OPTIMIZING THE 3D MILLING MACHINE PARAMETER TO IMPROVE THE CUTTING ACCURACY

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This report is submitted
in fulfilment of the requirement for degree of
Bachelor of Mechanical Engineering (Design and Innovation)

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DECLARATION

I declare that this project report entitle “Optimizing the 3D milling machine parameter to improve the cutting accuracy” is the result of my own work except as cited in the references.

Signature :……………………..………………………………

Name :………………………..…………………………………..

Date :……………………………..…………………………………

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Design and Innovation).

Signature : ……………………………………………...……

Name of Supervisor : ……………………………………………...……

Date : ……………………………………………...……

DEDICATION

To my beloved mother and father

ABSTRACT

3D milling machine is a machine that use to cut workpiece in three Cartesian coordinate which are x-axis, y-axis and z-axis. As the technology develop, there are many techniques and software that been introduced to help controlling the system. In UTeM, the movement of the machine can be control by using NXT Intelligent Brick (I-Brick) which is a programmable brick of NXT. The brain of the Mindstorms robot can be controlled by installing the Lego Mindstorms NXT software. In order to optimize the milling machine, MATLAB/Simulink been use as the programming environment to design the machine movement. The programming model are designed and been tested to achieved the desired requirements of cutting pattern. The machine parameters that influence the cutting accuracy such as motor voltage, cutting speed and tool bit diameter also has been determined and analysed. To analysed the parameter, it will be tested on the machine itself and the method of optimization using MINITAB software is used as an approach to minimize the number of experiment in a systematic way. The results are analysed and presented in this report.

ABSTRAK

3 dimensi mesin miling merupakan satu mesin yang digunakan untuk memotong bahan kerja dalam tiga koordinat iaitu paksi x, paksi y dan paksi z. Semakin teknologi berkembang, terdapat banyak teknik dan perisian yang telah diperkenalkan untuk membantu pengawalan sistem. Di UTeM, pergerakan mesin tersebut boleh dikawal menggunakan 'NXT Intelligent Brick (I-Brick)' yang merupakan satu alat yang diprogramkan untuk mengawal NXT. 'NXT Intelligent Brick (I-Brick)' boleh dikawal dengan memuat turun perisian 'Lego Mindstorms NXT' di dalam komputer. Untuk mengoptimumkan penggunaan mesin tersebut, perisian MATLAB/Simulink digunakan untuk merekabentuk pergerakan mesin tersebut. Model tersebut di rekabentuk untuk mencapai keperluan yang dikehendaki mengikut bentuk potongan. Parameter mesin yang mempengaruhi ketepatan pemotongan seperti kuasa motor, kelajuan pemotongan dan diameter mata alat juga dikenalpasti dan dianalisis. Ia juga akan diuji pada mesin tersebut dan kaedah optimisasi menggunakan perisian MINITAB akan digunakan untuk mengoptimumkan pengawalan sistem. Keputusan dianalisis dan dibentangkan dalam laporan ini.

ACKNOWLEDGEMENT

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Furthermore, I would like to acknowledge with much appreciation the crucial role of post graduated students in Innovation Laboratory, who give the permission to use the requirement equipment and necessary materials to complete my experimentation on the 3D NXT milling machine.

A special thanks to my family who help me in fabricating and assembling parts and gave a lot of suggestion regarding to this project where I found it is difficult for me to solve. A special thanks also to my classmate and teammate who help me on giving some suggestion and encourage me in completing this final year project.

Last but not least, I would like to express my gratitude to any individual or group whom I have not mention that has gave me support and advices in order to complete this project especially to Design and Innovation's students and lecturers.

To conclude, I hope that this report of final year project can fulfil the conditions as requested for degree of Bachelor of Mechanical Engineering (Design and Innovation), UTeM.

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LIST OF ABBREVIATIONS

3D	Three Dimensional
BMCD	Bachelor in Mechanical Engineering (Design & Innovation)
DOE	Design of experiment
I-Brick	Intelligent Brick
MATLAB	Matrix Laboratory
PID	Proportional Integral Derivative
USB	Universal Serial Bus
UTeM	Universiti Teknikal Malaysia Melaka

LIST OF SYMBOL

L	Number of level
P	Number of parameter
π	Pi (3.14)
n	Number of experiment/observation
β_0	Overall means response
β_{ij}	Main effects for each factors
β_{ii}	Quadratic effect for the i^{th} factors
V	Cutting speed
S	Spindle speed
F	feed
f	Feed per tooth
N	Number of rotation
D	Diameter of tool bit

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Milling is a machinery process that use rotary cutter to remove or cut the material from work pieces. The 3-dimension (3D) milling machine means that it can cut the work piece using three Cartesian coordinates or axes which are x-coordinate, y-coordinate and z-coordinate. Technologies nowadays help us on controlling the milling machine by using various type of software available now such as Lego Mindstorms NXT and Simulink. This software is used to create a programmable control of the milling machine.

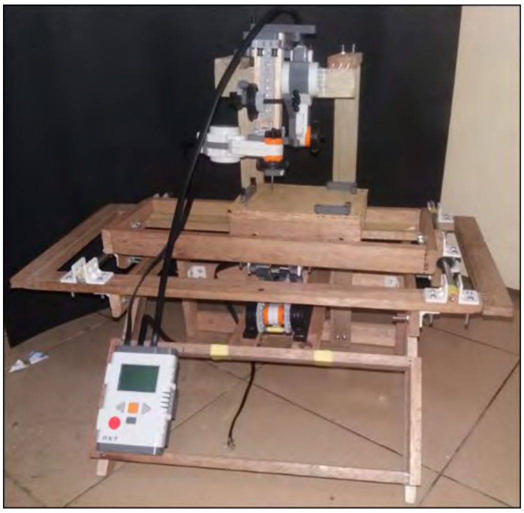


Figure 1.1: 3D NXT milling machine in UTeM

The existing 3D milling machine in UTeM is using the NXT intelligent brick (I-Brick). I-Brick is a programmable brick of NXT. The NXT is the brain of a Mindstorms robot. There are two type of communication that are used to download the programs which is by using Universal Serial Bus (USB) 2.0 port or by a wireless communication using Bluetooth function. A dot matrix display that supports 100x64 pixels can be found on the front of I-Brick. It can connect up to 3 different motor using different output port and can connect various types of Lego sensors devices at 4 different input ports. The basic NXT educational set usually came with 4 different type of sensor such as touch sensor, sound sensor, light sensor and ultrasonic sensor. The NXT servo motor can be control by adjust the direction of rotation between the range of power and degree of rotation. Each motor can be controlled separately. In order to move it to the right, the motor on the right side will turn in clockwise direction while the other motor will rotate counter clockwise. It also can synchronize the motor to move forward and backward. (Kim & Jeon, 2007). The Lego Mindstorms NXT's software is use to optimize the control and motion of the NXT. Before using the software, the code and symbols need to be understood first so it is easier to implant or determine which symbols or code should be used.

Figure 1.2: NXT Intelligent Brick (I-Brick)

Figure 1.3: Lego Mindstorms NXT's software

Simulink is a graphical programming environment that are used for creating model, simulate and analyse the multi-domain of the dynamic systems which been integrated with MATLAB. It is basically a graphical block diagram tool and can be customised using the block libraries. (The Mathworks Inc, 2016)

One of the method for optimization is by using the design of experiment approach. An optimal region usually can be determined after getting the result of the experiment between the influenced parameter and the response. Usually in engineering field, it is use to improve the response after conducting an experiment whether to minimize or maximize the response. (Engineering Statistics Handbook, 2013)

1.2 PROBLEM STATEMENT

There are some of problem occurs regarding to existing 3D milling machine which lead to inaccuracy and poor result to the work pieces. This problem occurs due to a few factors such as calibration of the machine, motor voltage and others. It is important to perform the calibrations on the prototype to obtain a better performance and reduce maintenance. The calibrations need to be done in the program and prototype itself so some improvement can be made and the precaution can be established.

Calibrations not only limits on changing the values of the code of the block diagram but also addition of other code such as loop into the block diagram to make a better program. Changing any dimension such as adding more height on the axes also means calibrating and known as physical calibrations.

1.3 OBJECTIVES

The objectives for this project are:

1.3.1 To design the 3D milling machine movement using MATLAB/SIMULINK software.

1.3.2 To analyse three machine parameters that influenced the cutting tool movement namely motor voltage, cutting speed and tool bit diameter.

1.3.3 To optimize the 3D milling machine parameter using MINITAB software.

1.4 SCOPE

The scopes of this project include:

1.4.1 The concept of the milling machine will only covers on the basic milling machine that is the vertical milling machine and will be implemented on the design.

1.4.2 The Lego Mindstorms NXT intelligent brick will be the brain of the milling machine’s prototype which will first be demonstrated in a simple gearing system.

CHAPTER 2

LITERATURE REVIEW

2.1 MACHINE TOOLS IN REMOVAL PROCESS

According to encyclopaedia Britannica (Lopez et al, 2009), the description for machine tools is given as any stationary power driven machine that is used to shape or form parts made by metal or other materials. The shaping is accomplished in four general ways which are by cutting excess material in the form of chips from part, by shearing the material, by squeezing metallic parts to desired shape and by applying electricity, ultrasound or corrosive chemicals to materials. (Lopez et al, 2009)

The basic function of a machine tool for removal process is to move the cutting tool along a more or less complex trajectory with sufficient precision, withstanding the forces from the removal material process. This can be done to reach the precision and or material removal rate.

The input for machine tool designers is a user requirement which lead to the machine features. The requirement must follow a few aspects and one of them is to determine the maximum part size that need to be machine. The machine workspace must be larger than the work piece size. The material removal rate also needs to be determined in order to achieve the precision of the machine. Usually the machine needs to be suitable for its operation and requiring a sufficiently accurate and highly productive machine at lower price.

The most importance aspect that needs to be follow while designing a machine is precision. There are two different concepts that involves which is accuracy and repeatability. Accuracy is the capability of being on target with specification and desired result. Repeatability is the ability to reach the same value. Therefore, a machine may be repeatedly inaccurate in one extreme case or imprecise yet very accurate at the other extreme. So, in order to achieve a determined grade or accuracy, there are few guidelines that need to be considered such as the effect of assembly in machine components on tool position, the structure deformations under the action of cutting and inertial forces and dynamic behaviour of the system under certain cutting forces. (Lopez et al, 2009)

2.2 THE MILLING STRUCTURE OF MACHINE

The principle of machine structure is the machine tools must support all components in machine. At the same time, it also must bear up the forces that produce from the process and upholding sufficient toughness in order to preserve the essential precision. There are two main types of features which included in the structures which are the frame, bed and the structural components. The frame is categorized as the main body of the structure constitutes the machine frame while bed is where all the other components rest. The important components are the part where the mechanism being linked with relative motion between them. (Lopez et al, 2009)

2.2.1 TYPES OF MILLING MACHINE

Peripheral (slab) milling is where the milled surface was created by teeth that are located on the edge of the cutter body and the axis of cutter usually placed at a plane which parallel to the workpiece surface that need to be machine.

Another type of milling machine is face milling where the cutter was attached on the spindle which the axis of rotation is perpendicular to the workpiece surface. The result of the milled surface located on the periphery and face of the cutter.

End milling usually rotate the cutter on an axis perpendicular to the workpiece. It can be slanted to machine tapered surface and the cutting tooth is located on both end of pace and periphery of cutter body. (Manufacturing Education, n.d.)

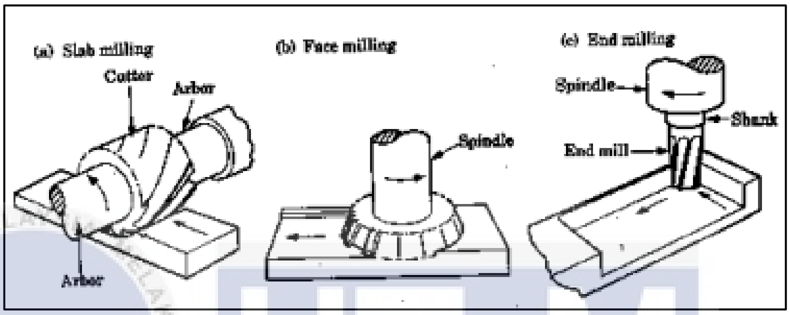
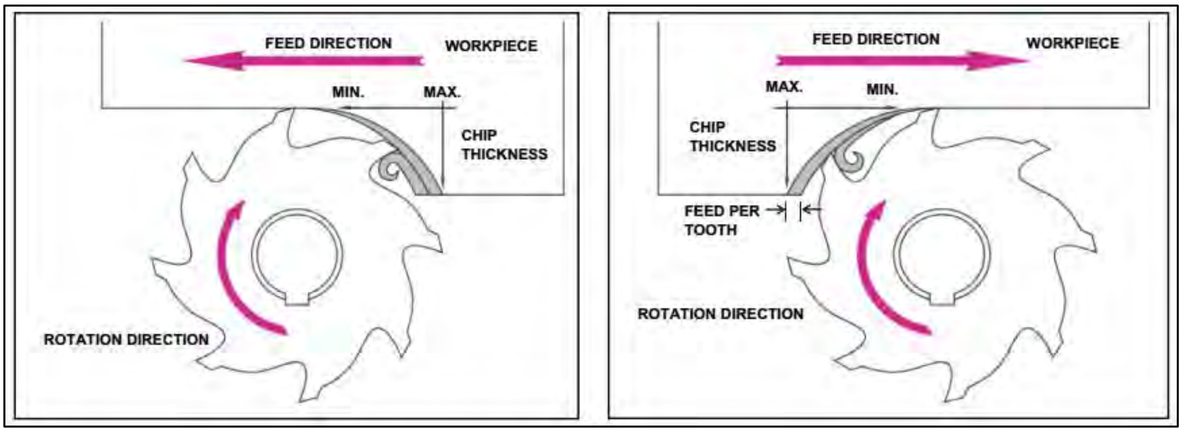


Figure 2.1: Type of milling operation

The common milling mode that been use in the industry are conventional milling and climb milling. (Nik et al, 2016). Up milling been categorize as a conventional milling where the direction of the rotation's cutter different from the feed motion but down milling been classified as a climb milling which the direction of cutter rotation is similar to the feed motion. The chip form in down milling is contrasting to the chip form in up milling where the cutter tooth is nearly parallel to the upper surface of the workpiece. It will start to mill the full chip thickness as the chip thickness is gradually reduced. (Milling Education, n.d)



a) Convectional (up) milling b) Climb (down) milling

Figure 2.2: Machining process for different milling mode

2.3 MILLING CUTTER

The end milling cutters need to have teeth on the end and periphery. A larger end milling end cutter is mounted on arbor while the smaller ones have a shank for chuck or direct spindle mounting. The end milling cutter is used to creation of keyways, slots and recessed. It also can used to mill angles, edges and shoulders of work piece. (Milling machine operation, n.d). There are several types of end milling cutter are shown in Figure 2.3 above.

Figure 2.3: Several types of end milling cutter

2.4 SOURCES OF ERROR IN MACHINE TOOLS

The main uncertainty sources in the design and construction of machine tools are categorised as geometric and kinematic error; thermal error; and stiffness and deflection of cutting tool error. (Lopez et al, 2009)

The geometric and kinematic errors can be define as a misalignments axes, slide ways degradation and the wear of joints and couplings are the example of the mechanical imperfections which lead to the errors. As the machine become complex, the possibility of kinematic error is very high.

Thermal errors have a complex non-linear nature which makes it difficult to handle which are mostly due to the local heating due to feed and main spindle motor. Stiffness error and errors addressed to the deflection of cutting tools. Usually, the machine tools are not perfectly rigid. Therefore, the weight of structural components on one side and cutting forces on the other, cause large errors which are highly dependent on the tool position. Cutting forces can cause important errors addressed to deflection of cutting tools. (Lopez et al, 2009)

2.4.1 MACHINE TOOL ERROR

According to Lopez et al 2009, there are a few tool errors that can lead to uncertainty of the milling machine's result such as guide way positioning error and uncertainty of the reference position. The machine origin or zero point is a fixed point set by the machine tool builder. So any tool movement should be measure based on that point. Some time, the reversal linear movement also can lead to error because the position measured values are different when slide goes forward and backward as the machine moves.

Thermal expansion also one of the errors which are due to the machine tool internal heat sources such as drives and friction. The error such as angular error, machine trajectory error and error in spindle also need to be considered in order to get a better result of product.

2.4.2 MACHINING PROCESS ERROR

During cutting process, a tool can bend considerably under the action of the cutting forces. The wear increases the cutting forces and produces a variation of tool dimensions with the consequent loss of accuracy. Other than that, vibration also can occur during this process. The most common type of vibration is a force vibration which due to tooth passing frequency. Thus, the natural frequency of the machine, tool and work pieces are near the characteristic frequency of the cutting force, a high dynamic amplification happens. (Lopez et al, 2009)

2.5 LEGO MINDSTORMS NXT PROGRAMMING ENVIRONMENT

As for programming and debugging a system, it is essential to have a well knowledge on programming. It usually takes a lot of time for programmer to become familiar and get used to the programming process. Lego NXT I-Brick are programmed by a programming environment which is powered by visual programming environment.

The NXT's visual programming is basically easy to use and handle because it is in a drag and drop setting for each block. The drag and drop blocks are represented on the left side of the display and each of it represent a different function. User just needs to drag the desired function which represented as a block and drop it in the workspace or also called as programming board. Combinations of blocks are defined as a program. (Kim & Jeon, 2007)

The Lego Mindstorms NXT robot kit has been came out with a low cost as it was widely used for education purpose nowadays. The developments process takes for about six decades on modular production techniques from Lego a long with years of computer based education method. Now, it has been represented as an educational platform. (Massimo & Simone, 2013)

The NXT educational set consist of a programmable NXT I-Brick a long with the USB and Bluetooth, four different type of sensor such as sound, touch, ultrasonic and light sensors, and three unit of servo motor. (Alexender et al, 2010)

Figure 2.4: Standard education kit for Lego Mindstorms NXT hardware (five sensors; sound, two touch sensors, ultrasonic, light sensor), three unit of servo motors and programmable NXT Brick

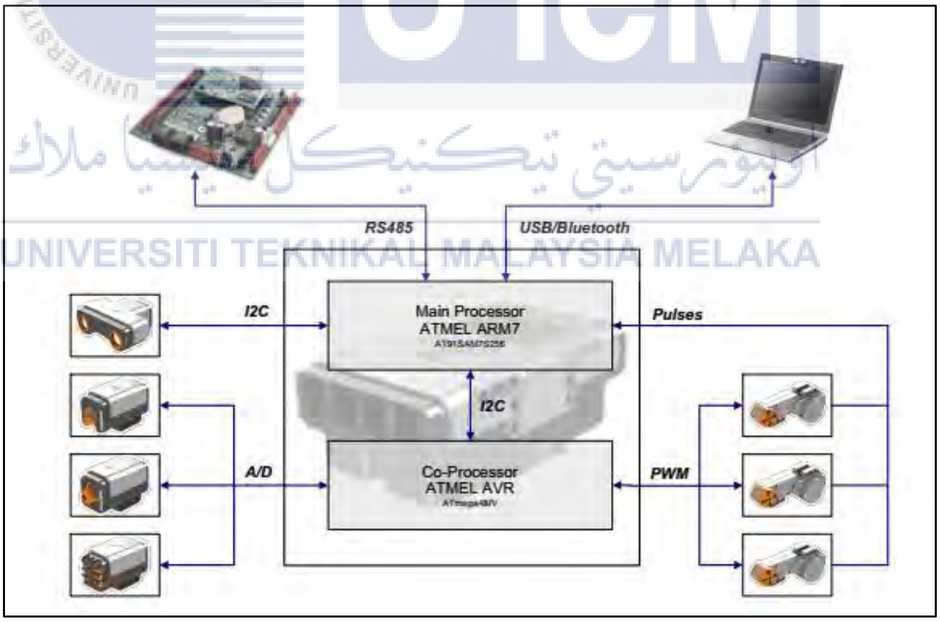


Figure 2.5: Lego Mindstorms NXT platform architecture

2.5.1 NXT SERVO MOTOR

The NXT servo motor has built-in rotation sensors that can measures in the motor rotations in degree or full rotation through NXT I-Brick. The rotational feedback allows the NXT to control the movement precisely. (Lego Mindstorms Education, 2006). Compared to the old motor of NXT, this motor is much slower but it can make up for the speed according to the amount of power it holds. The slower speed is due to an internal gear train inside the motor.

Usually, the motor can runs under no load condition at 170 rpm compared to the old ones which is 360 rpm. The servo motor also can draw 60 mA of power and as the power increase, it will provide more torque. However when there is a load, the servo will run slower and draw more current. (Watanabe, 2007)

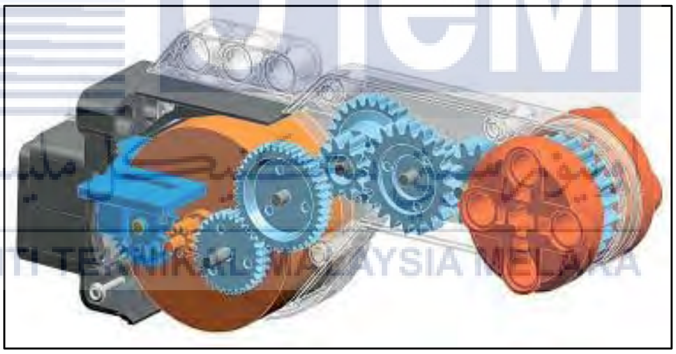


Figure 2.6: Internal view of NXT servo motor

2.6 MATLAB/SIMULINK TOOLBOX

As one of the influential programming and simulation tool, MATLAB has become more important in today's studies. It helps to plot matrices and vector algebra from the mathematical formula to program algorithms on basic programming. The function of MATLAB is allows user to abstract and solve a complex engineering task and a mathematical problem.

MATLAB also commonly used in industry for the algorithm and simulation development. Advanced programming skills in MATLAB also already become one of the important skills in engineering education. Combination of MATLAB and robots established with the term "MATLAB meets LEGO Mindstorms", which is a digital signal processing that are combined with computer programming and problem oriented in engineering field.

The earlier studies, G. Gutt (2006) introduced the first remote control of MATLAB-Mindstorms interface that use other communication software that can establish the Bluetooth connection between Mindstorms NXT robots and MATLAB. Another study using Simulink is developed by T.Chikamasa (2006) which involved an advanced control engineering concept and complex simulation model. It provides a simulation approach and produces embedded codes that not allow the program code to debug in step wise. It also emphases on advanced control concept and involves an original familiarity with Simulink. (Alexander et.al, 2010)

2.7 METHOD FOR OPTIMIZATION

In order to solve an optimization problem, objective functions need to provide a scalar quantitative performance measure whether it need to be minimized or maximized. A predictive model is required to describe the characteristic of the system within the scope. So, some constraints need to be set up that comprise a feasible region and range that define the limitation of the system. Some variable also need to be determined so that it can be adjusted to the predictive model to satisfy the constraints.

The objective for optimization is to find the combinations of parameters in order to achieve the minimum the cost of manufacturing process, improving the quality of production and increasing the tool life as well as reducing the maintenance cost of the machine. An improvement can be done by identifies and determines the area of critical factors that lead to desired responses with the range of acceptable variation. (IOPscience, 2016)

Optimization is a fundamental and usually been use in engineering field. However, this process needs to be done by any trial and error. So, it is important to consider optimization task as a regular basis and applying the fundamental knowledge on the formulation of optimization.

The main purpose in this optimization approach is to design a good system that consistent under an uncontrollable condition (Taguchi, 1978) (Byrne, 1987) (Phadke, 1989). The purpose is to adjust the design parameters to optimal level which is the system response. A few studies were conducted as an approach to optimize the turning parameters (Vernon et al, 2003) (Davim, 2003) which uses a several workpiece materials and controlled parameters to improve the dimensional accuracy, surface roughness and tool ware. Every of it used different combinations of feed rate, cutting speed, time, depth, workpiece length, geometry, material and other parameter. The useful correlation between the control and response parameter can be specify as there are a number of different parameters that can included in the study and an unique combination of parameters that can custom to a specified condition.

This techniques is an engineering method that use the design parameter (Ealey, 1994) for designing a product or process that focuses on determining the parameter to produce the best levels for a quality product with least variation. It also provides a great and effective method for designing process that can operate in optimal and consistent on variation of circumstances.

In order to get a good design, strategically designed experiments are necessary so it can expose the process to several design parameter level. The method of experimental design have been developed in early 20th century and been studied by statistician (Phadka, 1989) and helps to approach a design of experiment which is easy to adapt and can be applied with limited statistics knowledge.

The best opportunity is to reduce variation during product designing and process manufacturing. A quality engineering's strategies that have been develop can be used which involving three stage; first is system design, second is parameter design and third is reducing and controlling the variation. In design system, scientific and engineering knowledge been applied by engineers to produce a simple functional design of prototype. The design need to have a product design and process design phase. The selection materials, tentative product constraint value and components are involved in product design phase. For process design stage, analysis for processing arrangements, tentative process constraint value and the selection of production equipment is involved.

Design of a system is also known as an initial functional design. Therefore, it can be far from optimal in cost and quality. The function of design parameter is to optimize the settings of the process parameter values so it can improve the quality features and to determine the product parameter values under optimum process parameter values. It can be predict that the ideal process parameter values that been obtained from parameter design are unaffected to variation in the environmental environments and also to the other noise factors. To determine and analyse tolerances around the optimal settings, a tolerance design are used. It is required in order to minimise the variation gained by design parameter did not meet the performance. (Yang et al, 1998)

Table 2.1: Basic orthogonal array

Run	Control factors and levels		
	A	B	C
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This section will describe on the methodology that been used in this project. It will cover on the behaviour of milling machine and Lego Mindstorms NXT is considered as the medium to move and control the milling machine. The block diagram which been program in the Lego Mindstorms NXT will be included in order to transform a complex command into a simple command from the software to the Intelligent Brick (I-Brick). The MATLAB/Simulink's software also been approached in order to get a better performance of machine movement control which is more focussing on Simulink; a graphical editor and solver for modelling and simulating dynamic system. The parameters that influenced the cutting accuracy also been discussed as well as the method of optimization. Figure 3.1 above show the general flow of methodology in this project.

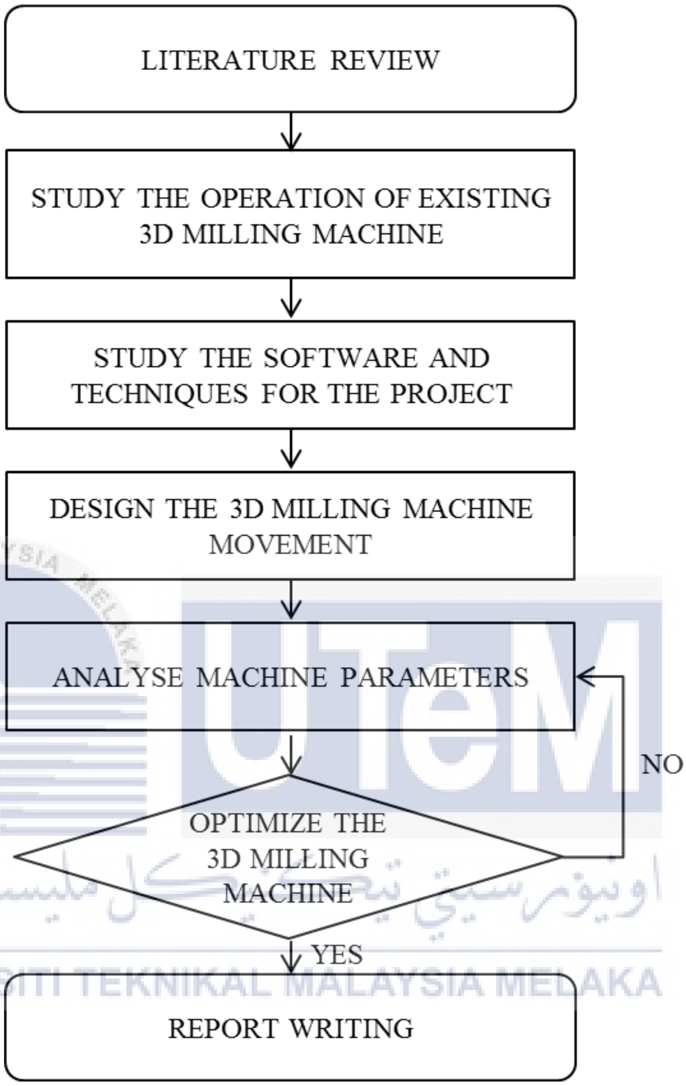


Figure 3.1: Flow chart for this project

3.2 OPERATION OF EXISTING 3D MILLING MACHINE USING LEGO MINDSTORMS NXT

The existing 3D milling machine is using the Lego Mindstorms NXT's software and NXT Intelligent Brick (I-Brick) as the medium to operate the machine. The operations in Lego Mindstorms NXT's software need to be explore in order to get a good understanding in controlling the machine according to desired movement.

First, the motor need to be connected to the NXT where one end of black wire need to be plug to the motor while the other end need to plug at the output port of the NXT. The port must be A, B and C for the output. It is different for the sensors where one end of the black wire need to plug into the sensor and the other end into one of the input port which is port 1, 2, 3 and 4. It is noted that all black wire can be used as the output and input cable but the output must be attached in A, B, C ports while input in 1, 2, 3 and 4 ports.

Figure 3.2: Ports to plug the output and input wire

The USB port and wireless connection (Bluetooth) are used to download and upload the data from user's computer and NXT. User can choose which options that they want to use according to their compatibility of computer. Some of the computer does not have a Bluetooth program, so it needs to use a USB cable to downloading and uploading data to NXT. The Lego Mindstorms NXT software also needs to be installed in the computer beforehand before connecting NXT to computer so that all data can be transferred according to the programmable software.

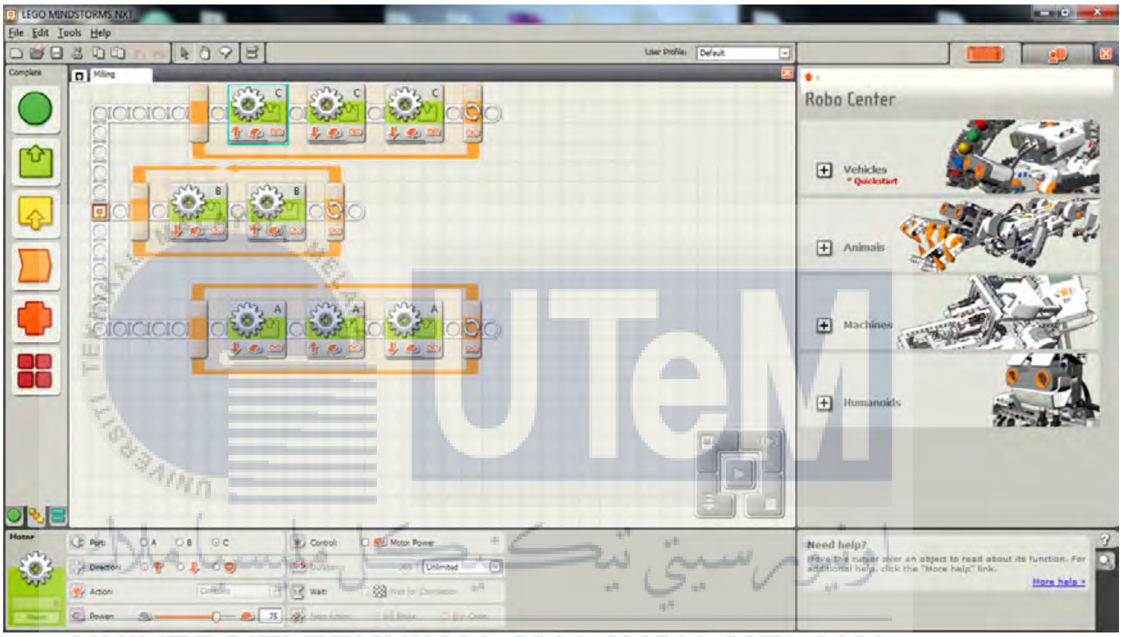
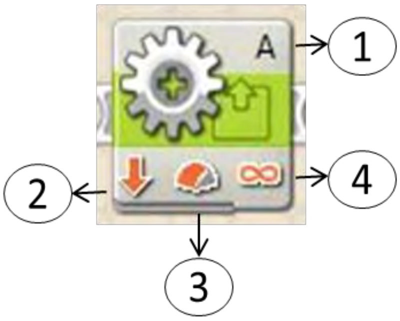
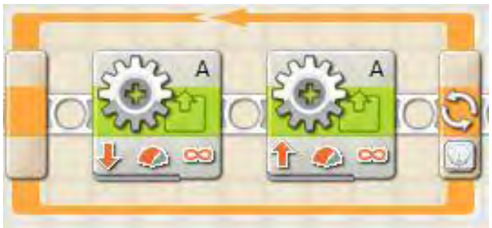
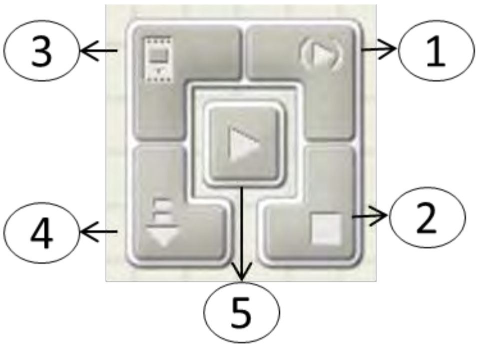


Figure 3.3: Program of Lego Mindstorms NXT software

Table 3.1: Common function that been used in Lego Mindstorms NXT's software

BLOCK	FUNCTION	DESCRIPTION
Move block  	Use to move robot forward and backwards in straight line or following curve.	1. Show the NXT's port that been controlled 2. Show the direction the robot moves 3. Show the power level. The speed might be affected by other condition such as the surface it moving such as moving up and down of a slope 4. Shows the duration property which can be set as unlimited, degrees, rotations or seconds. 5. Show that the motor stop.
Loop block 	Use to repeat the sequences of code	The condition of loop need to be set to end of loop. It can be set as infinity, sensor, time, number of repetitions and a logic signal. Other block can be added in the loop block by drag and drop the block inside the loop block and make the loop's frame expand sideways.

The controller 	To control the communication from computer to NXT I-Brick	1. To download and run the selected program code (use to see the small sequence of the program) 2. To stop a running program 3. Give an access to NXT memory and communication setting 4. To download the program to the NXT. 5. To download and run the whole program to NXT

3.3 MOVEMENT OF 3D MILLING MACHINE USING SIMULINK

MATLAB/Simulink environment is used as the feedback control system. A given controller can be modelled using extensive block library which can be downloaded as an add-on in MATLAB. For example, MATLAB has released the add-on library blocks for Lego Mindstorms NXT and it can be downloaded through the Mathworks Inc. website. The first things that need to be considered are the requirement for the add-on feature. Usually for the latest MATLAB released software, all extensions are available to install.

After the controller had been modelled, it can be tuned and tested. Simulink can discretise the continuous controller and it can generate the C code algorithm for embedded environments.

A control feedback mechanism (PID) is used to control the speed of the motor. The closed loop is implemented in Simulink to tune the PI and generate the functional C code for each of the back motor. The PI receives the different desired voltage and the actual voltage can be calculated by multiplying the speed of motor in rad/s with 57.2958 $(180/\pi)$ in order to obtain value in degree per second. Then, the value will be divided by 116 which are proven to be the best approximation to obtain volts from degree per second in NXT.

The way the NXT determines the motor speed is by dividing the difference between two consecutive readings from the motor encoder by elapsed time of the consecutive readings. The elapsed time will be close to the period of the task as the PI been executed.

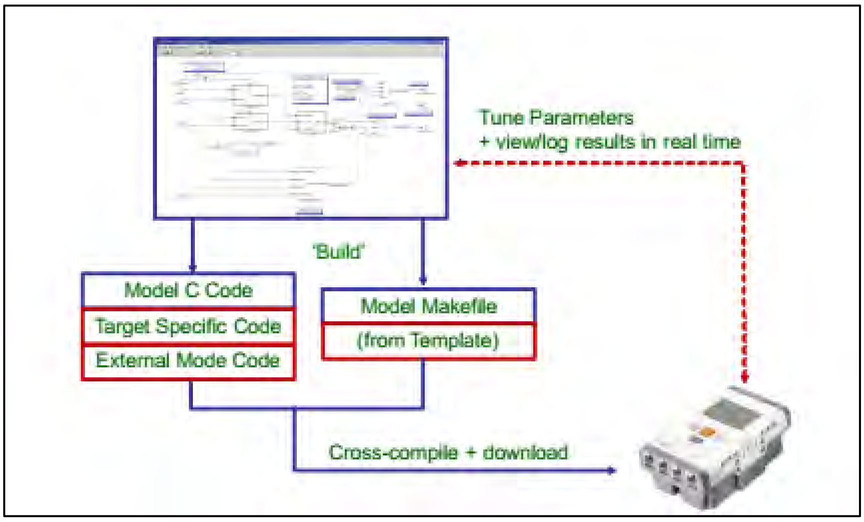


Figure 3.4: Simulink on NXT

3.4 MACHINE PARAMETERS THAT INFLUENCE CUTTING TOOL MOVEMENT

Most of milling machine will operate with a same principle and operation constraints. The most essential machine parameters are cutting speed where the speed of tool engages the works and feed rate where the distance of tool edge move in one cutter revolution. The tool distance are set below the un-machined surface which is axial depth and amount of work surface engaged by the tool call radial depth of cut also are important parameters that need to be considered regardless of the type of milling machine. The capability of the milling machine can be measured by motor voltage, maximum spindle speed and spindle taper size.

Spindle speed will follow the constant speed setting which is from the start of milling process toward the end. As for stability conditions, the lowest spindle speed will retained and the productivity will be affected.

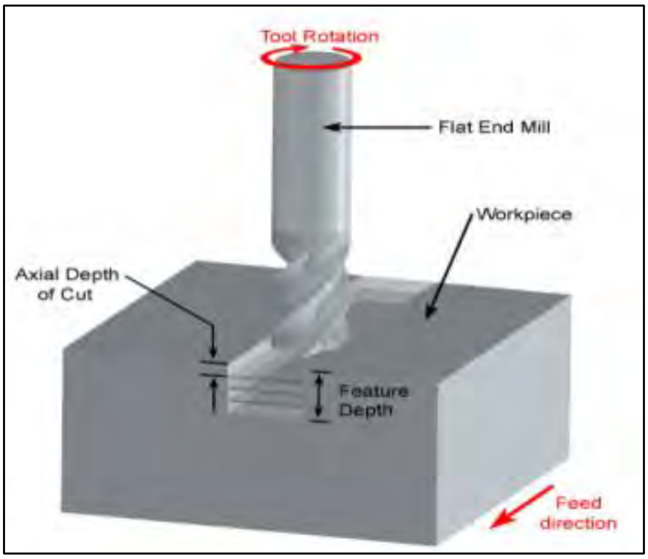


Figure 3.5: Cutting tool movement

Feed rate is the distance of cutting tool which moves through the material per minutes and the rate describes how much the material for each tooth of cutting tool removes per revolutions (rpm). The feed rate is reliant on the desired surface and available power at the spindle which can avoid the stalling cutter of workpiece. It also depends on the inflexibility of machine and tooling setup which include the vibration of machine. Workpiece strength, characteristic of material been cut and chip flow also need to be considered as well as the chip shape.

3.4.1 EQUATION FOR MILLING MACHINE

There are a few equation been determined which show a relationship between cuttings speed (V), spindle speed (S), feed (F), feed per tooth (f), number of rotation (N) and tool bits diameter (D).

Cutting speed; $$V = \frac{\pi D S}{12} \quad (1)$$

Spindle speed; $$S = \frac{12V}{\pi D} \quad (2)$$

Feed; $$F = S.f.N \quad (3)$$

Feed per tooth; $$f = \frac{F}{S.N} \quad (4)$$

From the formula stated above, the relationship between cutting speed, tool bit diameter and spindle speed been established and verified. So, the parameters been determined as the influenced parameter that effect the machine.

3.5 METHOD TO OPTIMIZE 3D MILLING MACHINE

The method are used to solve a large number of experiments that have to carried out when the number of the process parameters increases. So, a special design of orthogonal arrays is use to study the entire parameter space with a small number of experiment.

The minimum number of experiment is determined as:
Minimum experiment $= [(L-1) \times P] + 1 \approx L_9$
where L is number of level and P is the number of parameter.

In order to optimize the process with several performance characteristics, the performance characteristics need to be identified first and process of parameter need to be evaluated and been selected. The number of level for process parameters and possible interactions between the process parameter need to be identified. A suitable orthogonal array needs to be design and process parameter need to be assigned in the array.

Table 3.2: Experimental layout using an L_9 orthogonal array

Experiment number	Tooling movement parameter			Response	
	A	B	C	Error	
	Spindle speed (Volt)	Feed speed (rpm)	Diameter of slot (mm)	Diameter of slot (% error)	Length of slot (% error)
1					
2					
3					
4					
5					
6					
7					
8					
9					

After that, the experiment next need to be conducted based on the array. The optimization method need to be done as the experiment results been analysed. The optimum level of process parameters need to selected and been verified.

3.5.1 RESPONSE SURFACE

After the importance factor and response been identified, the response surface needs to be performed. The equation that is commonly used to model the responses surface is a quadratic model with a cross product term.

$$Y = \beta_0 + \sum_{i=1}^{p} \beta_i X_i + \sum_{i=1}^{p} \sum_{j=i}^{p} \beta_{ij} X_i X_j + \sum_{i=i}^{p} \beta_{ii} X_i^{\,2} \qquad (5)$$

Where; $i \neq j$

β_0= overall means response

β_{ij}= main effects for each factors (i = 1, 2,… p)

β_{ii}= quadratic effect for the ith factors

In order to fit the full second degree of polynomial in the equation (5), it will need more than two level of X variable to determine the high, medium and low level where coded as +1, 0 and -1. With the level of variables, it can model the possible curvature in three dimensions.

Experimental design that is use for response surface been categorise in three type which are the central composite design, the three level fractional factorial design and the D- or I-"optimal" designs. The central composite design is where the design point are the augmentation of two level fractional factorial with points on the faces of the hypercube and at the center of the design space. The three level fractional factorial designs are where the design point is subset of all possible 3^p points in the design space. Meanwhile, the optimal design is where the design point are selected by a design condition such it minimizing or maximizing the uncertainty on the estimation effects. It is useful when it is too many point that been required and has an irregular design space.

The optimization study using response surface also can be divided into three stages. First stage is a preliminary work where the independent parameter need to be determined as well as their level. Next stage is the selection of a suitable experimental design. It also include the prediction and verification of the selected model equation. Last stage is where the response surface and contour plot been obtained according to the independent parameters and responses. From the plot, the optimum value and point can be determined.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this section, some analysis will be issued. The analysis will focuses on designing the model of Lego Mindstorms NXT and run it to the NXT hardware. For each model, the movement of the NXT been recorded and the method of optimization will be conducted in order to optimize the milling machine cutting accuracy based on the parameter involved. Some discussion also will be included in this chapter.

4.2 SIMULINK SUPPORT PACKAGE FOR LEGO MINDSTORMS NXT HARDWARE BLOCK

As for modelling, there are a few functions that are used to model the movement of the NXT servo motor. The functions are shown in Table 4.1 below.

Table 4.1: Function for Lego Simulink Library

BLOCK	FUNCTION
Acceleration Sensor	Measure acceleration along three axes
Battery	Measure voltage of battery in NXT brick
Colour Sensor	Measure colour or light intensity
Compass Sensor	Read magnetic heading of compass sensor
GPS Sensor	Measure latitude and longitude or heading and distance to GPS position
Gyro Sensor	Measure rate of rotation
IR Receiver Sensor	Receive infrared signals from Lego Power Functions IR Speed Remote Control
Light Sensor	Measure light intensity
Receive via Bluetooth Connection	Receive data from another NXT Brick over Bluetooth
Send via Bluetooth Connection	Send data to another NXT Brick over Bluetooth
Sound Sensor	Measure sound level
Speaker	Play tones on speaker in NXT brick
Timer	Measure elapsed time from timer in NXT brick
Touch Sensor	Output state of touch sensor
Ultrasonic Sensor	Measure distance from object in centimetres

4.2.1 DESIGNING THE MODEL FOR SERVO MOTOR MOVEMENT

In this case of studies, there are a few common block that been used such as button, encoder, LCD and motor. Since the sensors of the NXT are will not be use, the function blocks are limited to a few blocks only.

Table 4.2: Common block that been used in this study

BLOCK	FUNCTION
Button	Output state of button on NXT brick
Encoder	Measure encoder rotation from NXT Interactive Servo motor
LCD	Display number on single line of NXT LCD Screen
Motor	Set motor speed and stopping action

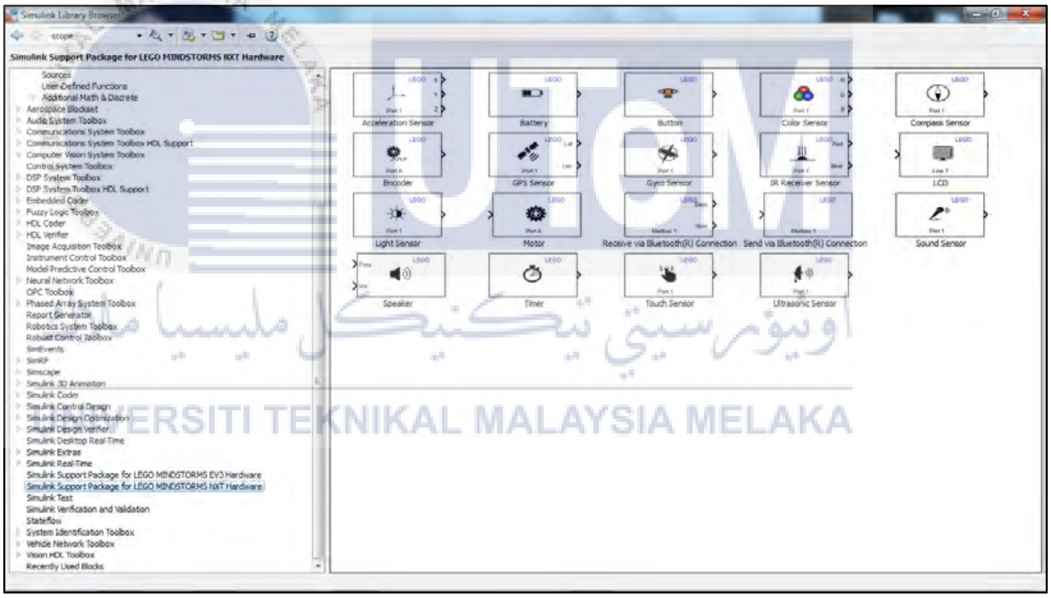


Figure 4.1: Simulink Library Browser

In order to move the servo motor, a simple Simulink model been constructed. Referring to Figure 4.2, this model are used rotate the servo motor by setting the constant value as the input of the motor. The input value can control the motor speed and also its direction. The higher the value of constant, the faster the motor will rotate. Positive and negative sign indicate whether it rotate clockwise or counter clockwise. In order to stop the motor, constant value of 0 is used. The stopping parameter also can be choose which is brake (stop immediately) of coast (stop gradually).

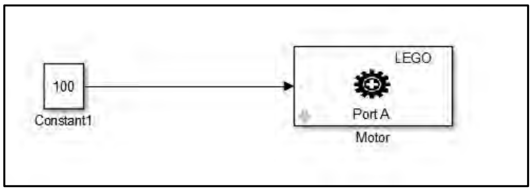


Figure 4.2: Model for rotating servo motor

Figure 4.3 show the model using encoder and LCD block. Encoder block is used to measure encoder rotation from NXT Servo Motor and LCD will display the value of rotating motor servo motor. The servo motor in Port A can control the speed of the servo motor in Port B by rotate the servo motor Port A. The value of rotating motor in Port B will be displayed on the top of the NXT I-Brick screen.

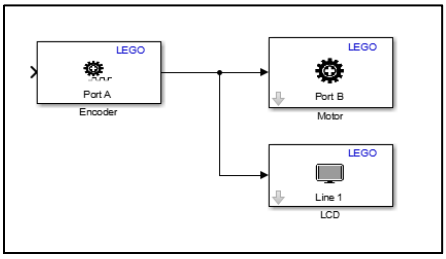


Figure 4.3: Model for rotating servo motor by rotating another servo motor

Figure 4.4: Value of Port B motor displayed at the NXT I-Brick

After the model been constructed, there are some configurations that need to be set up before it been run to the hardware. It needs to be changed to Lego Mindstorms NXT first or else the model will not be run.

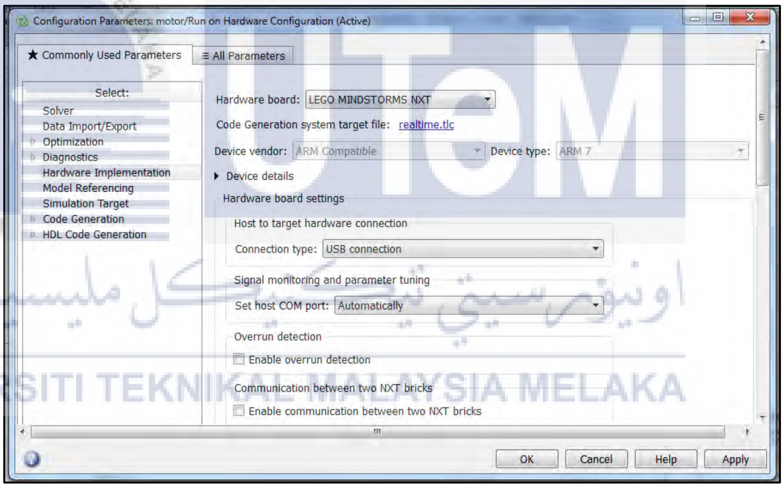


Figure 4.5: Lego NXT setting before deploy to hardware

4.2.2 RUN MODEL TO THE NXT I-BRICK

The models need to be tested and run by NXT I-Brick so that the result can be observed. Most of the model been tested and it can be stated that many of them can not completely cut the flower foam without having stuck at the middle of the process of cutting. This might happen due to the spindle speed that rotate the motor are not high enough to rotate the tool bit. From the observation, it also happen because of the position of the flower foam does not fix at the platform. The flower foam tends to move and resulting to inaccuracy of the cutting foam.

Figure 4.6: Result of the cutting foam

From another observation, it can be stated that the y-axis of the machine are quite difficult to handle because of there is no platform for the servo motor to move accurately. After some testing and comparison on each axes been done, it can be observed that the speed of servo motor in y-axis is slower compare to the speed in the z-axis when it running on the machine. This might due to the load that servo motor in y-axis need to support since it has a flexible base that use a conveyor concept and tend to slide on its platform as there are present of frictional force between the servo motor, the wall between the wheel and the platform. The servo motor tends to stuck at the middle of cutting process and results a poor result of cutting foam.

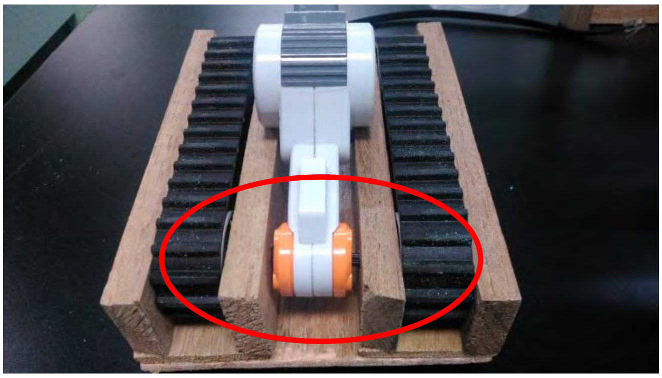


Figure 4.7: Servo motor in the y-axis of the machine

4.3 EXPERIMENTAL SET UP

In order to optimize the milling machine, all the parameter that been discussed need to be tested on the 3D milling machine itself first. The three parameter used are motor voltage, cutting speed and tool bit diameter. The experiment was conduct by using three different motor voltages, four different cutting speeds and three different tool bit diameter. Since the power of motor are depending on the power of battery used, so there are some limitations on choosing the suitable power of battery. The powers for motor has been used are 3, 6 and 9 Volt while the cutting speeds used are 20, 30, 40 and 50 RPM. The cutting speed can be adjusted from range zero to hundred RPM (0-100 RPM) in the Simulink model. The tool bit diameter that been chosen 3 mm, 4 mm and 5 mm.

Table 4.3: Experimental value for each parameter

MOTOR VOLTAGE (V)	TOOL BIT DIAMETER (mm)	CUTTING SPEED (RPM)
3	4	20
		30
		40
		50
6	5	20
		30
		40
		50
9	6	20
		30
		40
		50

The data obtained is the response of the machine in measurement of length of cut and also the diameter of slot. The cutting length and depth are fixed for every experiment which are about 40 mm and 5 mm respectively. After the flower form been cut, the length and diameter of the slot been measured and the error been calculated in order to get the percentage of error in the diameter and length of the slot that been cut.

$$Percentage\ of\ error(\%) = \frac{measured\ value - desired\ value}{desired\ value} \times 100\%$$

The data obtained are based on the cutting of flower form in z-axis only. This is because the z-axis has a better platform which is using two linear bearing and 3D printed vertical gear which has a stable structure for the motor to rotate instead of using the y-axis of the machine.

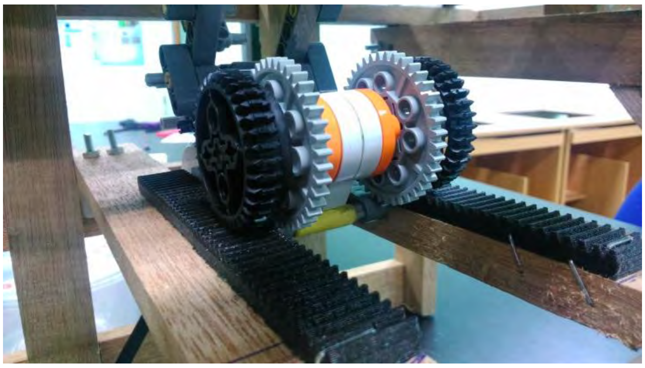


Figure 4.8: Platform of z-axis to rotate and move

4.4 EXPERIMENTAL DATA FOR MILLING MACHINE

Tool bit diameter : 3 mm

Length of slot : 40 mm

Table 4.4: Experimental data for tool bit diameter of 3 mm

MOTOR VOLTAGE (V)	SPEED (RPM)	TIME (s)	DIAMETER SLOT (mm)	LENGTH SLOT (mm)
3	20	1.1	3.2	41
	30	0.6	3.1	41
	40	0.3	3.0	41
	50	0.1	3.0	42
6	20	1.3	3.3	41
	30	0.4	3.2	42
	40	0.3	3.0	41
	50	0.1	3.0	41
9	20	1.2	3.2	41
	30	0.5	3.2	42
	40	0.4	3.1	42
	50	0.1	3.0	43

Table 4.5: Percentage of error for tool bit diameter of 3 mm

MOTOR VOLTAGE (V)	SPEED (RPM)	TIME (s)	DIAMETER SLOT (% error)	LENGTH SLOT (% error)
3	20	1.1	6.7	2.5
	30	0.6	3.3	2.5
	40	0.3	0.0	2.5
	50	0.1	0.0	5.0
6	20	1.3	10.0	2.5
	30	0.4	3.3	5.0
	40	0.3	0.0	2.5
	50	0.1	0.0	2.5
9	20	1.2	6.7	2.5
	30	0.5	6.7	5.0
	40	0.4	3.3	5.0
	50	0.1	0.0	7.5

Tool bit diameter : 4 mm

Length of slot : 40 mm

Table 4.6: Experimental data for tool bit diameter of 4 mm

MOTOR VOLTAGE (V)	SPEED (RPM)	TIME (s)	DIAMETER SLOT (mm)	LENGTH SLOT (mm)
3	20	1.3	4.1	40
	30	0.7	4.1	41
	40	0.4	4.1	41
	50	0.2	4.1	42
6	20	1.2	4.0	41
	30	0.5	4.0	41
	40	0.3	4.0	42
	50	0.1	4.0	42
9	20	1.1	4.1	41
	30	0.6	4.1	41
	40	0.4	4.0	41
	50	0.1	4.0	41

Table 4.7: Percentage of error for tool bit diameter of 4 mm

MOTOR VOLTAGE (V)	SPEED (RPM)	TIME (s)	DIAMETER SLOT (% error)	LENGTH SLOT (% error)
3	20	1.3	2.5	0.0
	30	0.7	2.5	2.5
	40	0.4	2.5	2.5
	50	0.2	2.5	5.0
6	20	1.2	0.0	2.5
	30	0.5	0.0	2.5
	40	0.3	0.0	5.0
	50	0.1	0.0	5.0
9	20	1.1	2.5	2.5
	30	0.6	2.5	2.5
	40	0.4	0.0	2.5
	50	0.1	0.0	2.5

Tool bit diameter : 5 mm

Length of slot : 40 mm

Table 4.8: Experimental data for tool bit diameter of 5 mm

MOTOR VOLTAGE (V)	SPEED (RPM)	TIME (s)	DIAMETER SLOT (mm)	LENGTH SLOT (mm)
3	20	1.1	5.3	40
	30	0.4	5.3	41
	40	0.3	5.2	41
	50	0.1	5.2	41
6	20	1.2	5.2	42
	30	0.4	5.2	42
	40	0.2	5.2	42
	50	0.1	5.1	43
9	20	1.2	5.3	41
	30	0.6	5.3	41
	40	0.4	5.2	42
	50	0.2	5.2	42

Table 4.9: Percentage of error for tool bit diameter of 5 mm

MOTOR VOLTAGE (V)	SPEED (RPM)	TIME (s)	DIAMETER SLOT (% error)	LENGTH SLOT (% error)
3	20	1.1	6.0	0.0
	30	0.4	6.0	2.5
	40	0.3	4.0	2.5
	50	0.1	4.0	2.5
6	20	1.2	4.0	5.0
	30	0.4	4.0	5.0
	40	0.2	4.0	5.0
	50	0.1	2.0	7.5
9	20	1.2	6.0	2.5
	30	0.6	6.0	2.5
	40	0.4	4.0	5.0
	50	0.2	4.0	5.0

From the data obtained, it shows some fluctuation in percentage error in length and diameter between each motor voltage and cutting speed regarding to each size of tool bits. This might due to uncertainty of the structure of milling machine such as the stability of the work table, the rotation of tool bit which a little bit off from its axis and the movement of the work table due to platform of the axis.

The cutting speed also will influence the time taken to finish the cutting process. It show a linear relationship between the two factors. As the speed increase, the time also will become faster as shown in Table 4.10 and Figure 4.9 below.

Table 4.10: Average time to cut the flower for 4 different cutting speeds

SPEED (RPM)	AVERAGE TIME (s)
20	1.19
30	0.52
40	0.31
50	0.12

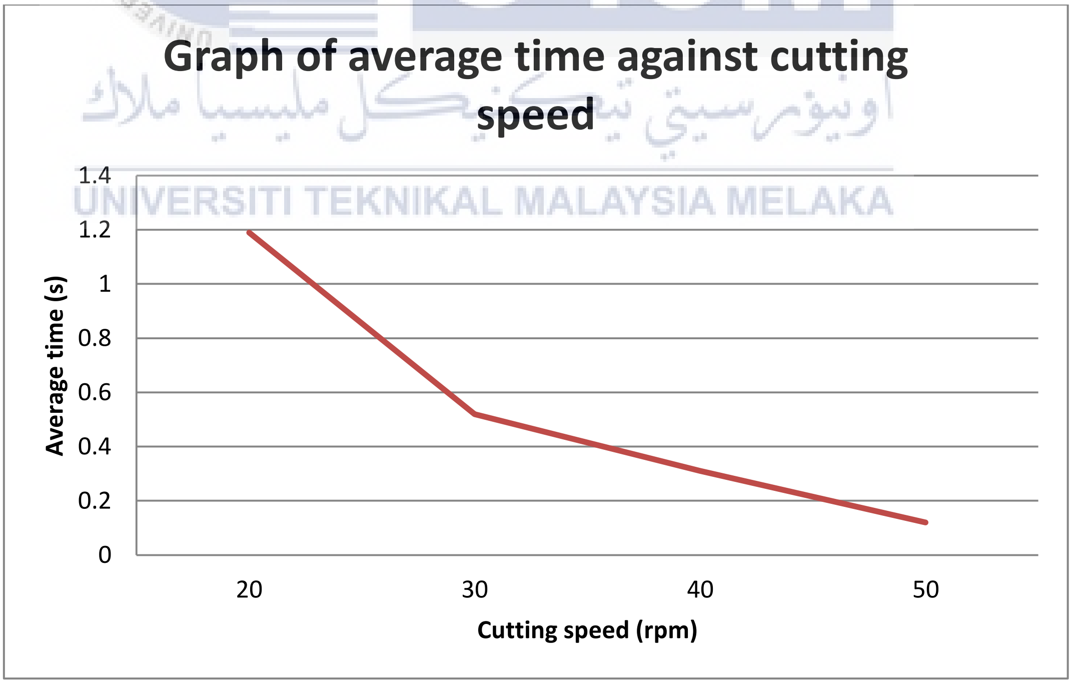


Figure 4.9: Graph of average time against cutting speed

4.5 OPTIMIZATION THE RESPONSE USING MINITAB

Basically, two levels factorial are designed to study the region response between 2 factors. However, the weakness is it not capable to quantify and detecting the curvature in 3 responses. So, to fit in the 3 responses, the design of experiment of responses surface design are used in order to resolving the curvature in responses which in a plot of 3D curvature.

Based on the experimental data obtain, the data been inserted in the MINITAB worksheet and some analysis been conducted in order to get the optimal values of the parameter which is the response are percentage of error in diameter and length of slot. As the responses is the percentage of error, the factor that been effect the error is the voltage of the motor (V) and the cutting speed (RPM).

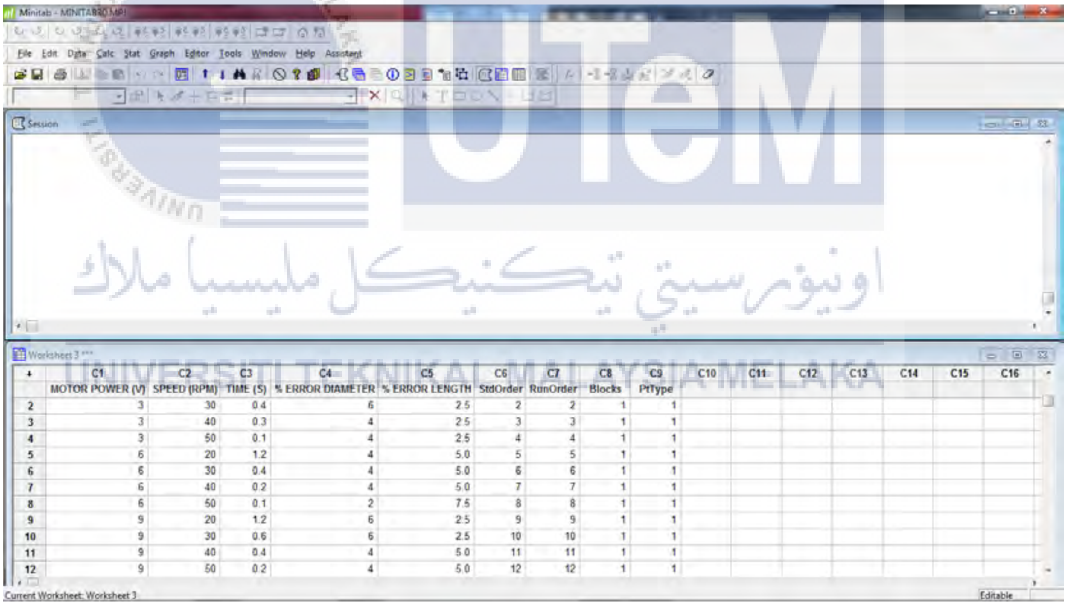


Figure 4.10: Working environment of the MINITAB 16

4.5.1 RESULT FOR THE RESPONSE SURFACE

Design of Experiment (DOE) is an effective method to minimize the number of experimental run while maximize the amount of information gain from a study and minimize the amount of data to be collected for each parameter.

The basic problems that usually use the design of experiment method is where the problem need to evaluate a system with some process input called factors in order to measure the output called responses.

As for this case, the factors is the parameter where influences the cutting accuracy such as motor voltage, cutting speed and tool bit diameter. The responses are the percentage or error in length and diameter of the slot as well as the time taken to complete the cutting process.

The experimental data been analysed in the MINITAB 16 where the function of Design of Experiment (DOE) been used and the result in term of response surface will be generated as graphs below.

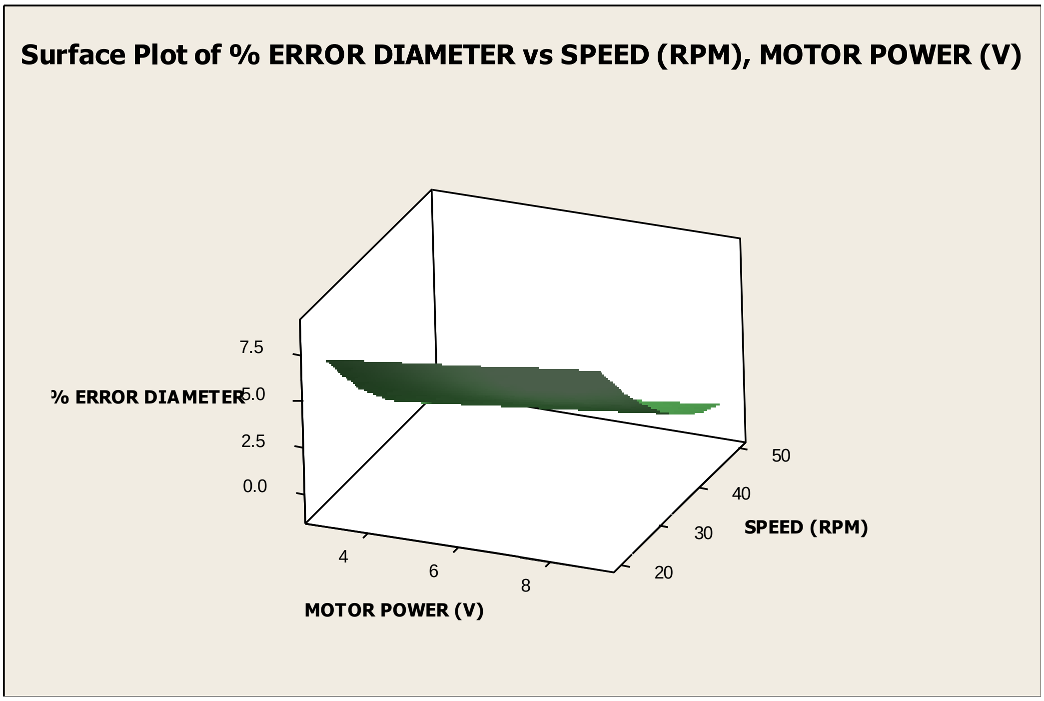


Figure 4.11: Surface plot of motor voltage vs speed vs diameter error for diameter of 3 mm

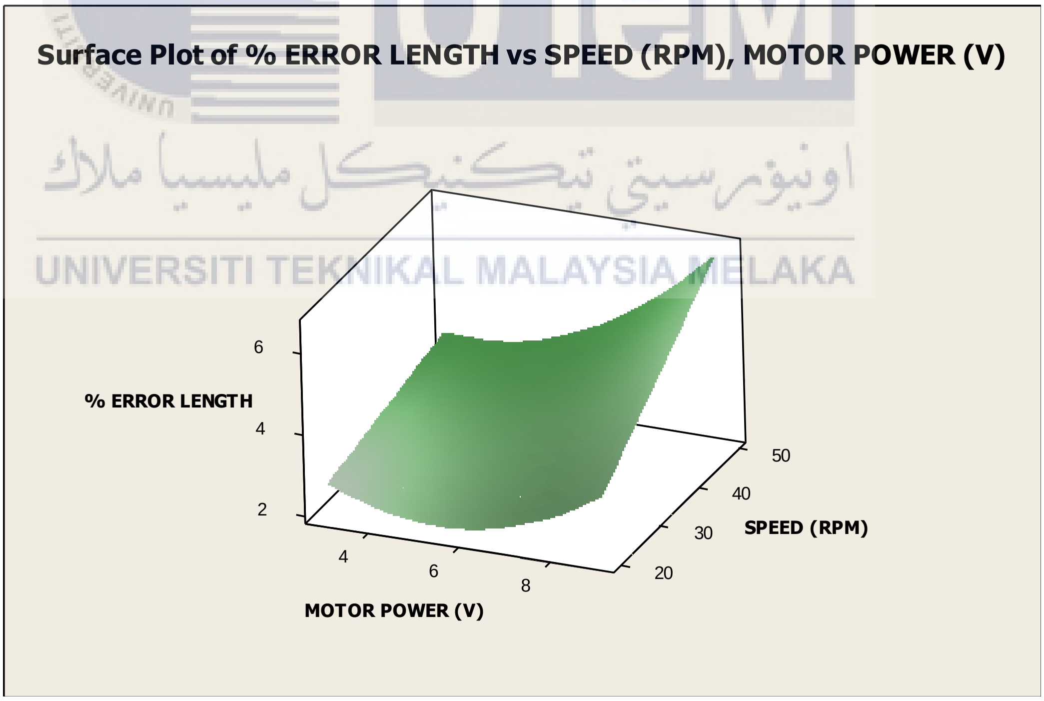


Figure 4.12: Surface plot of motor voltage vs speed vs length error for diameter of 3 mm

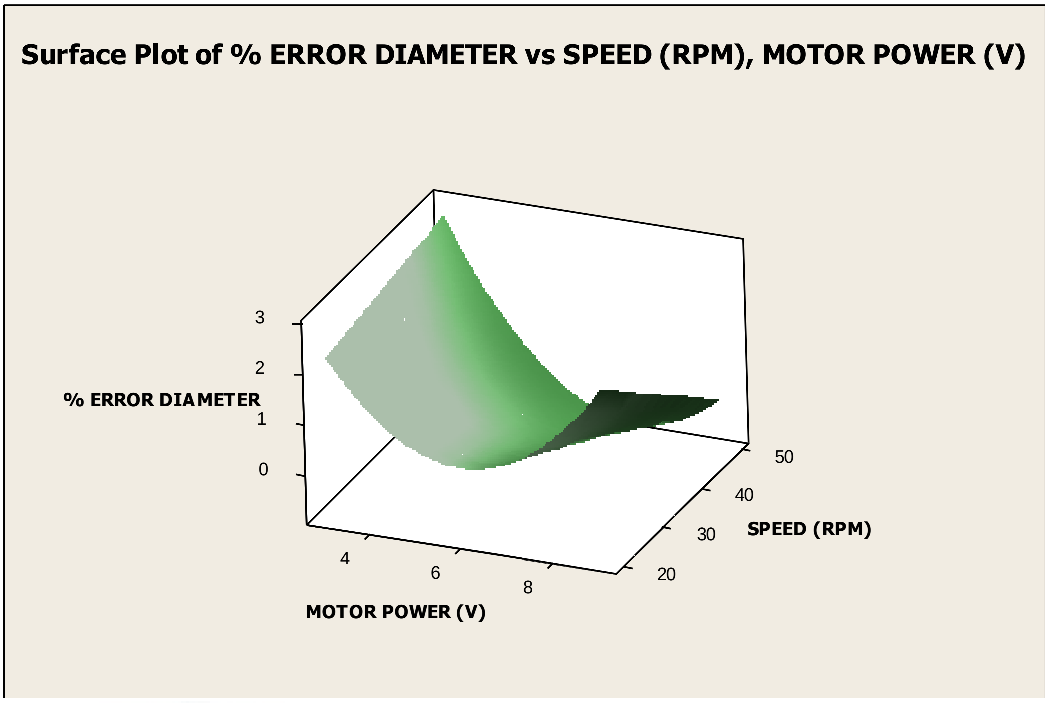


Figure 4.13: Surface plot of motor voltage vs speed vs diameter error for diameter of 4 mm

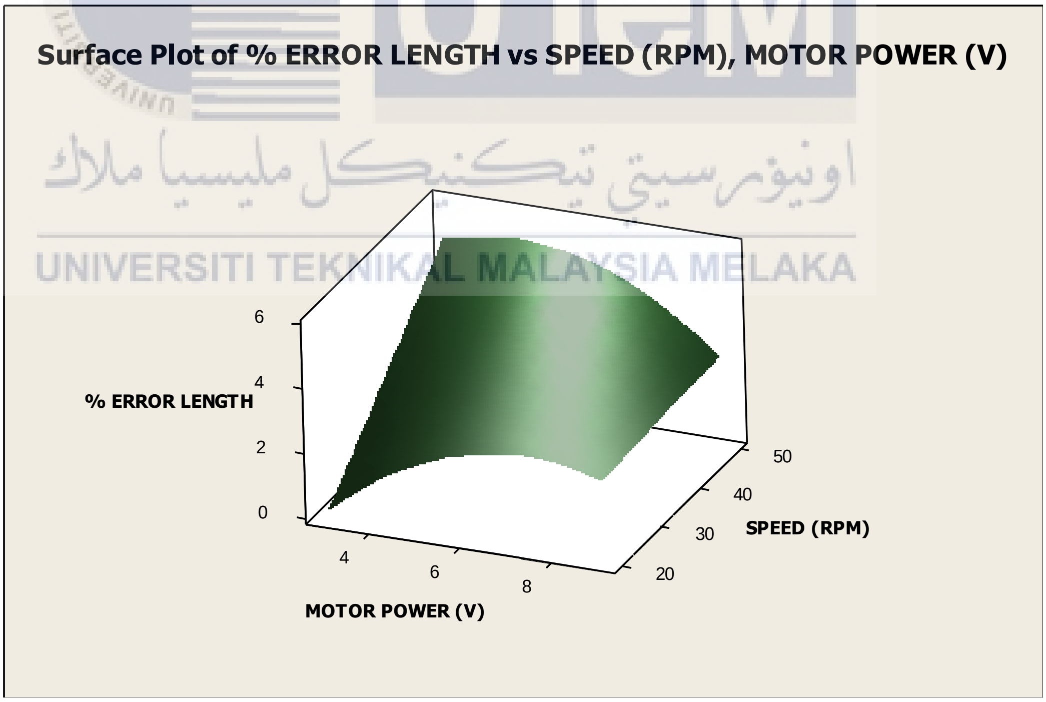


Figure 4.14: Surface plot of motor voltage vs speed vs length error for diameter of 4 mm

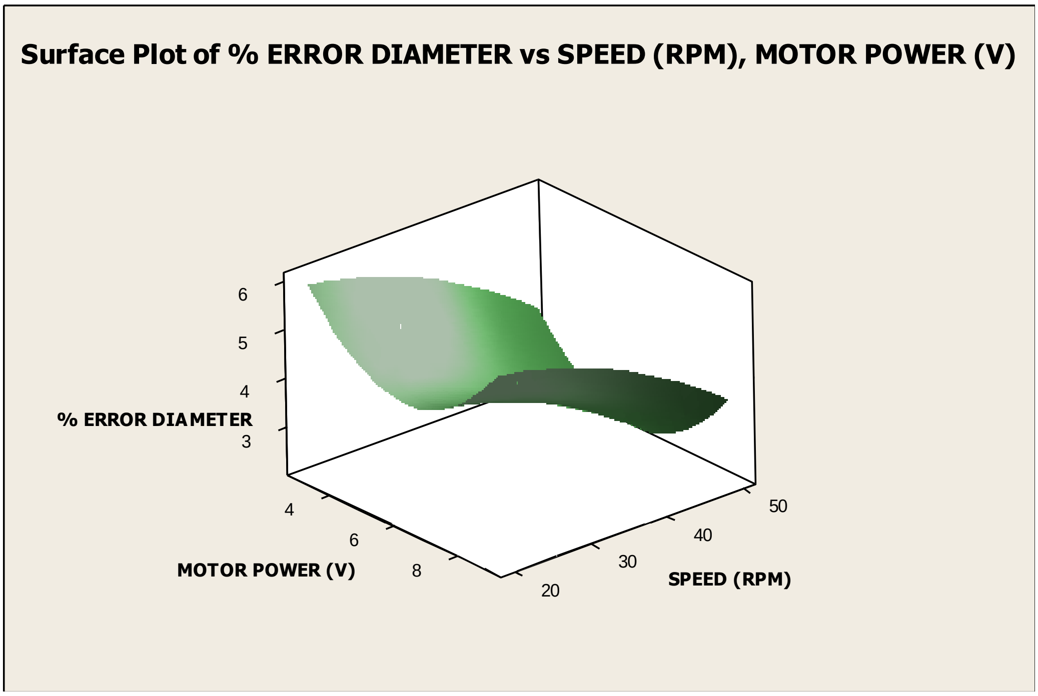


Figure 4.15: Surface plot of motor voltage vs speed vs diameter error for diameter of 5 mm

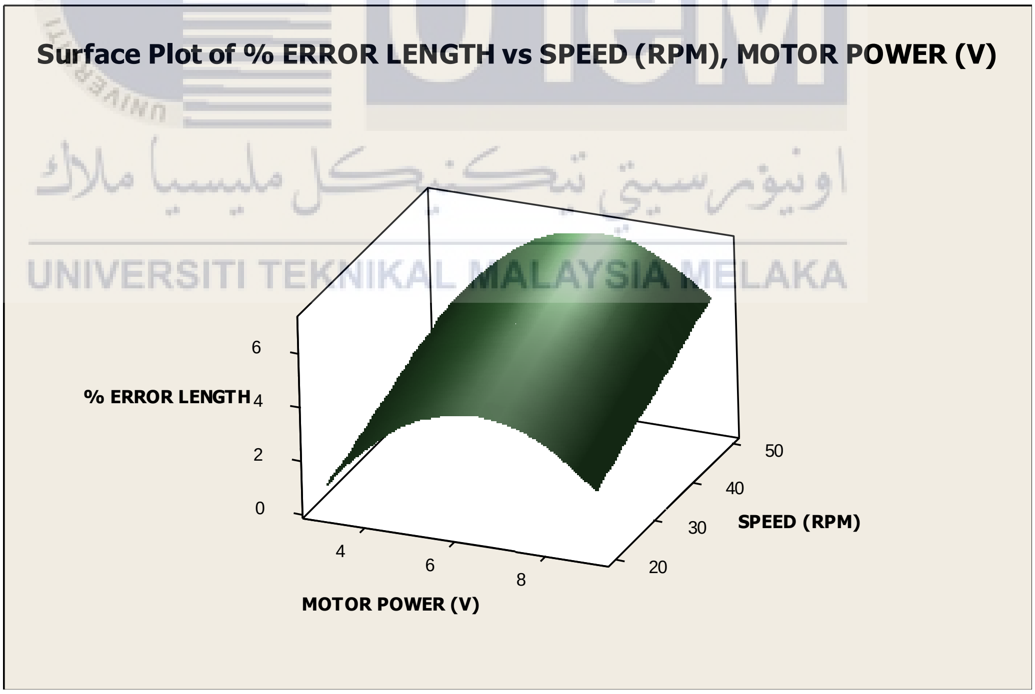


Figure 4.16: Surface plot of motor voltage vs speed vs length error for diameter of 5 mm

4.5.2 RESULT FOR THE RESPONSE OPTIMISER

From the graph of response surface, the function of response optimiser can be done by defining the target of the desired response. Response optimiser is a method used to analyse and determine the optimization of a set of responses. It is used to minimize the response, target the responses and also maximise the response. As for the cutting tool bit of each diameter, one optimum result are generated in order to achieve zero percentage of error in length and diameter is show in the graphs below.

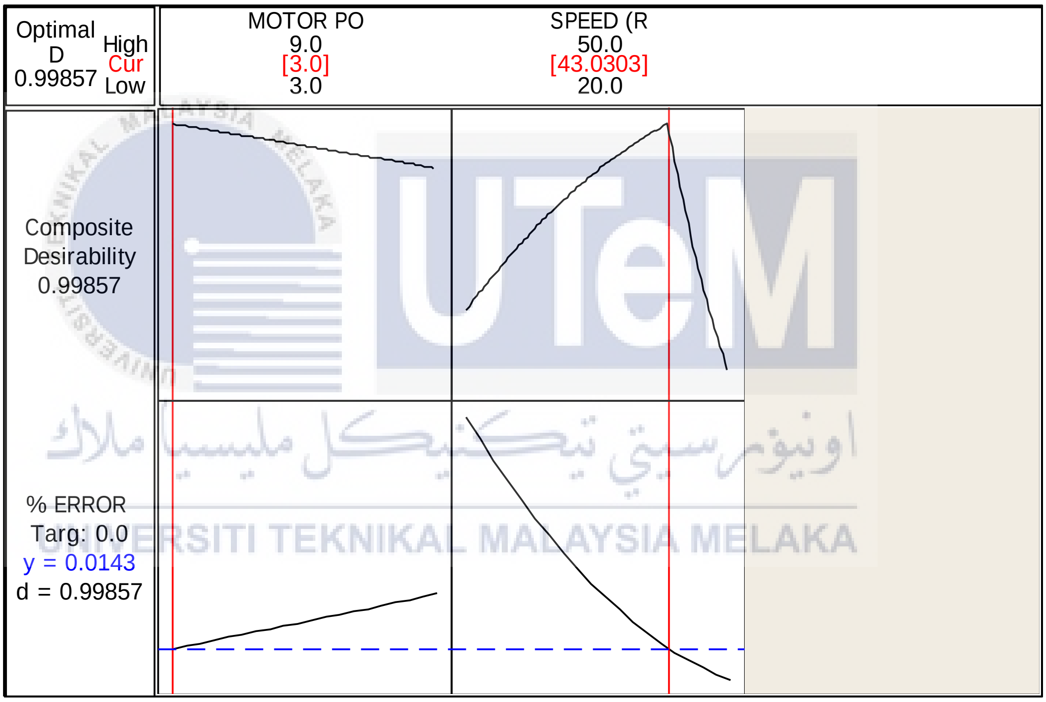


Figure 4.17: Response optimiser for optimal speed and motor voltage for zero percentage of diameter (3 mm)

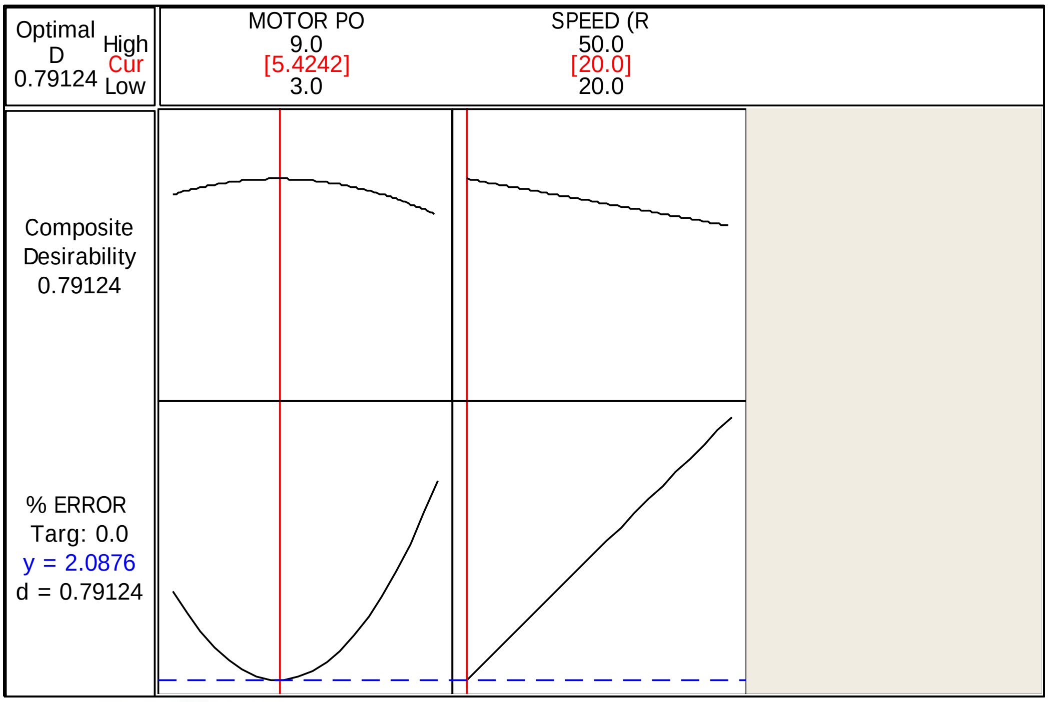


Figure 4.18: Response optimiser for optimal speed and motor voltage for zero percentage of length (3 mm)

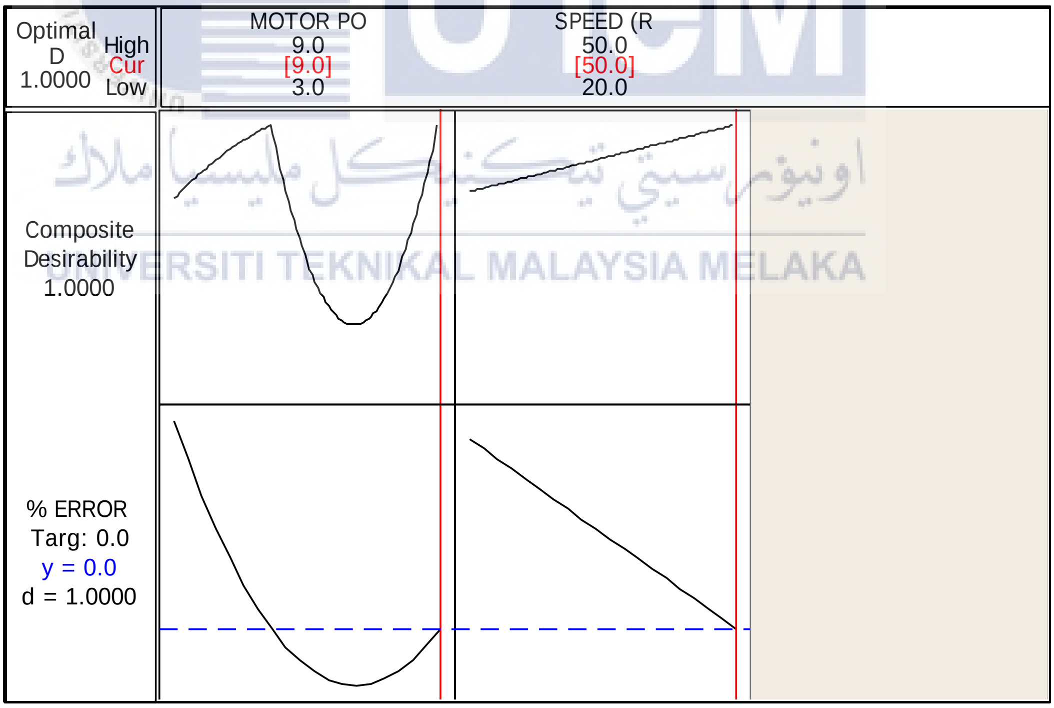


Figure 4.19: Response optimiser for optimal speed and motor voltage for zero percentage of diameter (4 mm)

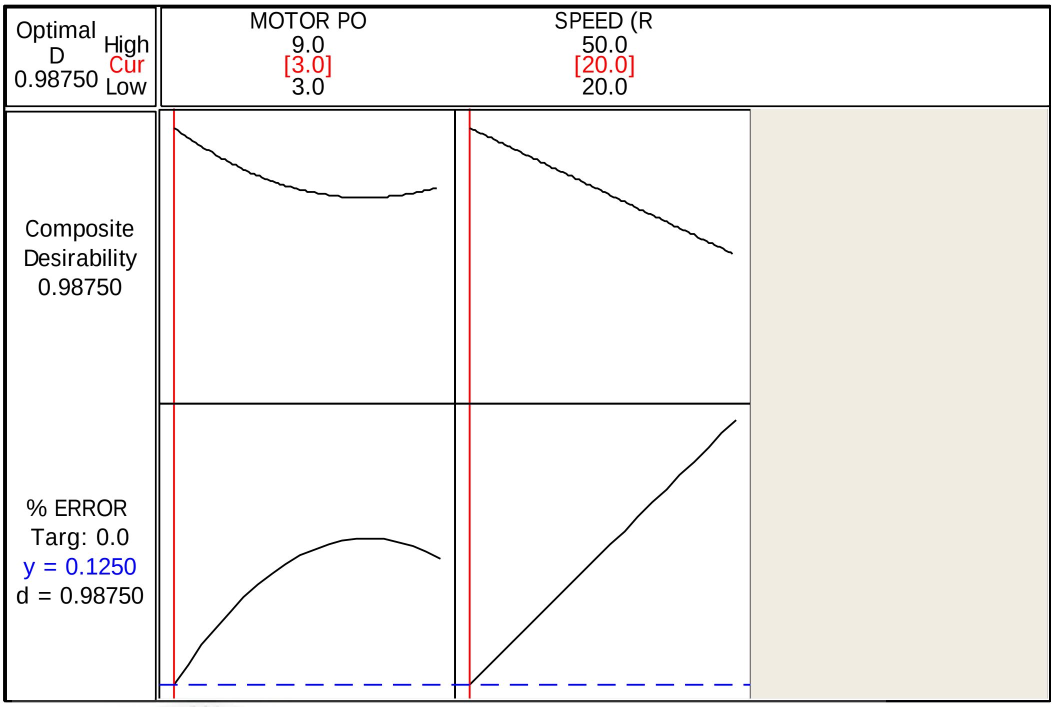


Figure 4.20: Response optimiser for optimal speed and motor voltage for zero percentage of length (4 mm)

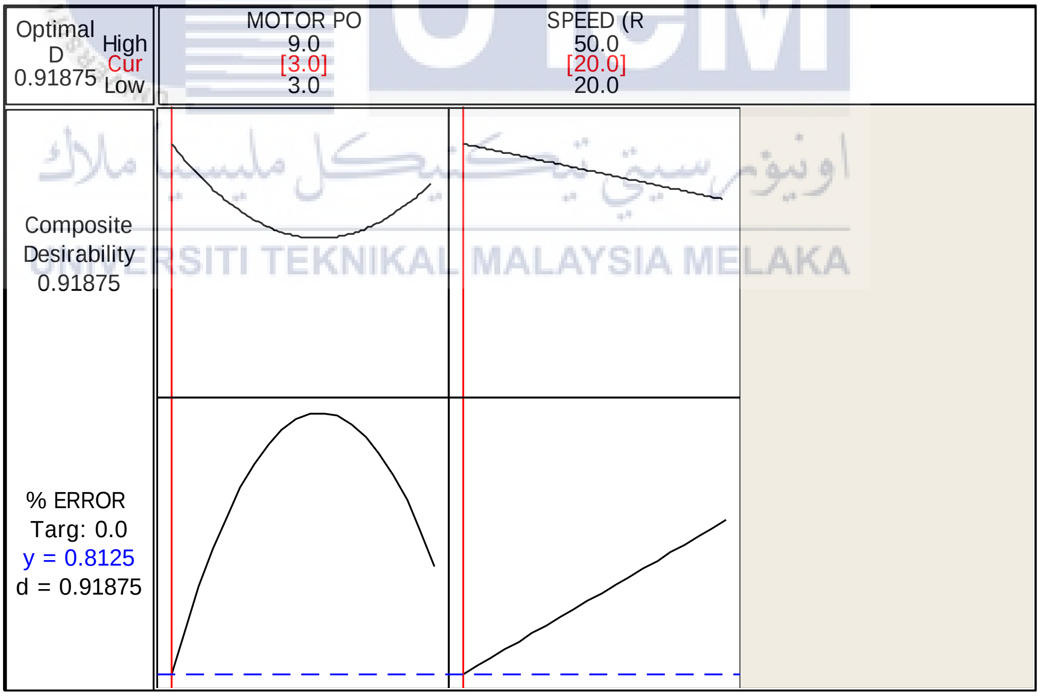


Figure 4.21: Response optimiser for optimal speed and motor voltage for zero percentage of diameter (5 mm)

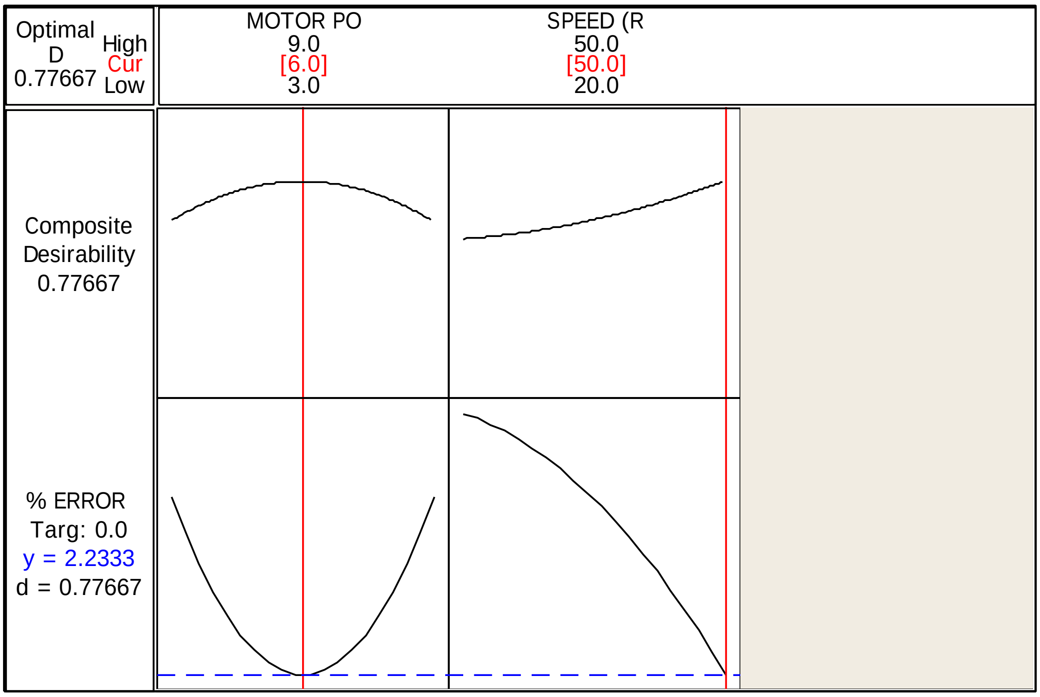


Figure 4.22: Response optimiser for optimal speed and motor voltage for zero percentage of length (5 mm)

To summarize the result, each cutting tool diameter has different responses in order to get a zero percentage of length and also diameter. It can be concluded as Table 4.10 below.

Table 4.11: Optimization response for each tool bit diameter

TOOL BIT DIAMETER (mm)	MOTOR VOLTAGE (V)	CUTTING SPEED (RPM)	CONDITION
3	3.00	43.03	Zero percentage of diameter error
	5.42	20.00	Zero percentage of length error
4	9.00	50.00	Zero percentage of diameter error
	3.00	20.00	Zero percentage of length error
5	3.00	20.00	Zero percentage of diameter error
	6.00	50.00	Zero percentage of length error

For the tool bit diameter of 3 mm, the optimimum value of motor voltage is 3 V and the cutting speed is 43.03 rpm in order to achieve the zero percentage of diameter error and for zero percentage error in length, the motor voltage that need to be use is 5.42 V with cutting speed of 20 rpm

.

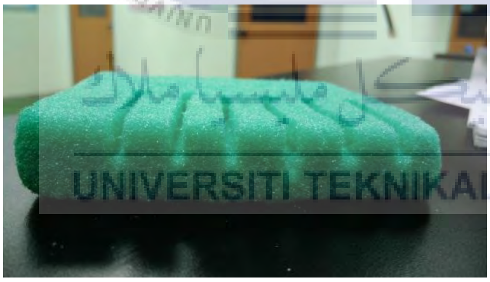
As for tool bit diameter of 4 mm, the motor voltage need to be use is 9 V and cutting speed of 50 rpm to achieve zero percentage of error in diameter while to achieve zero percentage error in length, motor voltage need to be use is 3 V with 20 rpm of cutting speed.

To achieve the optimum value in 5 mm tool bit diameter, 3 V of motor voltage and 20 rpm of cutting speed need to be use so that the percentage of error in diameter is zero. For zero percentage of error in length, 6 V motor power is use with 50 rpm of cutting speed.

4.6 TESTING ON 3D MILLING MACHINE

After getting the optimisation result, the shortened data been tested to verified the data whether it obey the result or not. There are too many unexpected factor that occurs and need to be considered since the results shows some error in cutting the slot such as the stability of the machine, the movement of platform axis and rotation of the cutting tool bit. So the result tends to change and give uncertainty to the length and diameter of cutting the slot.

The vibration produce by the rotation of the tool bit also effect the movement of the axis. This resulting the diameter of slot is bigger that it original diameter of tool bit.



(a)

(b)

(c)

Figure 4.23: Result of the testing

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As this research been conducted, the operation of 3D milling machine has been discovered using Lego Mindstorms NXT and also MATLAB/Simulink software. The major machine parameter that influenced the cutting tool movement also been identified which is motor voltage, cutting speed and diameter of tool bit whilw the minor parameter are reffering to the stability of the machine, vibration produce by cutting tool and rotation of the tool bit.

The experiment also been conducted in order to get the experimental data where all the parameter involved are tested and the responses in term of percentage of error in length of cut and diameter of slot are calculated. The highest percentage of error in length of slot is 7.5 percent by using 3 mm and 5 mm diameter tool bit. The highest percentage of error in diameter of slot is 10 percent which is by using 3 mm of tool bit diameter. This is might due to uncontrollable factors such as stability of the machine, movement of platform axis and rotation of the cutting tool bit.

As to optimize the response of this parameter, the result of percentage of error in length and diameter need be analyse and result using MINITAB software also been presented in order to analyse the effect between those parameter and also to get the optimum speed and motor voltage. From there, an optimum result been generated and the operation of milling machine can be improved.

5.2 RECOMMENDATION

Since there are a lot of unexpected factors that affect the cutting result of this machine, it is recommended that the future research to:

5.2.1 Redesign this machine by taking all factors that can affect the cutting result such as vibration, platform axis and others.

5.2.2 Investigate regarding to the factors of the vibrations and also way to solve it.

5.2.3 Use sensors to stop the movement of the table when there is no supervisor presence.

5.2.4 Use the adjustable motor that can perform various motor speed and power so the process of cutting can be performs according to desired motor speed depending to the type and diameter of tool bit.

5.2.5 Able to mill various cutting pattern.

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