PID CONTROLLER APPLICATION ON CUTTING TOOL VIBRATION IN MILLING PROCESS

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I certify that the project entitled “PID CONTROLLER APPLICATION CUTTING TOOL VIBRATION IN MILLING PROCESS” is written by Mohd Faizol Hafiz Bin Ab Majid. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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I hereby declare that we have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

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

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Dedication to

my late beloved dad, Ab. Majid Bin Abdullah, my mom Tuan Maimun Bt Tuan Endut that give a lot of support to me, my friends that fighting alongside me and my supervisor that help me and giving me ideas in complete this thesis

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All praise to supreme almighty Allah s.w.t. The only creator, cherisher, sustainer and efficient assembler of the world and galaxies whose blessings and kindness, give blessing and health, enabled me to accomplish this project successfully. Allah will bless you.

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ABSTRACT

The control system was used to suppress vibration chatter from machining process. Dynamic and mathematically model had derived from the one degree of freedom (1-DOF) for the cutting tool. Control system that been used in this project was passive system and active system. The passive system used to show the instability system and active system had been introduces to control the system. The PID (proportional-integral-derivative) was been used in this project.. To complete the active system, linear actuator had been used to counter the vibration occur. The simulation had been run using MATLAB/SIMULINK® software. Comparative study had been done between passive and active control system. From comparative study, PID showed an effectiveness result that suppresses vibration during machining process. PID produced small error compare to passive system (uncontrolled system). PID control was found suitable in control system for machining.

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ABSTRAK

Satu sistem kawalan telah digunakan untuk mengurangkan getaran dari proses pemesinan. Model dinamik dan model matematik telah diperolehi daripada satu darjah kebebasan (1-DOF) bagi alat pemotongan . Sistem kawalan yang digunakan dalam projek ini adalah sistem pasif dan sistem aktif. Sistem pasif yang digunakan untuk menunjukkan ketidakstabilan system dan sistem aktif telah memperkenalkan untuk mengawal getaran yang berlaku pada sistem ini. PID (proporsional-integral-derivatif) telah digunakan dalam projek ini. Untuk melengkapkan sistem aktif, linear actuator telah digunakan untuk melawan getaran yang berlaku. Simulasi telah dijalankan menggunakan perisian MATLAB / Simulink ®. Kajian perbandingan telah dilakukan di antara sistem kawalan pasif dan aktif. Hasil daripada perbandingan yang dijalankan, PID menunjukkan hasil keberkesanan dengan mengurangkan getaran yang berlaku semasa proses pemesinan. PID hanya menghasilkan getaran yang kecil berbanding dengan sistem pasif (sistem yang tidak terkawal). Kawalan PID telah didapati sesuai digunakan sebagai sistem kawalan bagi pemesinan.

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F	Force
mm	Millimeter
c	Damper
m	Mass
k	Stiffness of spring
k_p	Proportional gain
k_i	Integral gain
k_d	Derivative gain
x	Angular displacement
$\dot{x}$	Angular velocity
$\ddot{x}$	Angular acceleration
T	time
F_x	Force x-axis
F_y	Force y-axis
G(s)	Transfer fuction (controller)
Ks	transfer function (sensor)

LIST OF ABBREVIATIONS

S.D.O.F	Single Degree Of Freedom
P	Proportional
I	Integral
D	Derivative
PI	Proportional-Derivative
PID	Proportional-Integral-Derivative
FYP	Final Year Project
CVD	Dynamic Compound Deposition
PVD	Physical Vapor Deposition
EDM	Electrical Discharge Machining

CHAPTER 1

INTRODUCTION

1.1 GENERAL BACKGROUND

1.1.1 Machining

Conventional machining is a form of subtractive manufacturing, in which a collection of material-working processes utilizing power-driven machine tools, such as saws, lathes, milling machines, and drill presses. Machining process is used with a sharp cutting tool to physically remove material to achieve a desired geometry. Machining is a part of the manufacture of many metal products, but it can also be used on materials such as wood, plastic, ceramic, and composites. In modern day, machining is carried out by computer numerical control (CNC). Computers are used to control the movement and operation of mills, lathes, and a variety of other cutting machines.

The precise in machining has evolved over the past two centuries as technology has advanced. During the Machine Age, it referred to the traditional machining processes, such as turning, boring, drilling, milling, broaching, sawing, shaping, reaming, tapping and grinding.

The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planing, boring, broaching and sawing.

Turning operations are operations that rotate the workpiece as the primary method of moving metal against the cutting tool. Lathes are the principal machine tool used in turning. In turning, a cutting tool with a single cutting edge is used to remove material from a rotating workpiece to generate a cylindrical shape. The speed motion in turning is provided by the rotating workpart, and the feed motion is achieved by the cutting tool moving slowly in a direction parallel to the axis of rotation of the workpiece.

Milling operations are operations in which the cutting tool rotates to bring cutting edge to bear against the workpiece. Milling machines are the principal machine tool used in milling. A rotating tool with multiple cutting edges is moved slowly relative to the material to generate a plane or straight surface. The direction of the feed motion is perpendicular to the tool's axis of rotation. The speed motion is provided by the rotating milling cutter. The two basic forms of milling are:

i. Peripheral milling
ii. Face milling

Drilling operations are operations in which holes are produced or refined by bringing a rotating cutter with cutting edges at the lower extremity into contact with the workpiece. Drilling operations are done primarily in drill presses but sometimes on lathes or mills. Drilling is used to create a round hole. It is accomplished by a rotating tool that is typically has two or four cutting edges. The tool is fed in a direction parallel to its axis of rotation into the workpart to form the round hole

A finished product would meet the specifications set out for that workpiece by engineering drawings or blueprints. For example, a workpiece may be required to have a specific outside diameter. A lathe is a machine tool that can be used to create that diameter by rotating a metal workpiece, so that a cutting tool can cut metal away, creating a smooth, round surface matching the required diameter and surface finish.

Machining requires attention to many details for a workpiece to meet the specifications set out in the engineering drawings or blueprints. Besides the obvious problems related to correct dimensions, there is the problem of achieving the correct surface finish or surface smoothness on the workpiece. The inferior finish found on the machined surface of a workpiece may be caused by incorrect clamping, a dull tool, or inappropriate presentation of a tool. Frequently, this poor surface finish, known as chatter, is evident by an undulating or irregular finish, and the appearance of waves on the machined surfaces of the workpiece.

1.2 PROBLEM STATEMENT

The surface finish is the most desired characteristic on machining. In the manufacturing process, most of their product needs a precise surface finish and accurate cutting.

(i) There is very hard to manage the machine to get a good surface finish. However, a PID controller has an ability to control the chatter occur in the milling machine process to get good surface finish.

(ii) Corrosion may happen when the machining process has disturbance such as vibration.

1.3 OBJECTIVE OF STUDY

The main objective of the study is to suppress chatter on cutting tool of milling machine by using simulation based on active control vibration. Besides, the result obtained from technique will be compared to the passive system.

1.4 SCOPE OF STUDY

To design a PID controller that can be used to manage the friction during machining and also develop a system that can counter the friction and give us the good surface finish in the milling machine

i. Literature review from previous study
ii. 1-DOF displacement of the milling machine cutting tool.
iii. Dynamic model and mathematical model of milling machine cutting tool.
iv. Experimental Parameter of turning process from previous study.
v. Run simulation using MATLAB/SIMULINK® software.
vi. Implement the typical technique PID as controller.
vii. Evaluate system performance PID control system base on the result obtain.
viii. Comparative study between PID control and uncontrolled system.

1.5 SIGNIFICANCE OF STUDY

There are few significances of this study when objectives have been achieved. The significance of study is investigated suitable scheme control system for milling machine. The scheme control system function to suppress vibration in the milling machine. Control system designed implement in the milling cutting tool. The parameter used base on milling turning process.

This study focus on simulation method with simulate control system have been design by using MATLAB/SIMULINK® software and investigate every type of controller suitable for this system. The experiment study can be continuous for more real live situation the vibration in milling machine. This study tried improve the milling machine performance base on many type of expectation for the accuracy of the product and the other. The idea to create the active vibration control system to overcome the chatter milling operation by implement controller. This control system technology can be commercialized for industrial sector.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is more to recognize the basic understanding of knowledge about the study. The topics like milling machines, vibration, active vibration control and also controller should be familiar for facilitate of investigation.

The knowledge of milling machine operation and the parameter that related and suitable to apply in this project must be studied. Recognize the mathematical model of cutting tool by the dynamic model. The method to use for study is simulation. So, the controller that will use must be listed, learn and can be adept to apply for the next chapter.

Proportional-integral-derivative (PID) controllers are the controller use for this study. Proportional-integral-derivative (PID) controllers have been the most popular and the most commonly used industrial controllers in the past years (Y.X. Su, et.al, 2005). The method to design, tune, set parameter and software use will explain detail in this chapter.

All mechanical system is subjected to excitations that induce vibration in the system. Generally, these vibrations are undesirable (Shiuh-jier huang and ruey-jing lian, 1995).The vibration occurs on milling process and the application PID controller to control the significant machining vibration in the milling machine. The machine, tooling and workpiece are a complicated dynamical characteristic that may have vibration in certain condition. The vibration occurs can be divided into the type which is free vibration, forced vibration and self-excited vibration.

Free vibration course by impulse transferred to the structure by movement rapidly movement of reciprocating masses such as machine table. Besides that, the vibration also occurs when we engage the cutting tool to the workpiece. The force vibration occurs by a periodic force within the system such as unbalance rotating tooling.a new approach to the active dynamic absorber problem was proposed by Tewani and Stephens (Stephens, 1989) to control vibration occur. The combination of passive element and active element and an absorber mass used to apply a controlling force on the main system (Shiuh-jier huang and ruey-jing lian, 1995)

The machine tool will oscillate at the forcing frequency, and if this frequency corresponds to one of the natural frequencies of the structure, the machine will resonate in the corresponding natural mode of vibration. Self-vibration usually occurs from dynamical instability of the cutting process. This phenomenon is called machine tool chatter.

If large tool work engages are attempted, oscillation suddenly built up in the structure. By using PID controller, the vibration occurs can be managed and also may be countered the by install device such as an actuator. A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems.

PID commonly used the controller feedback to operate. Recently, motivated by the rapidly developed advanced microelectronics and digital processors, conventional PID controllers have gone through a technological evolution, from pneumatic controllers via analog electronics to microprocessor via digital circuits (S. Bennett,1993).

PID controller uses the error values as the differences between process variable compare to desirable value. The PID controller is a digital controller, which contains a PID control units arrangement, called the derivative of the output. This arrangement is often desirable if the reference input contains discontinuities (W. A. Wolovich ,1994). Figure 2.1 shows the feedback control system that applied in PID controller.

The PID controller calculates by three constant parameter such as proportional, integral and derivative. Proportional is the proportional to the error at the instant which is present error. The integral is proportional to the integral of the error up to the instant which can be interpreted as the accumulative of past error. The derivative is the proportional to the derivative of the error which can be interpreted as a prediction of future error.

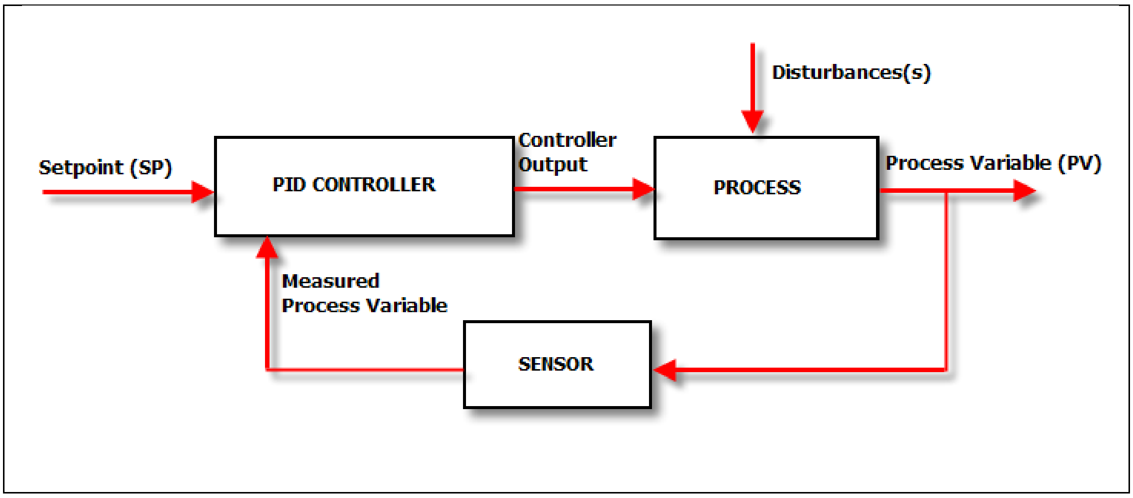

Figure 2.1: Feedback control system

Source: Jim Hogenson, 2010

This is important to control vibration on machine tool to avoid result in poor surface finish, cutting-edge damage and irritating noise. Better surface finish is the prediction of the performance of the mechanical component. Better surface finishes also avoid cracking and corrosion happen to mechanical product. PID controller also helps us to manage the friction in the moving component of the machine and improve the contouring accuracy in the presence of friction disturbances.

2.2 MILLING MACHINE

Rotating machinery is commonly used in mechanical systems, including machining tools and industrial turbomachiner, and aircraft gas turbine engines. Vibration caused by a mass imbalance is a common problem in rotating machinery.

A milling machine is widely used in the industry today. Milling machines were first invented and developed by Eli Whitney to mass produce interchangeable musket parts. Although crude, these machines assisted man in maintaining accuracy and uniformity while duplicating parts that could not be manufactured with the use of a file. Development and improvements of the milling machine and components continued, which resulted in the manufacturing of heavier arbors and high speed steel and carbide cutters. These components allowed the operator to remove metal faster, and with more accuracy, than previous machines (Franco, 2007).

Variations of milling machines were also developed to perform special milling operations. During this era, computerized machines have been developed to alleviate errors and provide better quality in the finished. In general the milling machine removes metal with a revolving cutting tool called a milling cutter. With various attachments, milling machines can be used for boring, slotting, circular milling dividing, and drilling. This machine can also be used for cutting keyways, racks and gears and for fluting taps and reamers.

Milling machines are basically classified as being horizontal or vertical to indicate the axis of the milling machine spindle. This form refers to the orientation of the main spindle. In milling machine, the machine needs to hold the workpiece stationary. In nearly all cases, a multiple-tooth cutter is used so that the material removal rate is high. The predictions of instabilities have been made for full-immersion and high-immersion milling perations during which regenerative effcts are likely to be dominant (Zhao, et.al, 2001).

These machines are also classified as knee-type, ram-type, manufacturing, and planer-type milling machines. Most machines have self-contained electric drive motors, coolant systems, variable spindle speeds, and power operated table feeds (Franco, 2007).

Knee-type milling machines are characterized by a vertical adjustable worktable resting on a saddle supported by a knee. The knee is a massive casting that rides vertically on the milling machine column and can be clamped rigidly to the column in a position where the milling head and the milling machine spindle are properly adjusted vertically for operation (Franco, 2007).

The floor-mounted plain horizontal milling machine's column contains the drive motor and, gearing and a fixed-position horizontal milling machine spindle. An adjustable overhead arm, containing one or more arbor supports projects forward from the top of the column. The arm and arbor supports are used to stabilize long arbors, upon which the milling cutters are fixed. The arbor supports can be moved along the overhead arm to support the arbor wherever support is desired. This support will depend on the location of the milling cutter or cutters on the arbor (Franco, 2007).

The knee of the machine rides up or down the column on a rigid track. A heavy, vertical positioned screw beneath the knee is used for raising and lowering. The saddle rests upon the knee and supports the worktable. The saddle moves in and out on a dovetail to control the cross feed of the worktable. The worktable traverses to the right or left upon the saddle, feeding the workpiece past the milling cutter. The table may be manually controlled (Franco, 2007).

The bench-type plain horizontal milling machine is a small version of the floor-mounted plain horizontal milling machine. It is mounted to a bench or a pedestal instead of directly to the floor. The milling machine spindle is horizontal and fixed in position. An adjustable overhead arm and support are provided. The worktable is generally not power fed on this size machine. The saddle slides on a dovetail on the knee providing cross feed adjustment. The knee moves vertically up or down the column to position the worktable in relation to the spindle (Franco, 2007).

The basic difference between a universal horizontal milling machine and a plain horizontal milling machine is in the adjustment of the worktable, and in the number of attachments and accessories available for performing various special milling operations. The universal horizontal milling machine has a worktable that can swivel on the saddle with respect to the axis of the milling machine spindle, permitting workpieces to be adjusted in relation to the milling cutter (Franco, 2007).

The universal horizontal milling machine also differs from the plain horizontal milling machine. The milling machine spindle is in a swivel cutter head mounted on a ram at the top of the column. The ram can be moved in or out to provide different positions for milling operations (Franco, 2007)

The ram-type milling machine is characterized by a spindle mounted to a movable housing on the column, permitting positioning the milling cutter forward or rearward in a horizontal plane. Two widely used ram-type milling machines are the floor-mounted universal milling machine and the swivel cutter head ram-type milling machine (Franco, 2007).

2.2.1 Major component in milling machine

First of all, when doing the machining, the most important part is to know the name and purpose of each of the main parts of a milling machine. Column, ram, spindle, spindle box, slide carriage and lathe bed are major components of super-heavy duty CNC floor type boring and milling machine. (Fenghe, 2012) .

This is important to make a machining process become easy and avoid dangerous to the user. In milling machine, there are a lot of part but to understand the operation of there are some part that must to know and understand each function. (Fenghe, 2012). Table 2.2 shows the function and how the major component operates.

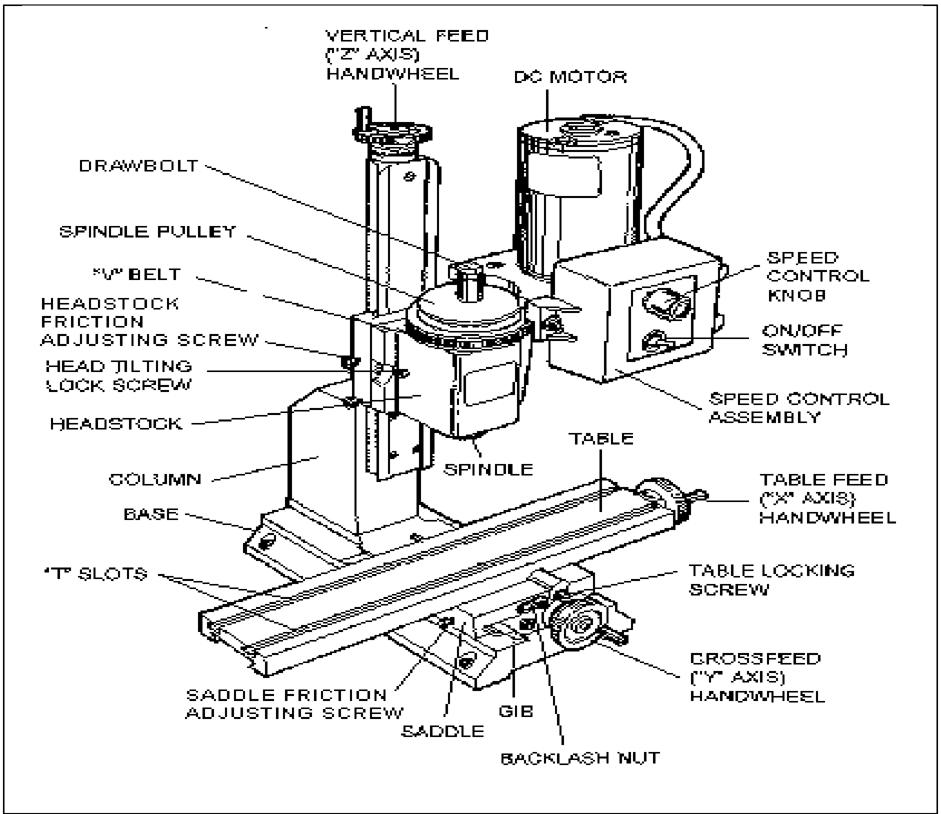

Figure 2.2: Major part in milling machine

Source: Sherline, 1997

Table 2.1: Major components in milling machine.

Component	Applications
Column	The column, including the base, is the main casting which supports all other parts of the machine. An oil reservoir and a pump in the column keep the spindle lubricated. The column rests on a base that contains a coolant reservoir and a pump that can be used when performing any machining operation that requires a coolant.
Knee	The knee is the casting that supports the table and the saddle. The feed change gearing is enclosed within the knee. It is supported and can be adjusted by the elevating screw. The knee is fastened to the column by dovetail ways. The lever can be raised or lowered either by hand or power feed
Saddle	The saddle slides on a horizontal dovetail, parallel to the axis of the spindle, on the knee. The swivel table is attached to the saddle and can be swiveled approximately 45° in either direction
Power Feed	The power feed mechanism is contained in the knee and controls the longitudinal, transverse (in and out) and vertical feeds. The desired rate of feed can be obtained on the machine by positioning the feed selection levers as indicated on the feed selection plates
Table	The table is the rectangular casting located on top of the saddle. It contains several T-slots for fastening the work or work holding devices. The table can be moved by hand or by power. To move the table by hand, engage and turn the longitudinal hand crank. To move it by power, engage the longitudinal directional feed control lever.

Spindle	The spindle holds and drives the various cutting tools. It is a shaft, mounted on bearings supported by the column. The spindle is driven by an electric motor through a train of gears, all mounted within the column
Over arm	The over arm is the horizontal beam to which the arbor support is fastened. The over arm, may be a single casting that slides in the dovetail ways on the top of the column. It may consist of one or two cylindrical bars that slide through the holes in the column.
Arbor Support	On some machines to position the over arm, first unclamp the locknuts and then extend the over arm by turning a crank. On others, the over arm is moved by merely pushing on it. The over arm should only be extended far enough to so position the arbor support as to make the setup as rigid as possible

Source: Sherline, 1997

2.3 CUTTING TOOL

Spindle and tool vibration measurements are of great importance in both the development and monitoring of high-speed milling. Measurements of cutting forces and vibrations on the stationary spindle head is the most used technique today. But since the milling results depend on the relative movement between the workpiece and the tool (Kourosh Tatar, 2008).

The demand on high productivity leads to increased chatter per unit time and higher spindle speeds, increased feed rate, and greater depth of cut. However, at certain combinations of machining parameters, process instabilities and vibrations can effect the accuracy, poorer surface finish, reduced tool life time and in the worst case spindle failure (Kourosh Tatar, 2008).

The cutting tool is the important part in machining. The majority of carbide cutting tools in use today employ CVD or PVD hard coatings. The high hardness, wear resistance, and chemical stability of these coatings offer proven benefits in terms of tool life and machining performance (Prengela, et.al 2001). Milling is a basic machining process by which a surface is generated by progressive chip removal. The workpiece is fed into a rotating cutting tool. Figure 2.3 shows the cutting tool position while doing the machining.

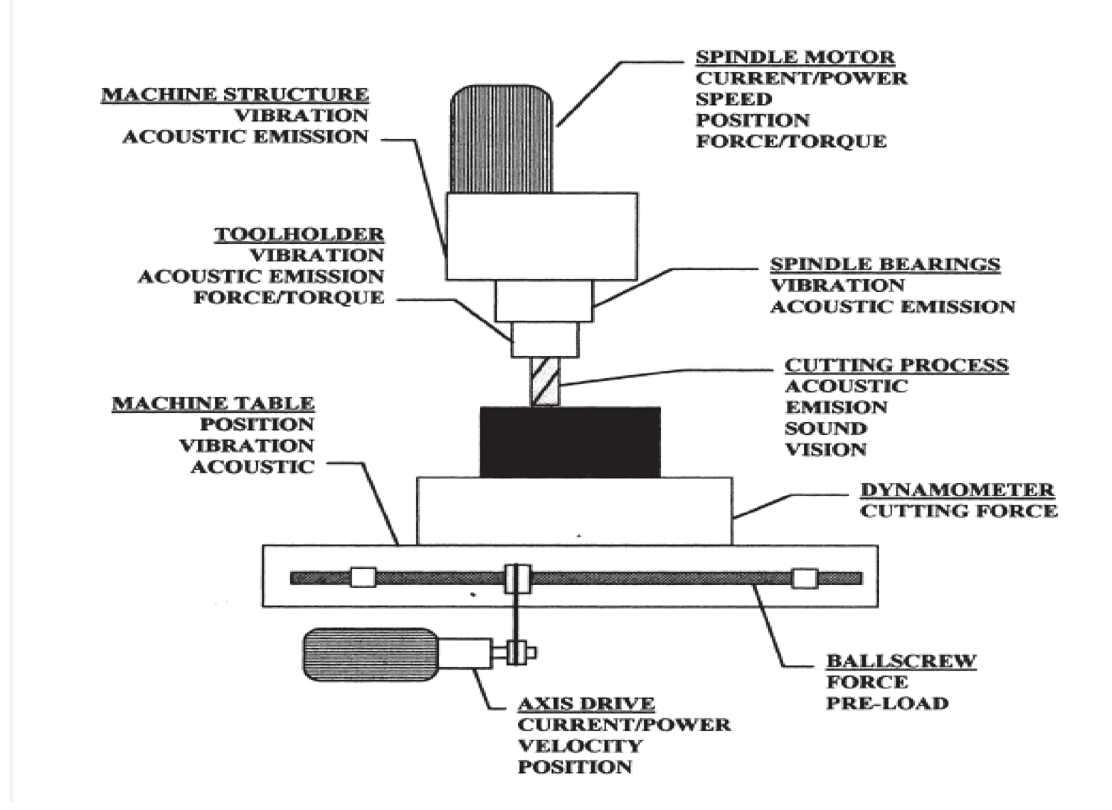

Figure 2.3: Cutting tool position in machining

Source: Prickett, 1999

The cutting tool used in milling is known as a milling cutter. Equally spaced peripheral teeth will intermittently engage and machine the workpiece. This is called interrupted cutting. These are a lot of types of cutting tool in market. Figure 2.4 shows the cutting tools for different type of cutting. Each type of cutting toll is use in different type of cutting.

Type of cutting tool can be divide into two group which is linear and rotary. Linear cutting tools include tool bits (single-point cutting tools) and broaches. Rotary cutting tool include the bit, countersinks and counter bores, taps and dies, cutters, reamers, and cold saw blades. Other cutting tools, such as bandsaw blades, hacksaw blades, and fly cutters, combine aspects of linear and rotary motion. (Schneider, 2009)

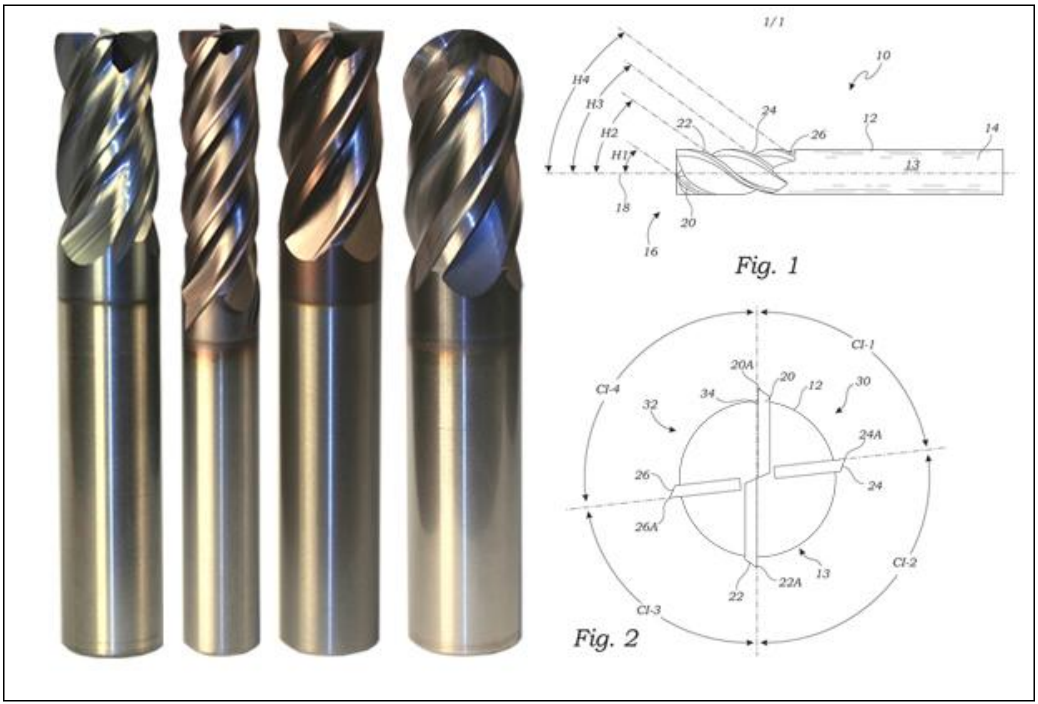

Figure 2.4: Cutting Tools for different type of cutting

Source: Surface Grinder and CNC Machine, 2012

Cutting tools must be made of a material harder than the material which is to be cut, and the tool must be able to withstand the heat generated in the metal-cutting process. The tool must have a specific geometry, with clearance angles designed so that the cutting edge can contact the workpiece without the rest of the tool dragging on the workpiece surface.

The angle of the cutting face is also important, as is the flute width, number of flutes or teeth, and margin size. In order to have a long working life, all of the above must be optimized, plus the speeds and feeds at which the tool is run. Some type of cutting tool is not suitable to cutting the some type of workpiece. Besides that, we must consider the price of cutting tool. For example, In industry today, cemented carbide is most common material used in machining. This is because this cutting tool is stable, not really expensive, high resistance to abrasion and it very common in milling cutters and saw blades. (Schneider, 2009) The cemented carbide cutting tool also offered in several grades containing different proportions of tungsten carbide and binder. Although diamond is the most hardness substance but this material is not suitable in machining because of it price is very high and also high chemical affinity to iron which results in being unsuitable for steel machining.

To produce quality machining process, the cutting tool must have three characteristics which are (Schneider, 2009):

i) Hardness: hardness and strength at high temperatures.
ii) Toughness : toughness, so that tools don’t chip or fracture.
iii) Wear resistance: having acceptable tool life before needing to be replaced.

Cutting tool materials can be divided into two main categories which is stable and unstable. Unstable materials usually steels are substances that start at a relatively low hardness point and then heat treated to promote the growth of hard particle such as carbide inside the original matrix, which increases the overall hardness of the material at the expense of some its original toughness.

Since heat is the mechanism to alter the structure of the substance and at the same time the cutting action produces a lot of heat, such substances is inherently unstable under machining conditions. Unstable materials being generally softer and thus tougher generally can stand a bit of flexing without breaking, which makes them much more suitable for unfavorable machining conditions, such as those encountered in hand tools and light machinery.

Stable materials usually tungsten carbide are substances that remain relatively stable under the heat produced by most machining conditions, this material do not attend their hardness through heat. This material may down to abrasion, but generally do not change their properties much during use.

Most stable materials are hard enough to break before flexing, which makes them very fragile. To avoid chipping at the cutting edge, most tools made of such materials are finished with a slightly blunt edge, which results in higher cutting forces due to an increased shear area.

2.4 CHATTER

During the milling process, chatter can occur at certain combinations of axial depth of cut and spindle speed. Chatter known as machining vibration is corresponding to the relative movement between the workpiece and the cutting tool.

Figure 2.5 shows chatter regeneration on the milling machine. This system shows the chatter are formed when machining are in progress. This condition creates an undesirable vibration of the machine system. The undesirable motions, which are often referred to as chatter, can result in wavy surfaces on the workpiece, inaccurate dimensions, and excessive tool wear (Arnold, R.N., 1946). This theory led to the stability-lobe description of machine-tool chatter.

The vibrations result in waves on the machined surface. This affects typical machining processes, such as turning, milling and drilling, and atypical machining processes, such as grinding. This is possible to avoid vibration during machining but we can reduce the vibration occur by applying basic rules of machinist which is (Frederick W. Taylor, 1907):

i) Rigidity the workpiece, the tool and the machine as much as possible
ii) Choose the tool that will excite vibrations as little as possible by modifying angles, dimensions and surface treatment
iii) Choose exciting frequencies that best limit the vibrations of the machining system such as spindle speed, number of teeth and relative positions.

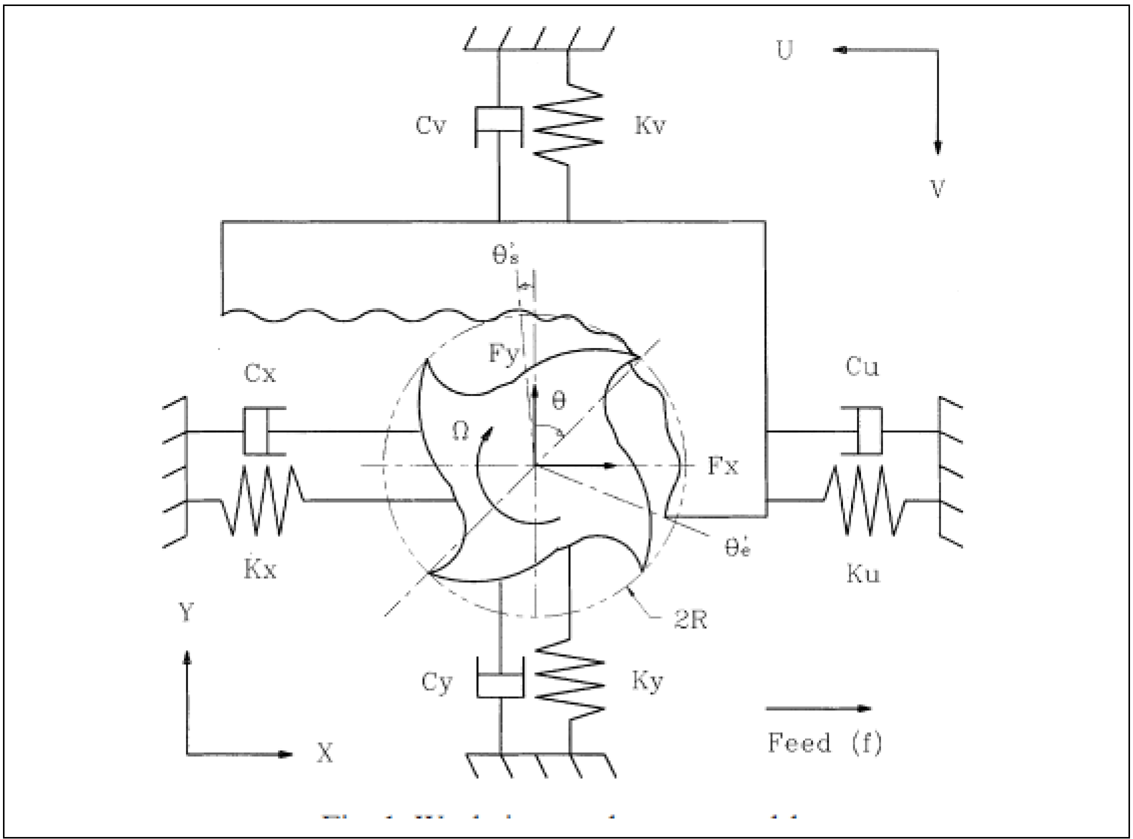

Figure 2.5: Chatter regeneration

Source: M.X. Zhao, 2001

2.5 VIBRATION CONTROL

Vibrations accompany us everywhere and in most cases these vibrations are undesirable. Vibration control is essential in improving machining surface finish, achieving longer bearing, spindle, and tool life in high-speed machining and reducing the number of unscheduled shutdowns.

From that point, the previous study will be refereed to know the technique used. The technique PID will briefly elaborate and analyzed. The comparative study will make between controls and uncontrolled system. For PID controller, the method review is Ziegler–Nichols method or the other suitable method

During the machining operation, a relative vibration between workpiece and the cutting tool which is called chatter. This condition develops under certain condition. This situation happens every time during machining but this situation is not desirable because it has an adverse effect on the machining accuracy, surface finish, and also affected tool life. The vibration can be divided into two which is passive and active vibration (Shiuh-jer huang.et.al, 1995).

All mechanical system composed of mass, stiffness and damping element exhibit vibratory response when subject to time-varying disturbance. The prediction and control of these disturbances is fundamental to the design and operation of mechanical equipment (Fuller, et.al 1997). The equation of motion and linear behavior of single degree of freedom system are outlined both free and forced response (Fuller, et.al 1997).

The passive vibration isolation system consists of a spring and damper. A dynamic absorber mass is then connected to the main system through passive elements (spring and damper). The spring is intended to soften vibrations and pushes, and the damper has to terminate the oscillation which is excited in the system. Figure 2.6 shows the simple vibration system on a machine.

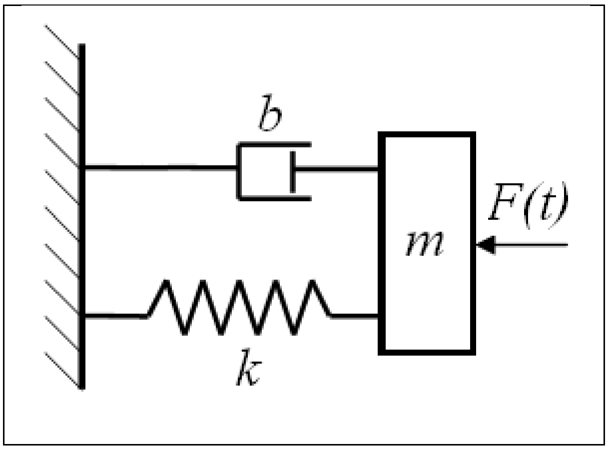

Figure 2.6: Simple vibration systems

Source: Colin M. Morison, 2006

The active system uses also accelerometers and electromagnetic drivers which allows higher degree of vibration isolation to be achieved. This system may be explained in easy way such as suspension bracket of the automobile. In any suspension bracket there are elastic elements, which soften pushes and impacts of the road. In Other hand of bracket is shock-absorber. This device is functional as intended to terminate excited the oscillation.

Active vibration isolation aims at improving the performance of the vibration isolation by including a force generating element in the isolation interface, a sensor at the receiving end of the transmission path, and a feedback control law connecting them (Preumont, et.al, 2002).

Active vibration isolation system among the spring there is feedback circuit which consists of a piezoelectric accelerometer, an analog control circuit, and an electromagnetic transducer. The spring supports the weight of mass such as body of car and the device which is mounted on the mass.

2.6 PID CONTROLLER

Proportional-integral-derivative (PID) controllers have been the most popular and the most commonly used industrial controllers in the past years (Su, et.al, 2005). A proportional integral derivative controller PID is a generic control loop feedback mechanism that widely used in industry.

The PID is commonly used feedback controller. The PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs.

The PID controller calculation algorithm involves three separate constant parameters that called proportional, the integral and derivative values. P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. Figure 2.7 shows the example of the PID controller system.

In the absence of knowledge of the underlying process, a PID controller is the best controller (Prengela, et.al, 2001). By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error.

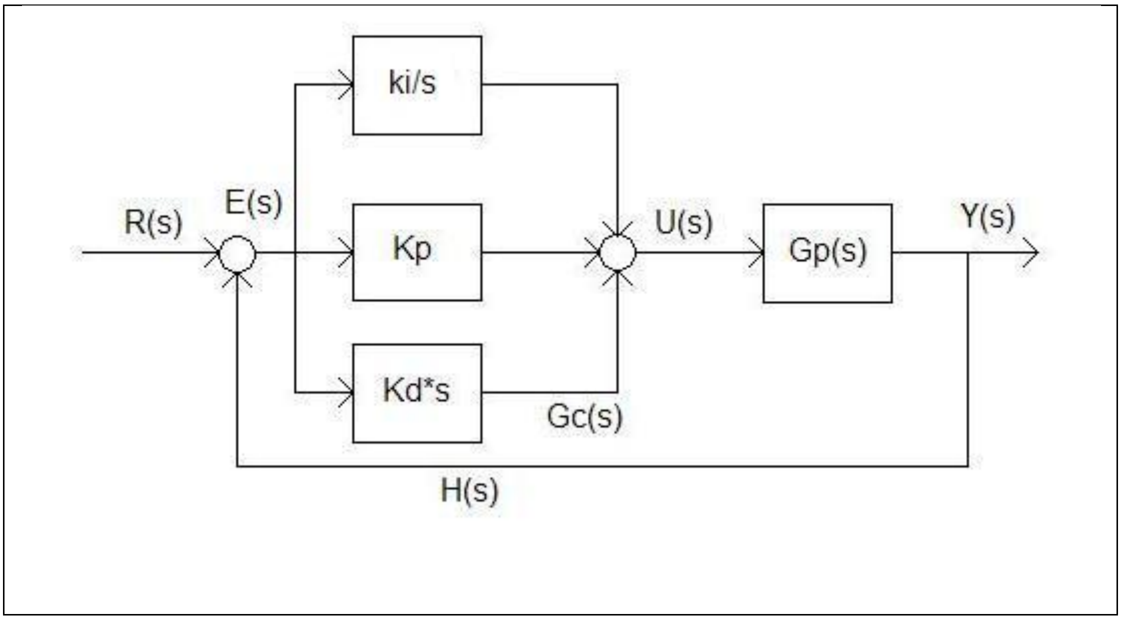

Figure 2.7: PID controller

Source: Jaime Vazquez del angel

Some applications may require using only one or two actions to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions.

PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the controler action. For example, PID describes three basic mathematical functions applied to the error signal. Equation 2.1 shows the error is calculated in PID controller.

$$V\ error = V\ set - V\ sensor \tag{2.1}$$

This error represents the difference between (V set), and (V sensor). V set is mean as the result that we want and v sensor is what happens just now to the system. The controller performs the PID mathematical functions on the error and applies the sum to a process. So we need to tune correctly to adjust the signal V sensor move closer to V set. Tuning a system means adjusting three multipliers Kp, Ki and Kd adding in various amounts of these functions to get the system to behave the way we want. The table 2.2 summarizes the PID terms and their effect on a control system.

Table 2.2: Application of PID

Term	**Math Function**	**Effect on Control System**
P Proportional	KP x V error	Typically the main drive in a control loop, KP reduces a large part of the overall error.
I Integral	KI x $\int$ Verror dt	Reduces the final error in a system. Summing even a small error over time produces a drive signal large enough to move the system toward a smaller error
D Derivative	KD x dVerror / dt	Counteracts the KP and KI terms when the output changes quickly. This helps reduce overshoot and ringing. It has no effect on final error.

Source: Tang, 2001

2.7 LINEAR ACTUATOR

A linear actuator is device that produces work by converting nonlinear energy into linear motion. There are many types of primary energy sources used in linear actuators such as electric motors to fluid, air pressure and thermal expansion. Figure 2.8 shows the actuator are been used in this project. Each type of actuator is suitable for different applications based on size, output, potential, and power requirements. These include door openers, heavy duty machine actuators, and tiny, precision process controllers.

Figure 2.8: Linear actuator

Source: N-381NEXACT linear actuator catalog

Actuators based on vibration are typically found in parts feeders and ultrasonic motors. The former can move many small objects simultaneously. However, it is impossible to generate a drive force because the force is dominated by the mass of the objects and the friction coefficient (Takeshi Hatsuzaw, 2003).

The latter can generate a fairly large torque and a high energy density. However, specific mechanisms such as belt drives or motion guides are necessary for the movement of objects that have various shapes (Takeshi Hatsuzaw, 2003).

The basic principle behind these indispensable devices is the conversion of one, typically small, nonlinear energy source into linear motion of increased magnitude. There are several commonly used primary energy sources in linear actuators.

Each actuator has its own particular conversion mechanism. In this experiment, we use linear actuator with 100 Hz based on the specification of the actuator N-381NEXACT linear actuator. Actuator actually used to invest the vibration occur on machining with create some vibration with same frequency to vibration occur in machining.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In general, methodology means a set or system of methods. This chapter is about how the research carried out. The step when doing the research will be shown in methodology. The study is about to detect the vibration occur on a milling machine. Then we also built a control system by using Matlab and create the active system to control and counter the vibration occurs. All the result and data from Matlab will be compared. The original system that we call passive system will be comparable to the active system. The flow chart of the methodology was being shown in Figure 3.1.

This study begins with the problem statement, project objective, scope and literature review. After all information has been collected, the further step is to sketch basic drawing of the system. First of all, we must design the dynamical model of the system. This research is only considering one single of freedom that mean the machine is only move in one direction which is X -direction. After complete the dynamical model, the second step is to find the parameter that suitable for this research. In its common meaning, parameter is the term that used to identify a characteristic, a feature, a measurable factor that can help in defining a particular system. It is an important element to take into consideration for the evaluation or for the comprehension of an event, a project or any situation.

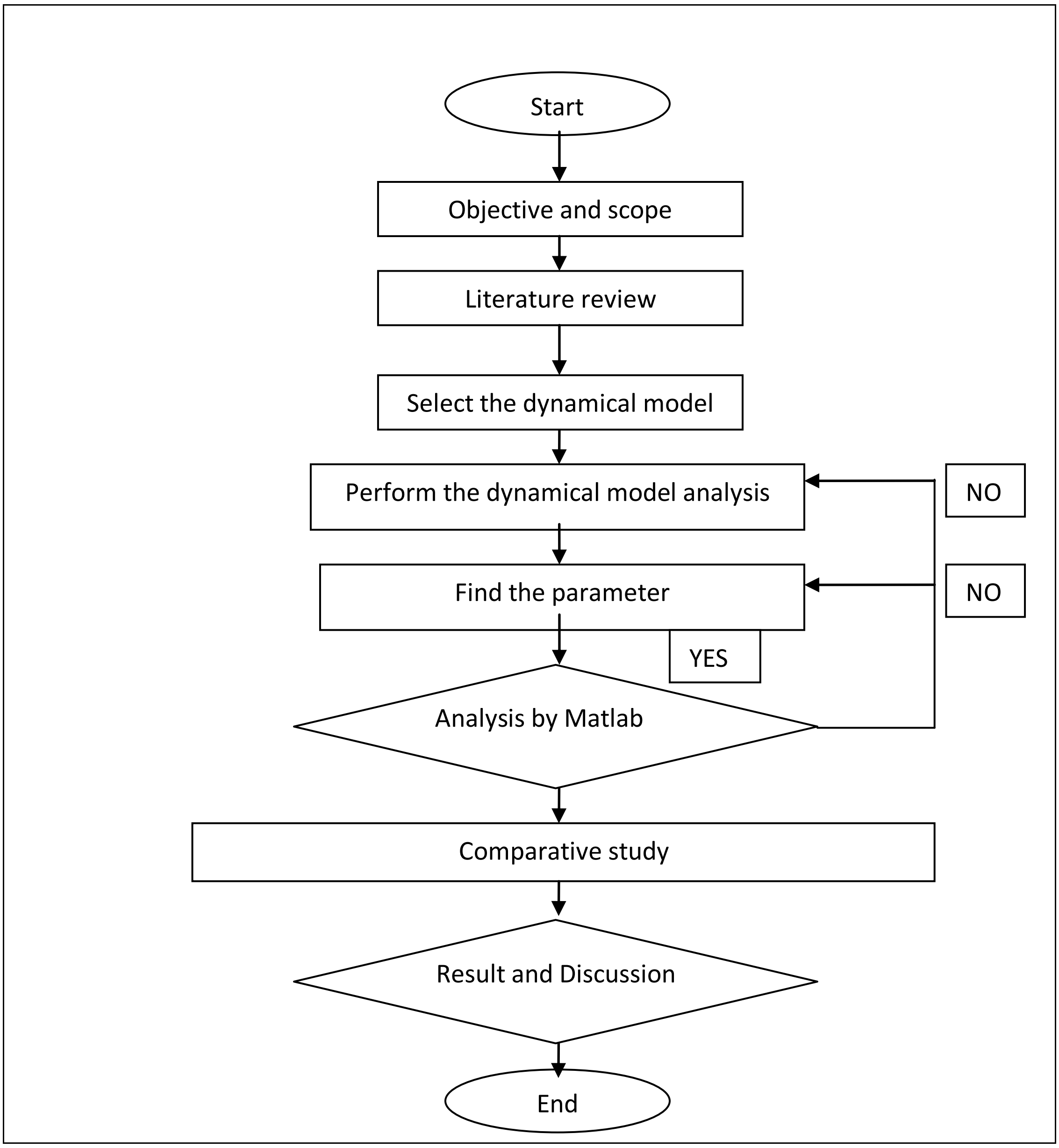

Figure 3.1: Flowchart

3.2 DYNAMICAL MODEL

In order to predict the stability of the cutting tool in the milling machine, the dynamical models for the cutting tool are needed. The dynamical model consists of a part which is describing the interaction part of cutting tool with the workpiece. The dynamical model of cutting tool can be seen in figure 3.2. The mass (m) of the tool, the damping coefficient (c) and the spring stiffness k can be determined. This structure is assumed to be flexible in x-direction only. These assumptions reduce the model into a single degree of freedom (s.d.o.f).

Single degree of freedom is the minimum number of independent coordinates required to determine completely the position of all parts of the system. The simple single degree of freedom is shown in figure 3.2. This figure shows a spring-mass system that represents a simpler possible vibratory system. This system is being called single degree of freedom from one coordinate(x) is sufficient to specify the position of the mass at any time.

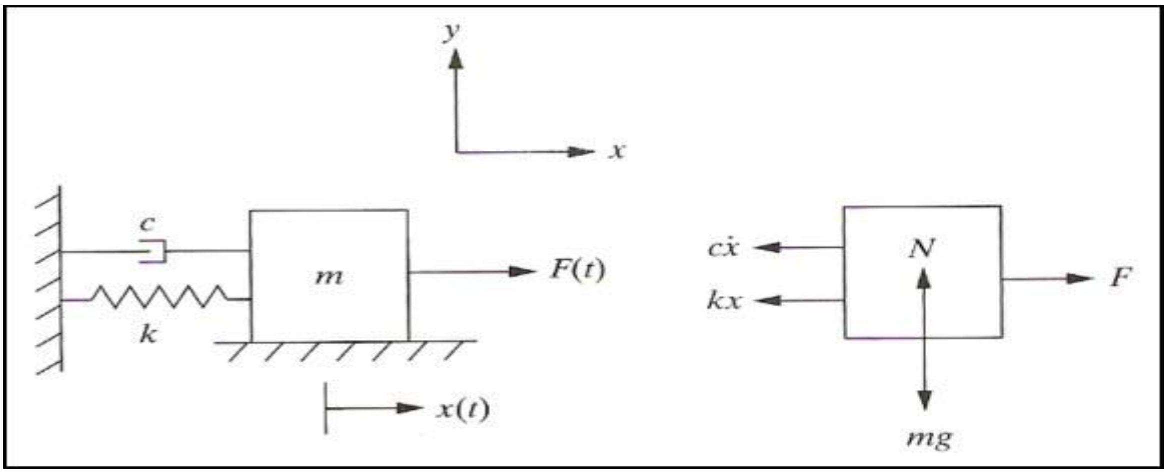

Figure 3.2: Dynamical model

Source: Colin M. Morison, 2006

3.3 MATHEMATICAL MODEL

A mathematical model is an abstract model that uses mathematical language to describe the behavior of a system. A mathematical model is a description of a system using mathematical concepts and language. The process of developing a mathematical model is termed mathematical modeling. A mathematical model may help to explain a system and to study the effects of different components, and to make predictions about the behavior (Eykhoff, 1974)

Mathematical models can take many forms and not limited to dynamical systems, statistical models, differential equations, or game theoretic models. In general, mathematical models may include logical models, as far as logic is taken as a part of mathematics. In many cases, the quality of a scientific field depends on how well the mathematical models developed on the theoretical side agree with the results of repeatable experiments. Lack of agreement between theoretical mathematical models and experimental measurements often leads to important advances as better theories are developed. For this project, the mathematical models are from parameter from previous research by Halley. The mathematical are derived in form of Laplace transform.

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3.3.1 Parameter for milling process

For the calculations, the following experimentally identified parameters were used Based on the experimental results of Halley. The parameter has be show in table 3.1. This parameter is important to know the behavior of milling machine when doing the machining. This parameter is include the mass of tool, damping value and also spring constant for the milling machine.

Table 3.1: List of parameter in milling cutting tool

Parameter	**Value**
Mass	2.586kg
Damper	18.13 Ns/m
Spring	2.2x10^6 N/m

Source: J.E. Halley, 2007

3.3.2 Derivative of mathematical model

In this research, the analysis is based on the mathematical model that is built from a dynamical model of cutting tool. The mathematical models in this research are in form of Laplace transform as shown in Eq 3.4 and Eq 3.5. The mathematical model is deriving from the free body diagram from figure 3.3. In general, mathematical models may include logical models, as far as logic is taken as a part of mathematics.

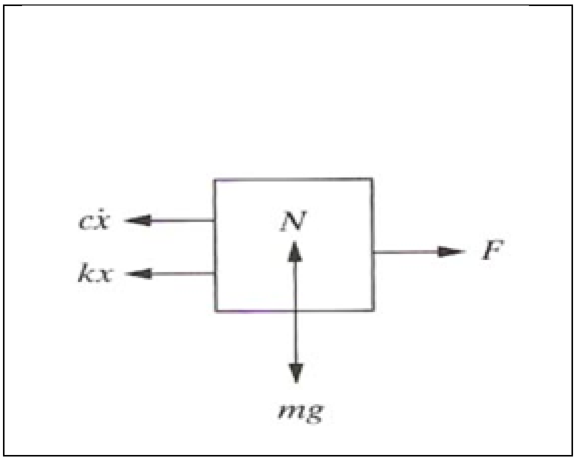

Figure 3.3: Free body diagram

Source: Colin M. Morison, 2006

$$M\frac{dx^2(X)}{d(t)^2} + f_{v^2}\frac{dx(t)}{dt} + Kx(t) = f(t) \qquad \text{Eq 3.1}$$

$$Ms^2X(s) + f_{v^2}X(s) + KX(s) = F(s) \qquad \text{Eq 3.2}$$

$$(Ms^2 + f_{v^2} + K)X(s) = F(s) \qquad \text{Eq 3.3}$$

$$G(s) = \frac{X(s)}{F(s)} = \frac{1}{Ms^2+f_{v^2}+K} \qquad \text{Eq 3.4}$$

$$G(s) = \frac{X(s)}{F(s)} = \frac{1}{2.586^2+18.13+2.2x10^6} \qquad \text{Eq 3.5}$$

3.4 MATLAB/ SIMULINK

3.4.1 Matlab

Matlab (matrix laboratory) is a tool for doing numerical computing with matrices and vectors environment and language. It can also display information graphically. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran. MATLAB are use in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology. For a million engineers and scientists in industry and academia, MATLAB is the language of technical computing (The MathWorks, Inc, 1994).

3.4.2 SIMULINK

SIMULINK developed by MathWorks, is a commercial tool for modeling, simulating and analyzing multidomain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. SIMULINK is widely used in control theory and digital signal processing for multidomain simulation and Model-Based Design. This research used SIMULINK to create the passive and active system. By using SIMULINK, the performance of the control system will be analyzed to make a comparison with uncontrolled system (The MathWorks, Inc, 1994).

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3.5 SIMULATION

Simulation is the imitation of the operation of a real-world process or system over time (Banks, 2001). The act of simulating something first requires that a model be developed. This model represents the key characteristics or behaviors of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.

Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video games. Training simulators include flight simulators for training aircraft pilots to provide them with a life like experience. Simulation is also used with scientific modeling of natural systems or human systems to gain insight into their functioning (Encyclopedia of Computer Science,).

Simulation can be used to show the eventual real effects of alternative conditions and courses of action. Simulation is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist (Sokolowski, 2009)

For this study, the result produces by simulation. The function of simulation is to investigate the performance of the control system. The successful simulation of the control system will be implemented into the milling cutting tool. For this study, experimental is not carried out and just focusing on design a control system and analysis by simulation to know the performance.

The software that is used to run the simulation is by using SIMULINK/Matlab. This simulation is run for control system and the other one is uncontrolled system. The conversional PID controller had been used to control the system. A Comparative study was made between the control systems and uncontrolled system.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter is discussing about the effect of PID controller applied on cutting tools of the milling machine. These results are based on simulation by Simulink/Matlab. The result is collected based on the parameter that found by research of Helley. PID controller tuning rules may be classified as follows:

(1) Tuning rules based on a measured step response
(2) Tuning rules based on minimizing an appropriate performance criterion
(3) Tuning rules that give a specified closed loop response
(4) Robust tuning rules, with an explicit robust stability and robust performance criterion built into the design process
(5) Tuning rules based on recording appropriate parameters at the ultimate frequency

4.2 PASSIVE SYSTEM

The passive system is the references for vibration occur in this cutting tool while doing the milling machine. The main objective of this research is to reduce the vibration occur in this passive system. Passive systems are uncontrolled system. The system have mass, damper, spring and force and also moving in free vibration. This system in milling machine is undesirable because it will effected the accuracy in cutting progress

In this section figure 4.1 and figure 4.2 shows that the cutting tool dynamic system have been run by using SIMULINK with step input 0.001 m. This step is to see and measure the effect of vibration on the displacement of the passive system. The output value must be the same as the input value to avoid defect phenomenon.

For the figure 4.1, the system does not include the PID controller. The parameter of the cutting tool have been placed at get the button on integrator, damper and spring get button. The value input must be entered to get the output value. The values of input have been placed in step button.

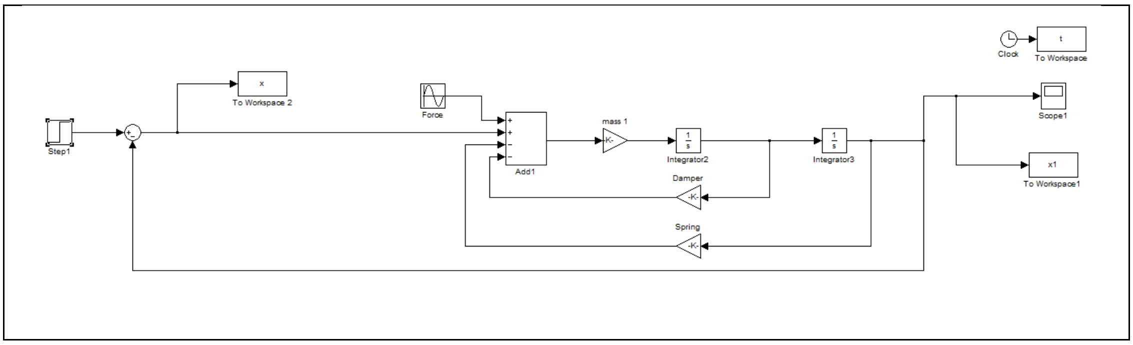

Figure 4.1: Passive system

The figure 4.2 shows the displacement versus time graph. The graphs are in a steady state condition. From this graph, the patterns of the vibration in term of displacement are showing the reducing the length of vibration occurs. That means, the vibration occur on the system are reduced but take more cycle and time. The displacements are reducing in term of time. This system creates an undesirable vibration on a milling machine and will affect the surface finish on workpiece.

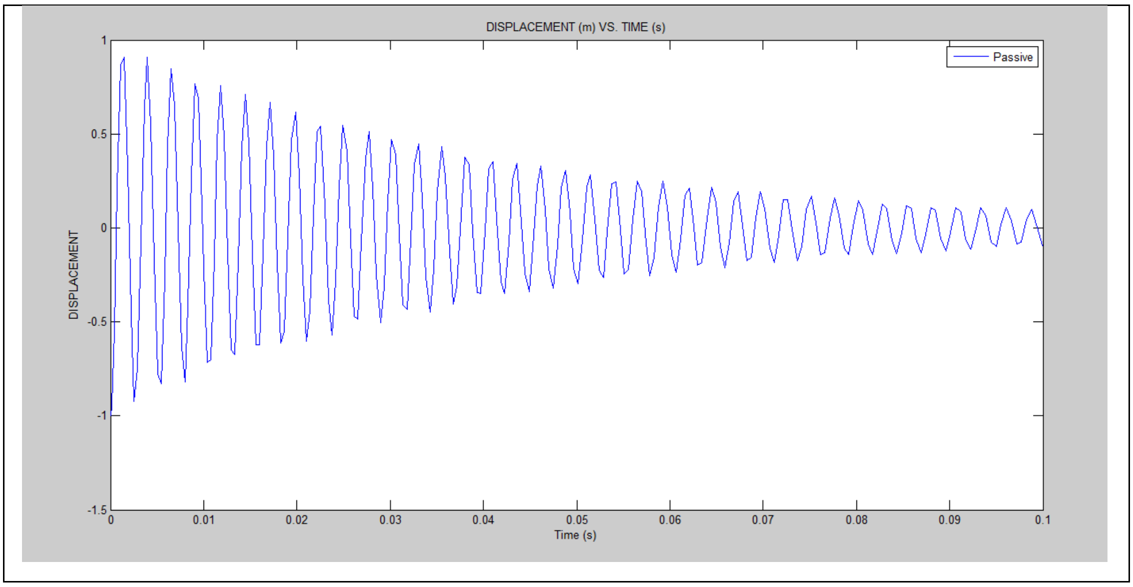

Figure 4.2: Graph of Passive Systems

Figure 4.3 shows the graph error for passive system. Errors of this system are defined for the steady state error. These simulations on this system are using steady state error. Normally is the system is stable, the error graph is inversely proportional with the displacement versus time graph.

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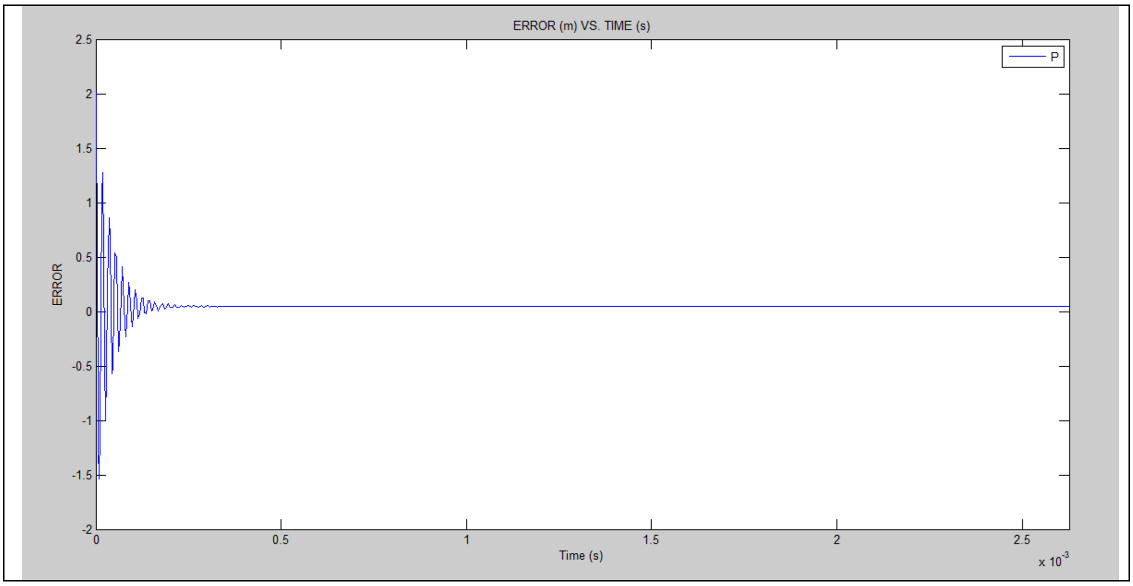

Figure 4.3: Graph of error in passive system

4.3 ACTIVE SYSTEM

The active system is the control system. These systems are controlled by PID controller and actuator as a vibration counter. The PID controller is the most common form of feedback. PID will operate to get the desired output to reduce the vibration occur on a milling machine. The vibration occurs in machining is being viewed in term of the graph. This displacement is refers to the distance of vibration occur.

Therefore the control systems also use value to control the system. For example, we put the value of 1 in step input. That means the output value must be 1 also. If the value is 1, the systems are considered as stable.

Although the value of output is 1,the system cannot be classified as desire control system because of how many cycles the output gets the value of 1. If the system wants to be considered as desire control system, the value of 1 must obtain before the wave completing one cycle.

If the pattern of graph shows the value of one before one cycle, the vibration in this system will be considered are approximately zero. Figure 4.4 shows the system are designed in SIMULINK with the control system. These systems have included the PID controller button and the actuator button.

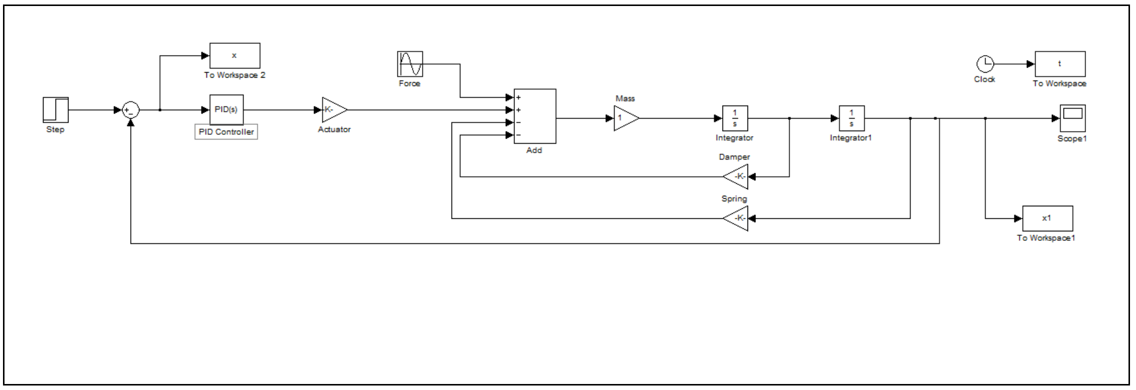

Figure 4.4: Active System

In this active system, the displacement versus time graph show the value of output that the system needs to operate without vibration occur before the wave completing one cycle. Figure 4.5 shows the graph of displacement versus time active system.

The output value will constantly maintain at desire value until the process of machining finish. The PID controller calculation algorithm involves three separate constant parameters that called proportional, the integral and derivative values. P depends on the present error, I on the accumulation of past errors and D is a prediction of future errors, based on current rate of change. All components give a several effect of the cutting tool dynamic.

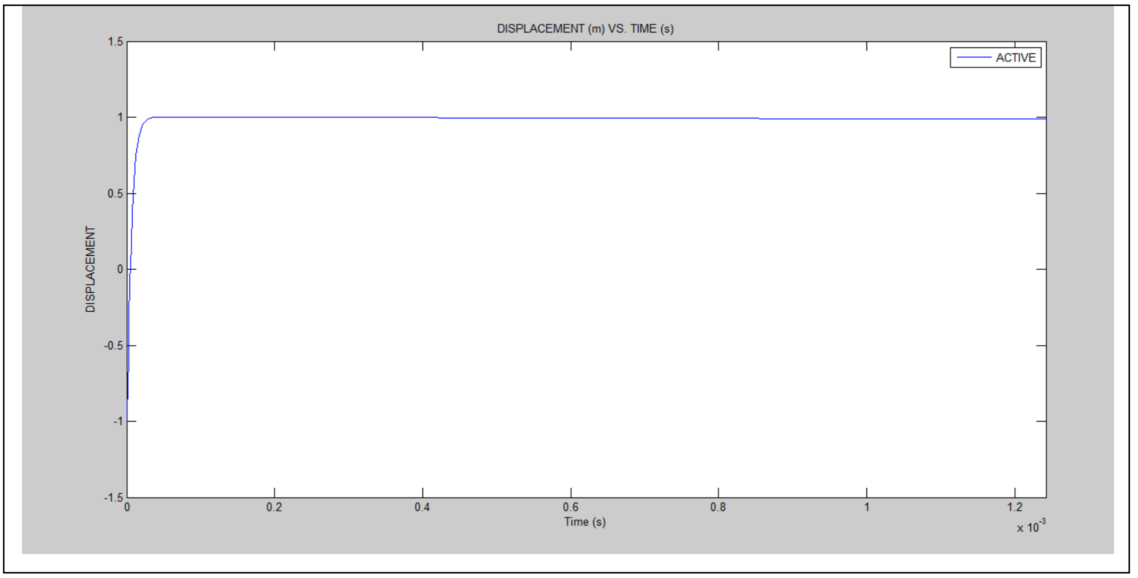

Figure 4.5: Graph of Active Systems

Graph 4.6 shows the graph of error occurs when PID is applied in the dynamic system. The patterns of this graph are inversely proportional with the displacement versus time graph for active system. The PID is used feedback controller.

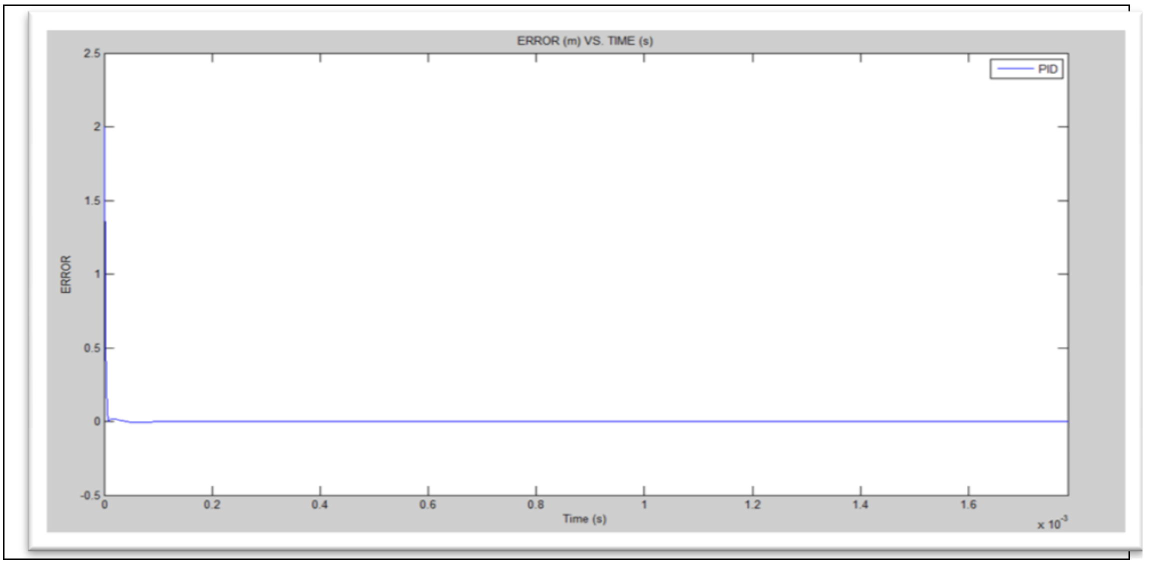

Figure 4.6: Graph of error in Active Systems

The PID controller calculates an "error" value as the difference between a measurement process variable and a desired set point. That mean PID will control the feedback value and compare the output value that we want. Figure 4.7 shows the steady state error. The final value must be the same as the output value that we enter to consider the system are in controlled. In this system, error is calculated by using steady state error. For example,

- The system to be controlled has a transfer function G(s).
- There is a sensor with a transfer function Ks.
- There is a controller with a transfer function Kp(s).

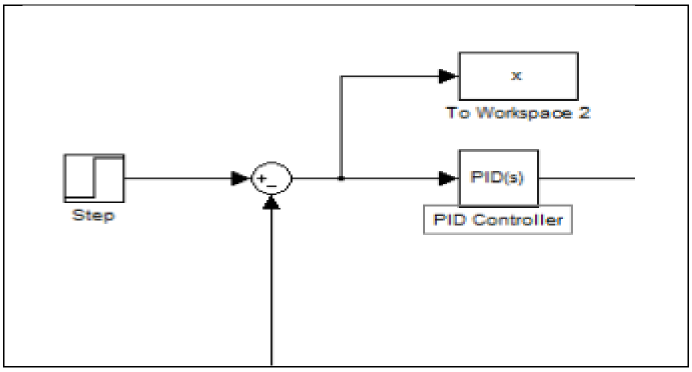

Figure 4.7: Steady State Errors

The input is often the desired output. In other words, the input is what we want the output to be. If the input is 1, then the output must to settle out to that value. The output is measured by a sensor. Often the gain of the sensor is one. The error signal is the difference between the desired input and the measured input. The error signal is a measure of how well the system is performing at any instant. When the error signal is large, the measured output does not match the desired output very well.

4.4 COMPARATIVE BETWEEN P VERSUS PI VERSUS PID

Proportional (P) controller is the most conventional feedback controller in the milling machine. It sends correction signals proportional to the difference between the reference position and the actual position. The proportional gain, is usually designed so that the closed loop damping ratio is equal to 0.707. For this damping ratio, the following equation can be used for the selection of the proportional open-loop gain. The damping ratio are calculate by using equation 4.1.

$$k = \frac{1}{T+2t} \tag{4.1}$$

Where T is the sampling period, t is the open-loop time constant, and k is the Open-loop gain, which is the product of the P controller gain (Kp). Figure 4.8 show the effect of proportional.

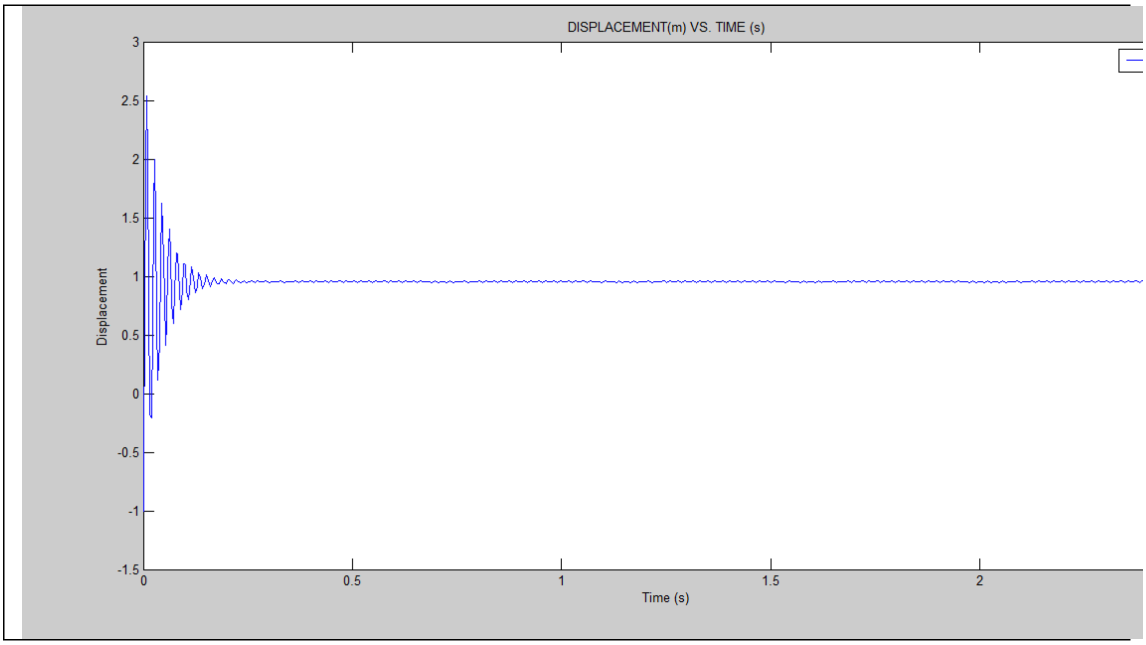

Figure 4.8: Proportional (Kp) Graph

In PID controller, the correction signal is a combination of three components: a proportional, an integral, and a derivative of the position error. The task of the integral (I) controller is to eliminate the steady-error when position ramp inputs are the references, as in the case of linear cuts, and to reject the external disturbances.

However, implementing an I-controller by itself will cause instability, and it must be combined with a proportional action to enable a stable system. Figure 4.9 shows the Ki graph. From the graph, the frequency of vibration is reducing in term of time.

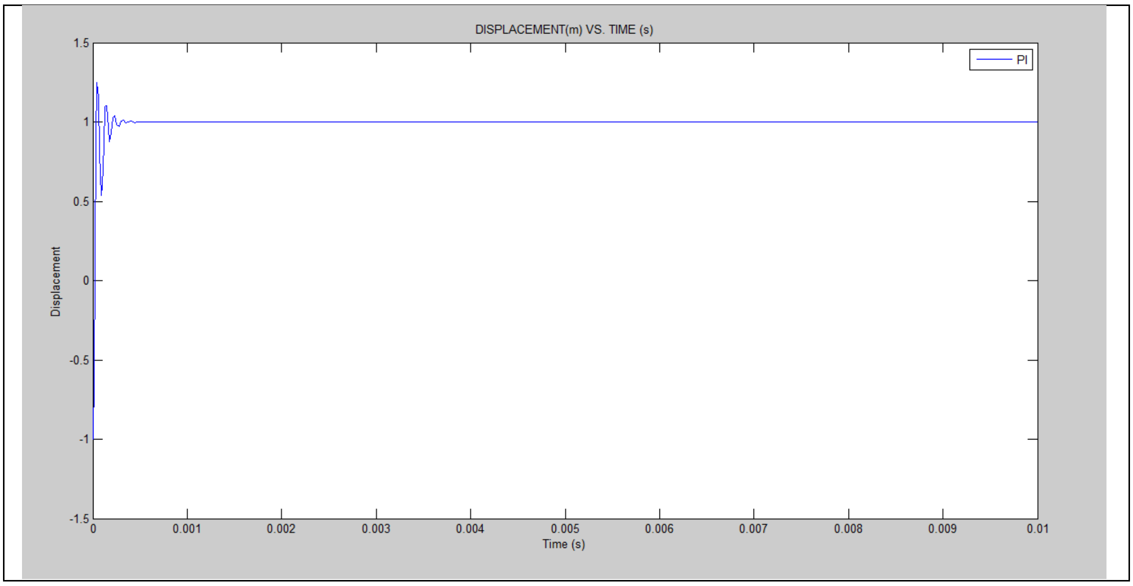

Figure 4.9: Integral (Ki) Graph

The derivative (D) controller aids in shaping the dynamic response of the system. The combination is known as a PID controller. Since a computer is utilized as the controller, a digital PID is implemented. Figure 4.10 show the effect of applying derivative on PID.

There are different ways to design digital PID controllers. For example, formulate the digital PID controller law by approximating the continuous-time PID controller with backward difference. In the following analyses, the PID controller law for X- axis and Y-axis respectively is formulated based on backward difference approximation, using Laplace transform.

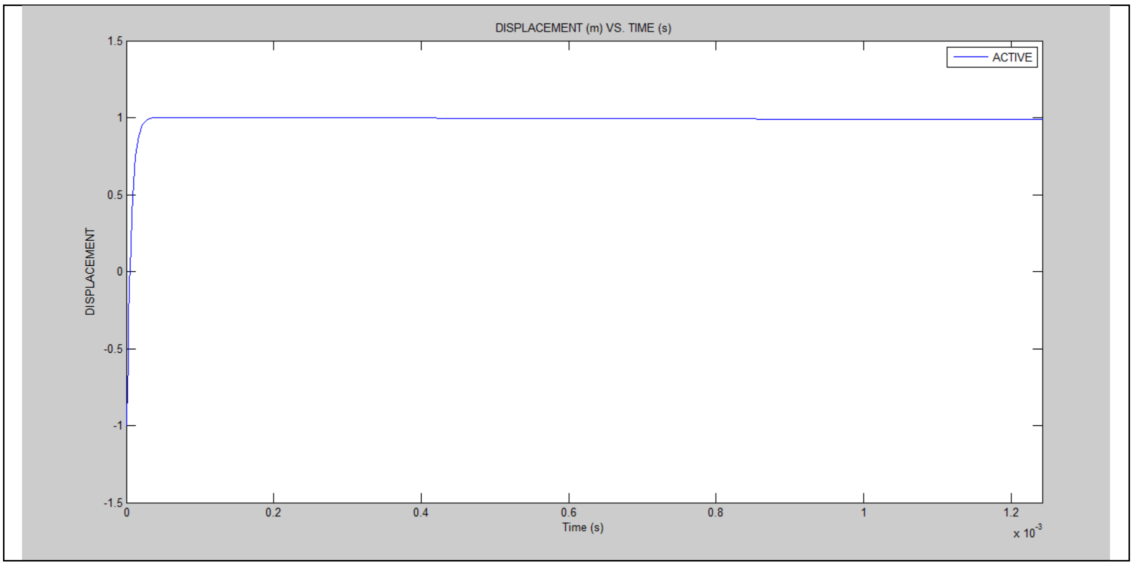

Figure 4.10: Derivative (Kd) Graph

The integral gain I is chosen large enough to guarantee a good ability in disturbance rejection, and the derivative gain D is designed to guarantee small overshoot. Usually, the controller gains can be designed based on root locus or frequency domain methods. The two main problems with PID controllers in contouring application are:

(l) Poor tracking of corners and nonlinear contours

(2) Significant overshoots.

To reduce the effect of these problems, the gain integral should be small and the implementation of the controller requires careful preprogramming of acceleration and deceleration periods, whereas these are not needed with a P controller.

Figure 4.11 and figure 4.12 show the comparative study between proportional controller, proportional-integral controller and proportional-integral-derivative controller for displacement analysis. This displacement analysis contains the natural frequency of the vibration active system.

Method that be used for tune PID controller are Ziegler-Nichols and root locus method. For this application both Ziegler and root locus method hardly used because not suitable with cutting tool system. So another option for tuning PID was being used which is heuristic method or crude approximation method.

By using heuristic methods, proportional control will b tune first on the cutting tool system. The plot of displacement versus time will be plot after get the exactly value

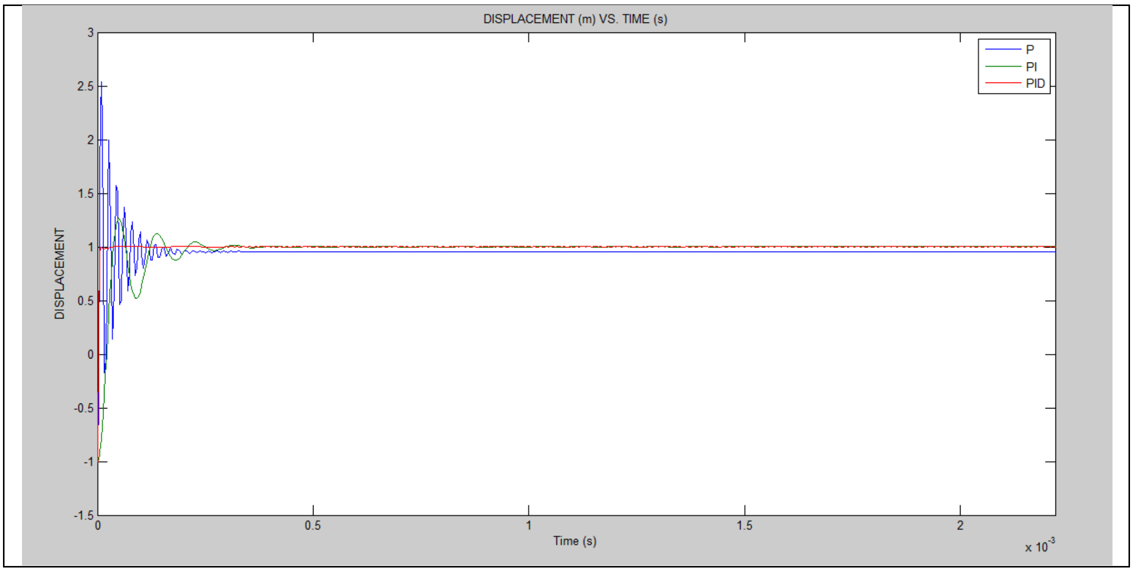

Figure 4.11: P vs PI vs PID Graph

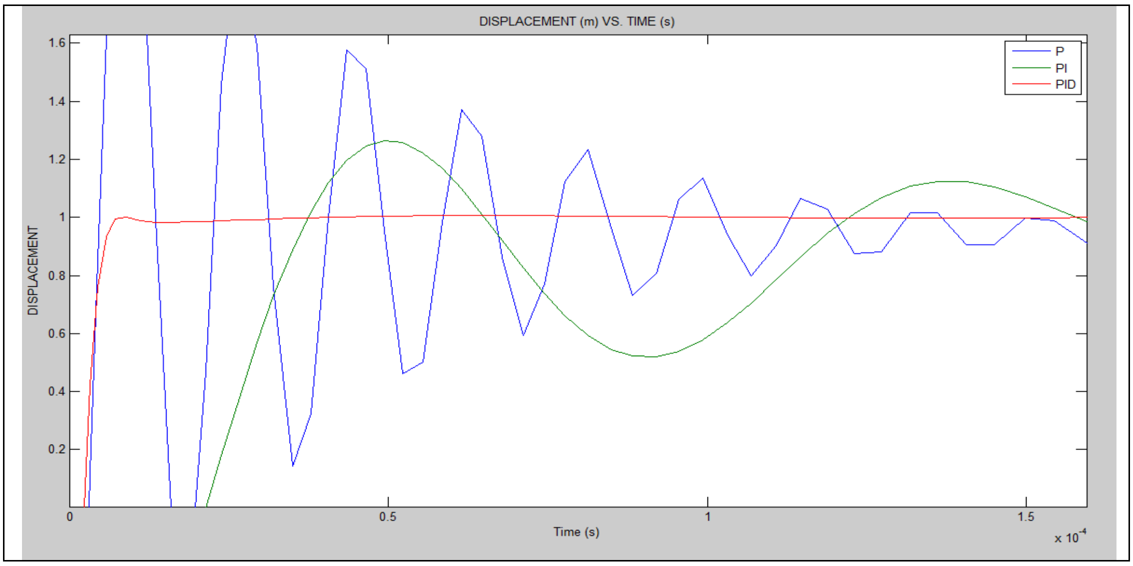

Figure 4.12: P vs PI vs PID Graph (zoom)

From the both figures, the graph shows the vibration is reducied in term of displacement. The frequency becomes smaller. P is functioning as proportional control. This control system is to control the steady state error in proportional error. When proportional applied on the system, the P line shows that the effect which reducing the passive system displacement but still not stable and had vibration effect.

The error will decrease with the increasing gain but the tendency towards oscillation will also increase. PI will affect the wavelength to become larger in term of time. That means the vibration occurs is reduced in time. PID will give the output value that we need before the wave complete one cycle. The vibration are reduced until approached no vibration occur in this system.

4.5 COMPARATIVE BETWEEN ACTIVE AND PASSIVE SYSTEM

Generally these sections are focusing on comparison of system performance between passive and active system which is using PID controller. Basically the comparison study is evaluated via optimum system response in term of displacement.

The optimum system response depends on optimum control parameter such as PID controller and actuator. Thus, a series of trial had been performed in this study in order to obtain the optimum control parameter. The displacement response for passive is added as a reference in order to enhance the comparison study. Figure 4.11 and 4.12 shows the comparison between passive system and the active with PID system.

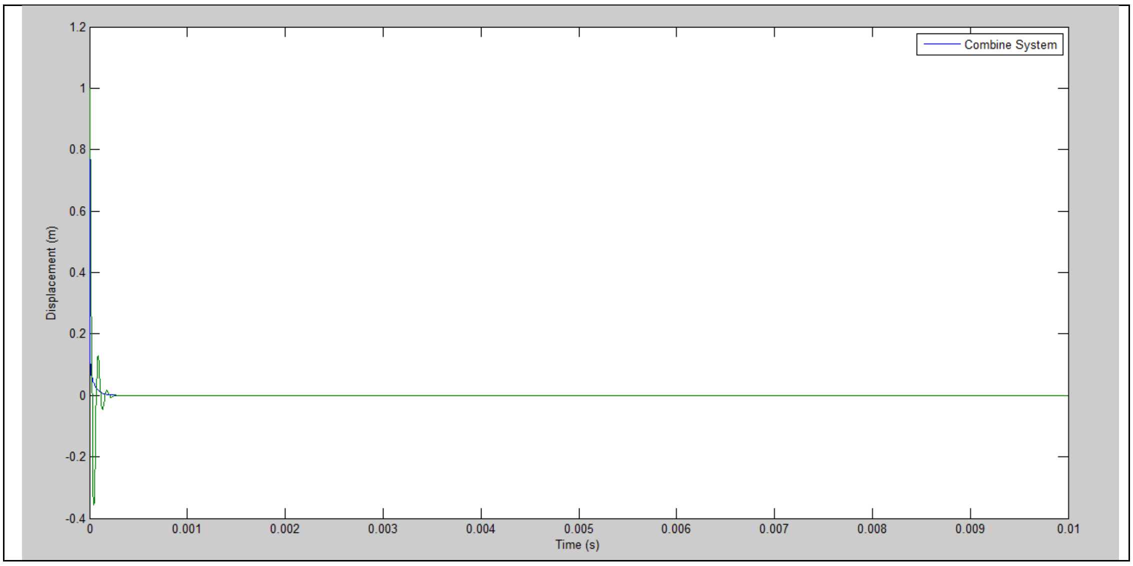

Figure 4.13: Comparison passive and active (PID) system

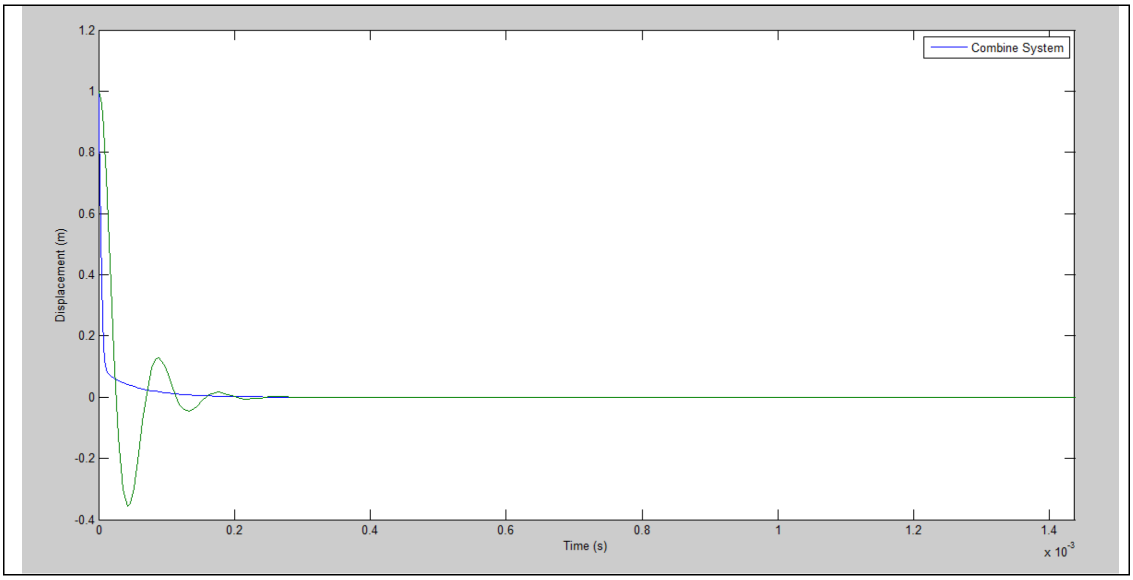

Figure 4.14: Comparison passive and active with PID system

Comparative between two system which is passive system and active system based on displacement versus time respond. PID which is active system is produce more stable in term of displacement plot. Passive systems have a big response error compare to the PID system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

A PID controller has been proposed in this project. It is a discrete-time version of the conventional PID controller. The results demonstrate that its performance is much better without a control system. This PID controller is suitable for the control in manufacturing industrial applications, as demonstrated by the examples given in this paper. This study shows the improvement of the milling machine performance base for many types of expectation for the accuracy of the product and the other. The idea to create the active vibration control system to overcome the chatter in the milling operation by implementing controller.

In the absence of knowledge of the process, a PID controller is the best controller. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error.

The understanding of mathematical model for each dynamical model, parameter and active controller is required before run the SIMULINK. Basically this simulation involve passive and active model for cutting tool isolation models. The PID controller is successfully implemented in the active model.

For the comparison result, it shows the active model give an advantage in control the vibration occurs in machining. As a conclusion, applying the PID controller have suppress the chatter on cutting tool of milling machine by using simulation based on active control vibration.

5.2 RECOMMENDATION

The control system performance can be improved by combining the feedback (closed-loop) control of a PID controller with feed-forward (open-loop) control. Knowledge about the system can be fed forward and combined with the PID output to improve the overall system performance. The feed-forward value alone can often provide the major portion of the controller output. The PID controller can be used primarily to respond to whatever difference or error remains between the set point (SP) and the actual value of the process variable (PV). Since the feed-forward output is not affected by the process feedback, it can never cause the control system to oscillate, thus improving the system response and stability. Besides that, applying the fuzzy logic control also give more accurate result in suppress the vibration occur in milling machine.

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APPENDICES

Technical Data (Preliminary)

Model	N-380 Open-Loop	N-381 Closed-Loop
Active axes	X	X
Motion and positioning		
Travel range	30 mm	30 mm
Step size (in step mode)	0.1 to 15 µm	–
Integrated sensor	–	Incremental linear encoder
Sensor resolution	–	20 nm*
Travel range in analog mode	7 µm	7 µm
Open-loop resolution	0.03 nm**	0.03 nm**
Closed-loop resolution	–	20 nm*
Step frequency	0 to 800 Hz	–
Max. velocity	10 mm/s*	10 mm/s*
Mechanical properties		
Stiffness in motion direction	2.4 N/µm	2.4 N/µm
Max. push / pull force (active)	10 N	10 N
Max. holding force (passive)	15 N	15 N
Lateral force	10 N	10 N
Drive properties		
Drive type	NEXACT® linear drive	NEXACT® linear drive
Operating voltage	-10 V to +45 V	-10 V to +45 V
Miscellaneous		
Operating temperature range	0 to 50 °C	0 to 50 °C
Material	Stainless steel / CFRP	Stainless steel / CFRP
Mass	250 g	255 g
Cable length	1.5 m	1.5 m
Connector	15-pin HD-Sub-D connector, one channel	15-pin HD-Sub-D connector, one channel
Recommended controller/driver	E-860 series (see p. 1-20)	E-861.1A1 (see p. 1-20)

*With E-861. Depending on drive electronics.
**Depending on the drive electronics. 1 nm with E-861.

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Figure 6.1: Technical data for actuator

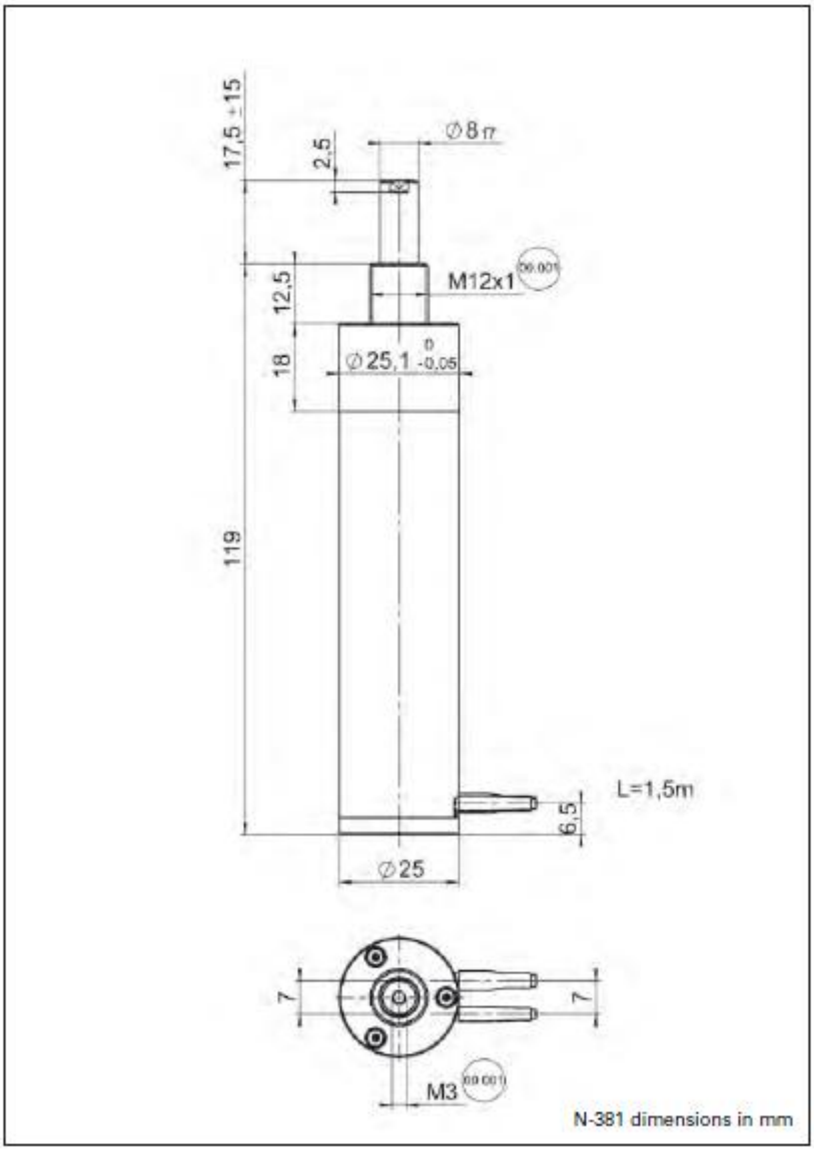

Figure 6.2: Actual dimension for actuator

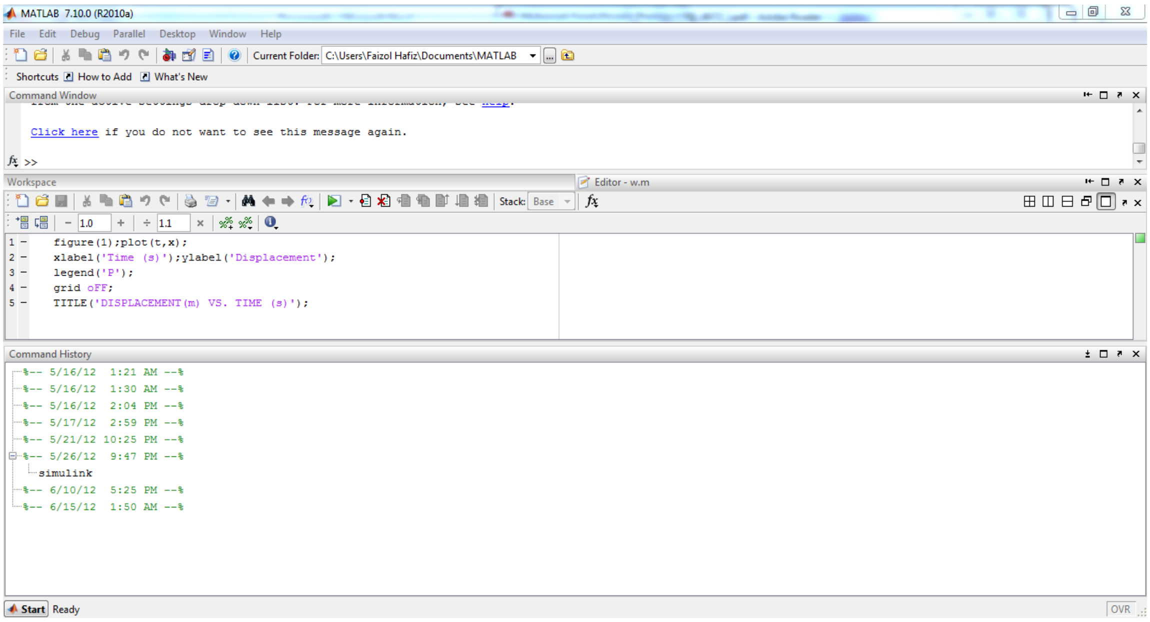

Figure 6.3: MatLab

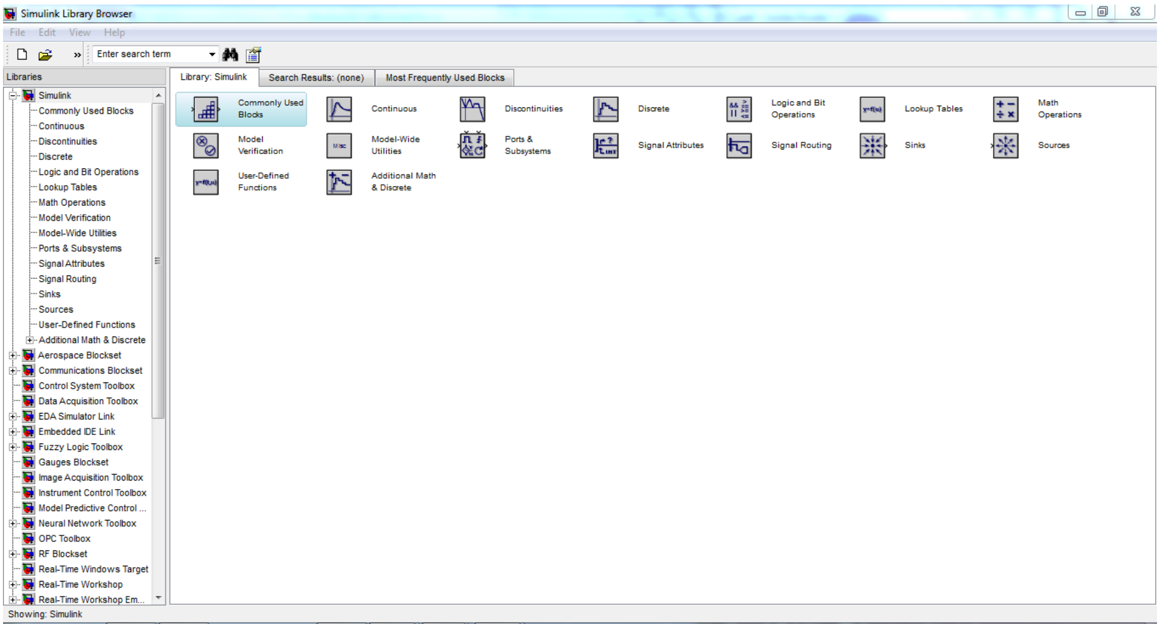

Figure 6.4: SIMULINK

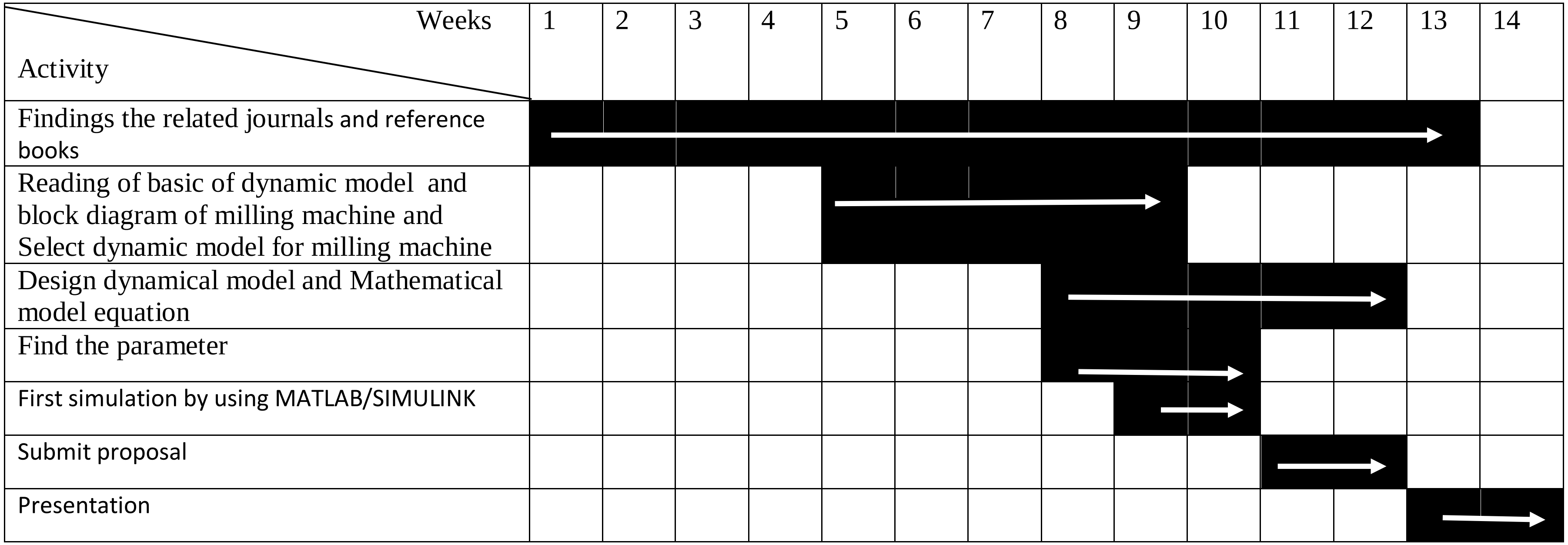

Figure 6.5: Gantt chart FYP 1

Weeks / Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Running simulation on Matlab/Simulink														
Compare simulation between P, PI, and PID														
Finishing FYP report														
Submit proposal														
Presentation														

Figure 6.6: Gantt chart FYP 2