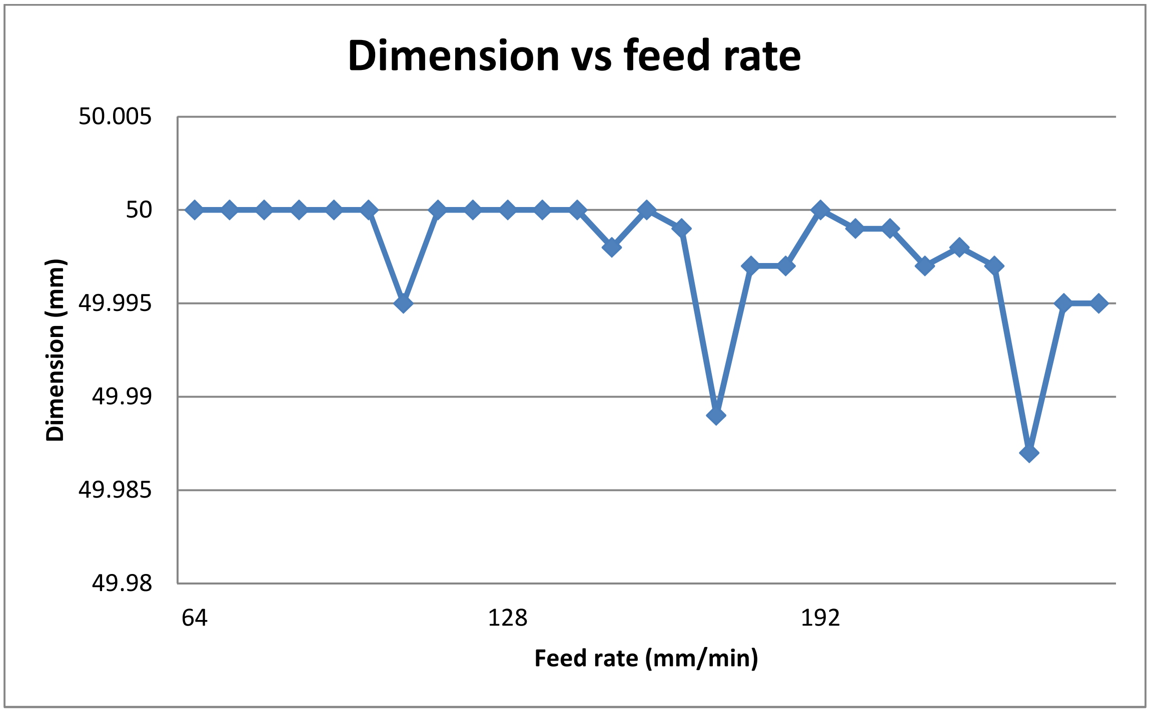


Figure 4.10: Line graph for dimension against feed rate

Line graph for dimension against feed rate in Figure 4.10 shows the consistency in achieving dimensional accuracy at first 14 experiments except for seventh and thirteenth experiments. This shows the lowest value of feed rate (64mm/min) can gives 50mm of dimension that is the most accurate dimension of the pocket. At the highest feed rate (192mm/min), the result obtained gives inaccurate dimension for pocket that is 49.987mm. It is also proved that feed rate gives more effect on the dimensional accuracy after spindle speed.

4.2.4 Surface plot

Surface plot graph is to show the relationship between two factors on a single response. This is to study the change in each factor that affect the dimension. Each surface plot was analyzed to obtain the most influent factor from three parameters.

4.2.4.1 Dimension versus spindle speed (A) and depth of cut (B)

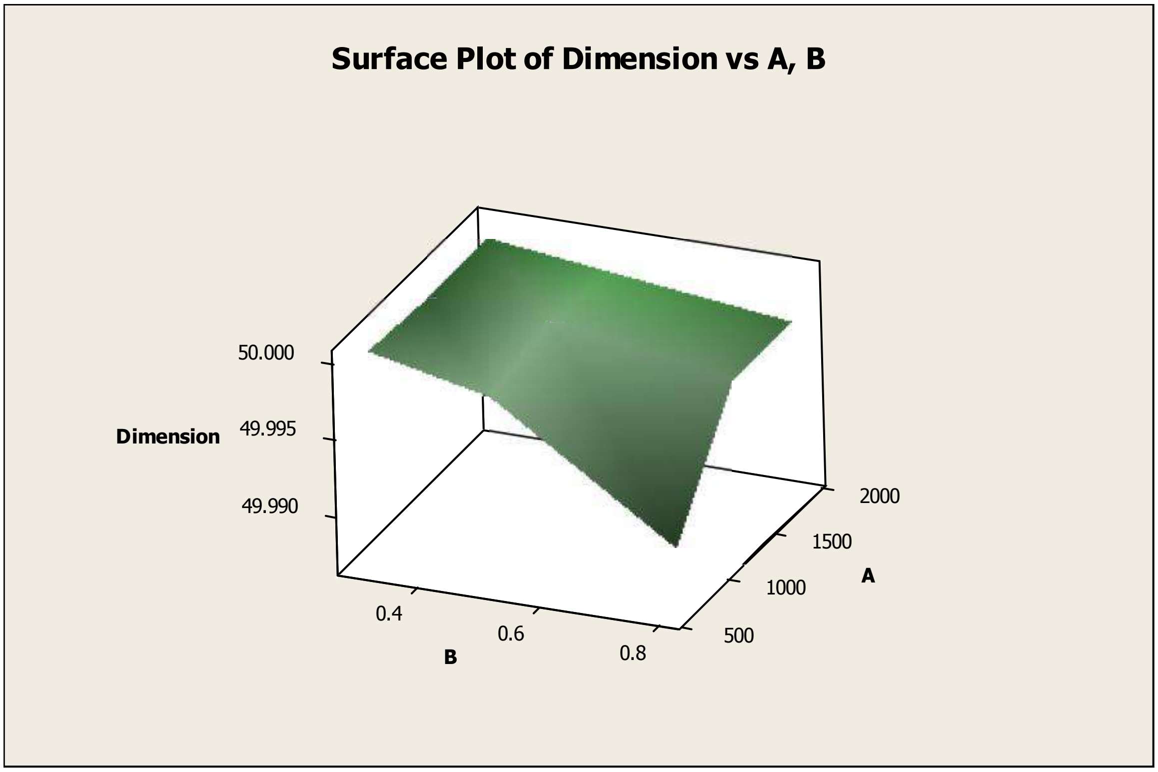


Figure 4.11: Surface plot for dimension versus A and B

Figure 4.11 shows the effect of spindle speed (A) and depth of cut (B) towards dimension. The surface plot shows the relationship between spindle speed and depth of cut. Increasing in depth of cut will gives inaccuracy in dimension. It can be proved when at highest depth of cut (0.8mm) with any value of spindle speed, it shows dimensional in accuracy where the dimension is at low value. Hence, the smallest depth of cut (0.3mm) will increase dimensional accuracy because accurate dimension can be achieved only at lowest value. While, spindle speed gives less effect on the dimension because the plot shows that any value of spindle speed can gives accurate dimension with lowest value of depth of cut but inaccurate dimension when comes to highest depth of cut.

4.2.4.2 Dimension versus spindle speed (A) and feed rate (C)

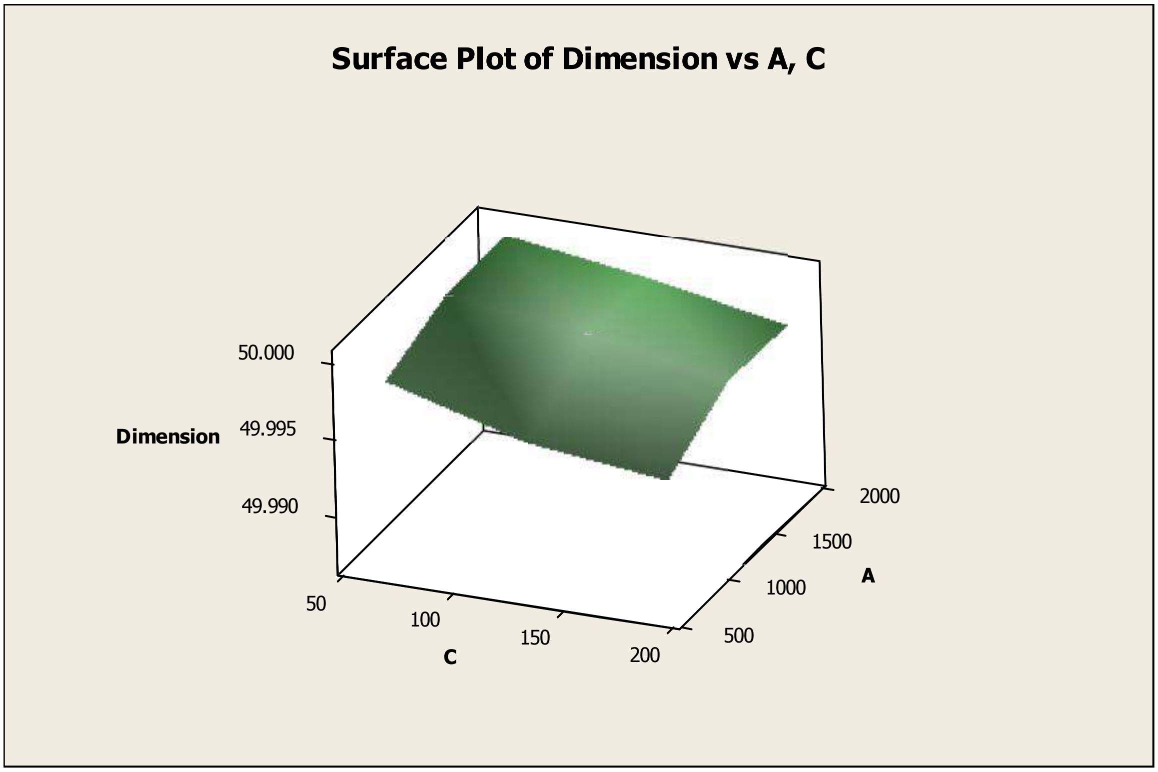


Figure 4.12: Surface plot for dimension versus A and C

Surface plot for dimension against spindle speed (A) and feed rate (C) in Figure 4.12 shows the factor A and C almost gives an equal effect. As we can see in surface plot, only the lowest value of feed rate (64mm/min) and middle value of spindle speed (1280rpm) can achieved accurate dimension. Besides lowest value of feed rate (64mm/min) and highest value on spindle speed (1920rpm), it will give inaccurate dimension.

4.2.4.3 Dimension versus depth of cut (B) and feed rate (C)

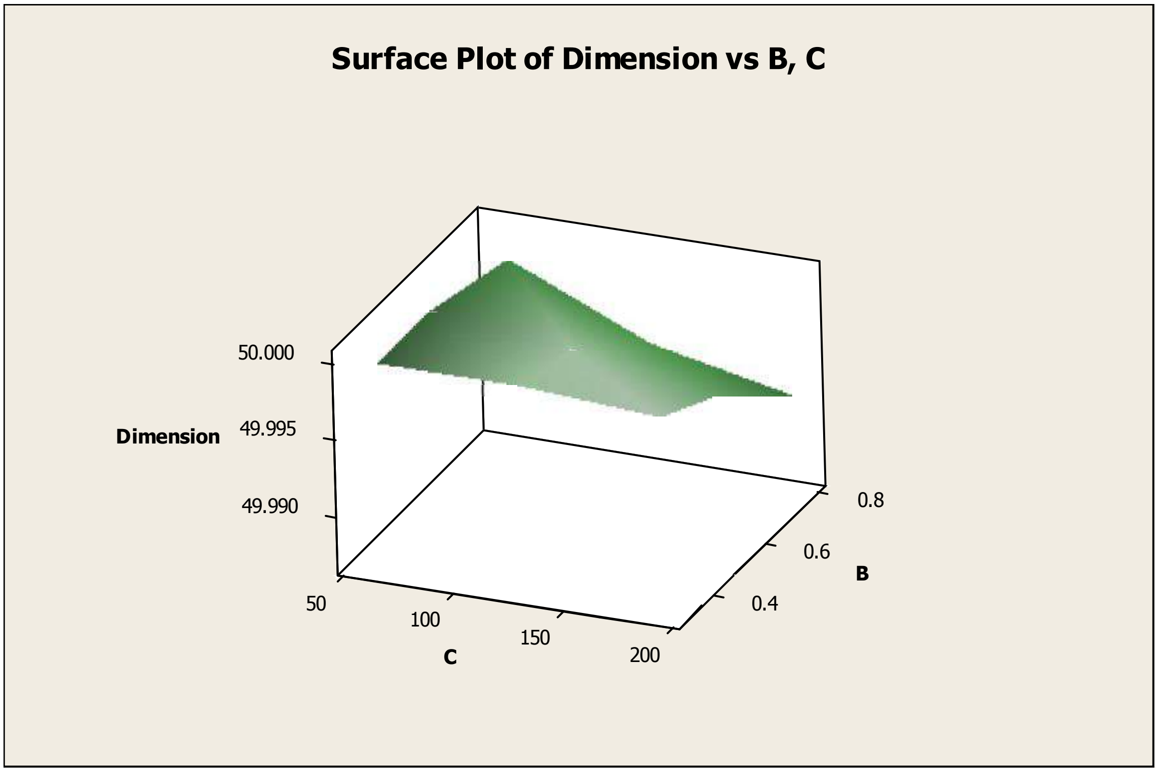


Figure 4.13: Surface plot for dimension versus B and C

Surface plot for dimension against depth of cut (B) and feed rate (C) with constant spindle speed in Figure 4.13, it shows that high significant of factor depth of cut. The surface plot shows accurate dimension can be obtain when only depth of cut at the lowest value (0.3mm). While, feed rate gives the least effect because, all feed rate value can achieved accurate dimension only at lowest value of depth of cut (0.3mm). At middle (0.5mm) and highest value depth of cut (0.8mm), all feed rate value gained dimensional inaccuracy. Hence, depth of cut is the most influence factor.

4.2.5 Optimum parameters

Table 4.4: Optimum parameters

Factors	**Optimum level**	**Optimum Value**
Spindle speed	2	1280rpm
Depth of cut	1	0.3mm
Feed rates	1	64mm/min

From the analysis of data using SN ratio and surface plot, the optimum parameter has been achieved and concluded in Table 4.4. The optimum parameters are gained from calculation of SN ratio with larger is better condition that is second level of spindle speed which is 1280rpm, first level of depth of cut which is 0.3mm and first level of feed rates which is 64mm/min.

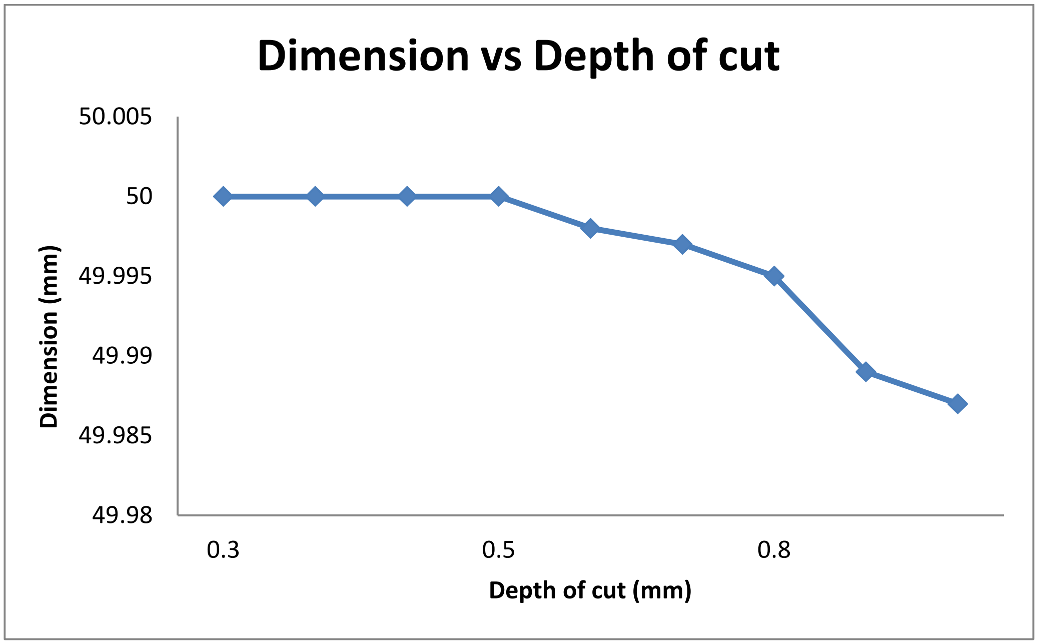


Figure 4.14: Graph dimension against depth of cut

Figure 4.14 shows the most influential factor that is depth of cut. The graph shows how depth of cut influences the dimension of the deep pocket. The lower the value of depth of cut, dimensional accuracy of the deep pocket also decreases. This is proved to be the optimum depth of cut is 0.3mm.

4.3 Summary

The study on tool deflection during deep pocketing cycle can be response to its dimensional accuracy of the pocket. The measurement of the pocket wall deflects the tapper problem. An experiment has been carried out to optimize the parameters controlled. The L27 Taguchi method was adopted to investigate the effect of spindle speed, feed rate and depth of cut on dimensional accuracy.

Three parameters with three levels each were calculated through signal to noise ratio with larger is better condition. Depth of cut had shown the greatest influence in this experiment. With the lowest value of depth of cut that is 0.3mm, it can achieve accurate dimension of deep pocket.

Feed rate has give second effect in order to achieve dimensional accuracy in deep pocketing process. With the first level of feed rate, the optimum value is 64mm/min. This value of feed rate can obtain accurate dimension, meanwhile, spindle speed with the least influences has came out with optimum value which is 1280rpm.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Tool deflection during deep pocketing cycle has cause tapper in the pocket. This problem logically can affect entire product that being produce. The defect on products can be costly for manufacturers and its need the best solution to overcome the tool deflection problem. Optimum machining parameters are of great concern in manufacturing environments, where economy of machining operation plays a key role in competitiveness in the market.

By using Taguchi L27 experimental design, three parameters with three levels each have been listed and 27 runs of experiments have been carried out by using milling machine. Mild steel as the raw material and 10mm diameter of coated carbide end mill as cutting tool have been used during the experiment.

Based on the data collected, the best machining parameters have been obtained. It shows that spindle speed of 1280rpm, depth of cut of 0.3mm and feed rate of 64mm/min are the optimum cutting parameters for deep pocketing process. By using the parameters, the best dimensional accuracy has been achieved and tool deflection problem has been overcome.

5.2 Recommendation

Based on this project, few recommendations for further study on this project have been listed. This project can be carry out by study on the cutting condition such as wet cutting and dry cutting. This cutting condition can gives different optimum machining parameter. This current project only study on dry cutting condition.

Another recommendation is to study on tool path of pocketing process. Recent work only used spiral tool path as a fixed parameter. Zigzag tool path can be study to gives better outcome on machining parameter. Spiral tool path can be split into several types, which are spiral in and spiral out while zigzag tool path can be split into one way and zigzag.

Further study on this project can used distant tool length and work piece clamping as a studied parameter. This also can give the optimum outcome and overcome tool deflection during deep pocketing process alongside with tool path and cutting condition. This to ensure that optimum parameter can be used in any condition for pocketing process.

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APPENDIX A

APPENDIX B

Appendix B1 (G-code)

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%
O5555

N1 G17 G90 G54 X0
Y0 Z100.
N2 G21 T1 M3 S1920
N3 G0 X45. Y55.
N4 G43 Z39.4 H0
N5 G1 Z-.8 F192.
N6 Y45. F192.
N7 X55.
N8 Y55.
N9 X45.
N10 Y57.5
N11 Y60.
N12 X40.
N13 Y40.
N14 X60.
N15 Y60.
N16 X45.
N17 Y62.5
N18 Y65.
N19 X35.
N20 Y35.
N21 X65.
N22 Y65.
N23 X45.
N24 Y67.5
N25 Y70.
N26 X30.
N27 Y30.
N28 X70.
N29 Y70.
N30 X45.
N31 G0 Z.3
N32 Y55.
N33 G1 Z-1.6 F192.
N34 Y45. F192.
N35 X55.
N36 Y55.
N37 X45.
N38 Y57.5
N39 Y60.
N40 X40.
N41 Y40.
N42 X60.
N43 Y60.
N44 X45.
N45 Y62.5
N46 Y65.
N47 X35.
N48 Y35.
N49 X65.
N50 Y65.
N51 X45.
N52 Y67.5
N53 Y70.
N54 X30.
N55 Y30.
N56 X70.
N57 Y70.
N58 X45.
N59 G0 Z-.3
N60 Y55.
N61 G1 Z-2.4 F192.
N62 Y45. F192.
N63 X55.
N64 Y55.
N65 X45.
N66 Y57.5
N67 Y60.
N68 X40.
N69 Y40.
N70 X60.
N71 Y60.
N72 X45.
N73 Y62.5
N74 Y65.
N75 X35.
N76 Y35.
N77 X65.
N78 Y65.
N79 X45.
N80 Y67.5
N81 Y70.
N82 X30.
N83 Y30.
N84 X70.
N85 Y70.
N86 X45.
N87 G0 Z-.9
N88 Y55.
N89 G1 Z-3.2 F192.
N90 Y45. F192.
N91 X55.
N92 Y55.
N93 X45.
N94 Y57.5
N95 Y60.
N96 X40.
N97 Y40.
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N102 Y65.
N103 X35.
N104 Y35.
N105 X65.
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N111 Y30.
N112 X70.
N113 Y70.
N114 X45.
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N116 Y55.
N117 G1 Z-4. F192.
N118 Y45. F192.
N119 X55.
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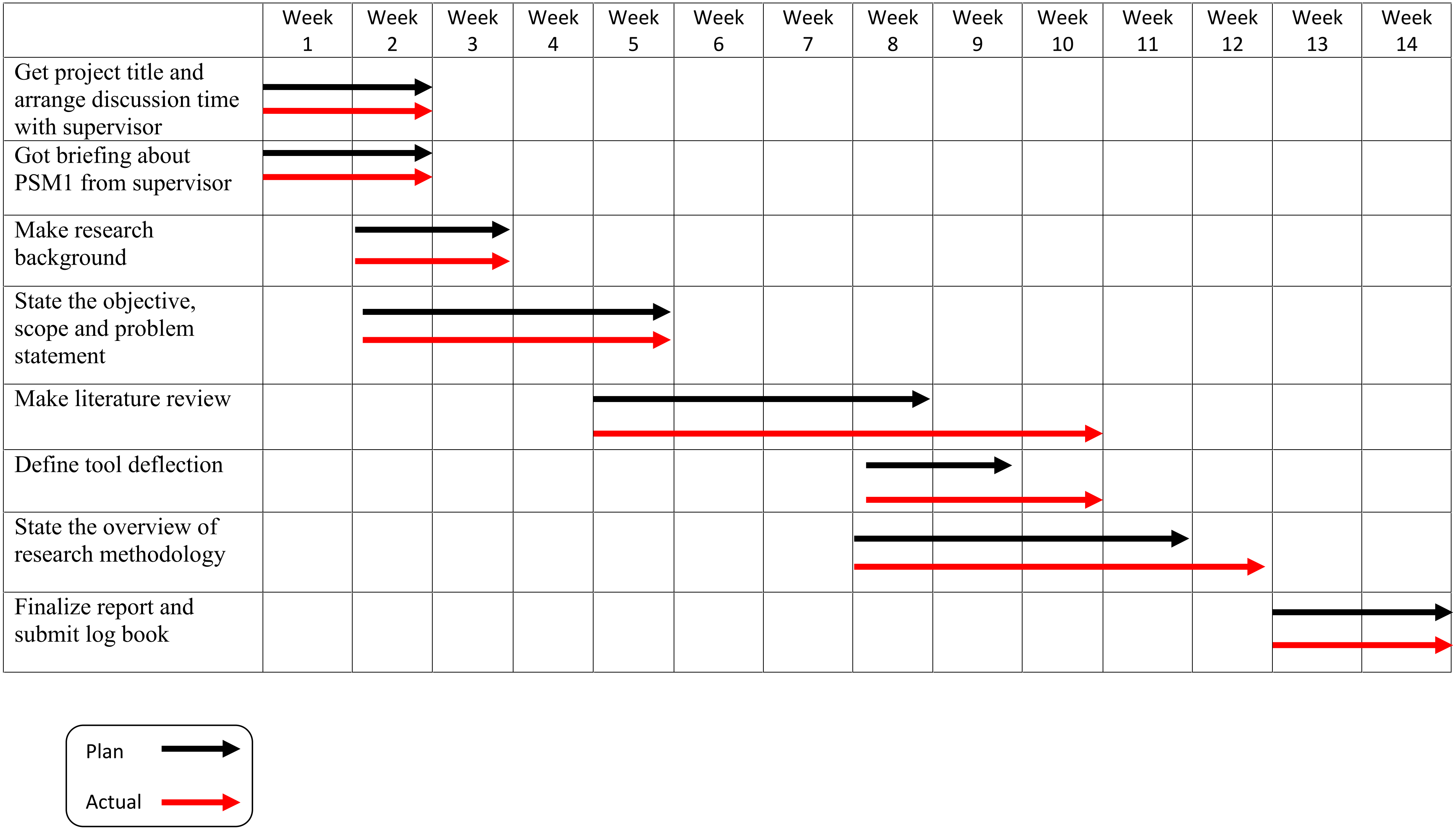
Appendix A1 (Gantt chart for FYP1)



Appendix A2 (Gantt chart for FYP2)