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JUDUL: **DEVELOPMENT OF ONCE PER REVOLUTION SENSOR CHATTER**

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DEVELOPMENT OF ONCE PER REVOLUTION SENSOR CHATTER

EDZAMILA BINTI DZAIDI

Thesis submitted fulfillment of the requirements for the award of

Bachelor of Mechatronic Engineering

Faculty of Manufacturing Engineering

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EXAMINER APPROVAL DOCUMENT

We certify that the thesis entitled "Development of Once per Revolution Sensor Chatter" is written by Edzamila Binti Dzaidi. We have examined the final copy of this thesis and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We here with recommend that it be accepted in fulfillment of the requirement for the degree of Bachelor of mechatronic Engineering

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SUPERVISOR'S DECLARATION

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

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

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Name : Edzamila Binti Dzaidi

ID Number : FB09055

Date **:**

Special thanks to my parents on their support and cares,

Dzaidi Bin Abd Rahman

Hasnah Binti Said

Also for my husband,

Special dedicates for my supervisor,

Dr. Ahmad Razlan Bin Yusoff

On his guiding towards my project

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ABSTRACT

This research focused on the experimental development of once per revolution sensor chatter. In milling operation, self excited vibrations also called the chatter are one of the main factors that limit productivity. The project is used sensor chatter and non-sensor chatter to measure the variance of the signal sampled at a once per revolution rate. The sensor chatter is one of the main factors that lower the productivity. Higher efforts tend to accelerate tool wear and can lead to tool breakage. This project used the accelerometer to measures vibration and proper acceleration. The mounting of an accelerometer is easy but it is location must be carefully chosen. Indeed, if the sensor is close to a vibration node, signal amplitude would be very low. It is very difficult to put accelerometer on a rotating part. Beside that, the sensor tachometer (RPM gauge) is an instrument measuring the rotation speed of a tool milling machine. The device usually displays the revolutions per minute (RPM) on a calibrated analogue dial, but for this project the software of DasyLab that used can convert to revolution per second (RPS). A fast Fourier transform (FFT) is an algorithm to compute the discrete Fourier transform (DFT) and it is inverse. The result means the FFT operation, periodic functions will include changing the peak is not one, but two places. However, both these components are symmetric, so it was only necessary to see one to obtain frequency information. And providing information about the frequency, the FFT can be used to apply signal processing techniques such as filtering the signal and image compression is much easier to implement in the frequency domain. Detection of chatter, non-chatter and marginal chatter clearly can see in accelerometer, FFT and once per revolution signal. According to the results of machining experiment, it was proven that different parameter like spindle speed, feed rate and depth of cut producing chatter vibration.

ABSTRAK

Penyelidikan ini adalah berkenaan dengan eksperimen tentang perkembangan setiap satu pusingan lengkap bagi sensor getaran. Dalam proses milling, getaran teruja adalah salah satu faktor utama bagi menghadkan produktiviti. Dalam kajian ini sensor getaran dan tanpa sensor getaran adalah untuk mengukur perbezaan isyarat pada kadar setiap satu pusingan lengkap. Getaran sensor adalah salah satu faktor utama untuk mengurangkan produktiviti. Selain daripada itu, ia lebih cenderung untuk mempercepatkan kehausan mata alat dan boleh menyebabkan kerosakan. Kajian ini menggunakan sensor accelerometer untuk mengukur getaran dan kelajuan. Untuk memasang sensor ini adalah mudah tetapi perlu memilih lokasi yang tepat. Sekiranya sensor ini diletakkan berhampiran dengan nod getaran, amplitud isyarat akan menjadi sangat rendah. Ia akan mengalami kesukaran sekiranya diletakkan pada bahagian berputar. Selain daripada itu, sensor tachometer (RPM mengukur) merupakan sensor untuk mengukur kelajuan putaran mata alat bagi mesin milling. Sensor ini akan memaparkan revolusi per minit (RPM) pada analog, tetapi untuk kajian ini DasyLab telah digunakan untuk menukar kepada revolusi sesaat (RPS). Fast Fourier Transform (FFT) adalah satu algoritma untuk mengira Discrete Fourier Transform (DFT) . Dalam kajian untuk mendapatkan FFT, fungsi berkala akan menukarkan bukan pada satu peak sahaja tetapi dua peak. Walau bagaimanapun, kedua-dua komponen adalah simetri, maka ia hanya perlu untuk melihat satu sahaja peak untuk mendapatkan frekuensi. Bagi memperolehi maklumat mengenai frekuensi, FFT boleh digunakan untuk pemprosesan isyarat seperti menyekat isyarat dan mengeluarkan imej adalah lebih mudah untuk mendapatkan frekuensi domain. Pengesanan getaran, tanpa getaran dan marginal getaran boleh di lihat dengan jelas di accelerometer, FFT dan setiap satu pusingan lengkap. Berdasarkan keputusan eksperimen, ia telah membuktikan bahawa parameter yang berbeza seperti kelajuan mata alat, kadar suapan dan kedalaman memotong akan menghasilkan getaran.

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LIST OF ABBREVIATIONS

mm/m	millimeter per minute
mm	millimeter
mm/s	millimeter per second
cm/s	center miter per second
cm/m	center miter per minute
CNC	Computer Numerical Control
FFT	Fast Fourier Transform
FKM	Fakulti Kejuruteraan Mekanikal
rpm	Revolution per Minute
rps	Revolution per Second
hz	hertz
t	time

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUD

In milling operation, self excited vibrations also called the chatter are one of the main factors that limit productivity. The project is used sensor chatter and non-sensor chatter to measure the variance of the signal sampled at a once per revolution rate. The sensor chatter is one of the main factors that lower the productivity. Higher efforts tend to accelerate tool wear and can lead to tool breakage. One primary limiting factor in achieving high material removal rate (MRR) in milling operation is unstable cutting or chatter, characterized by increased forces and varying levels of work pieces and/or tool damage.

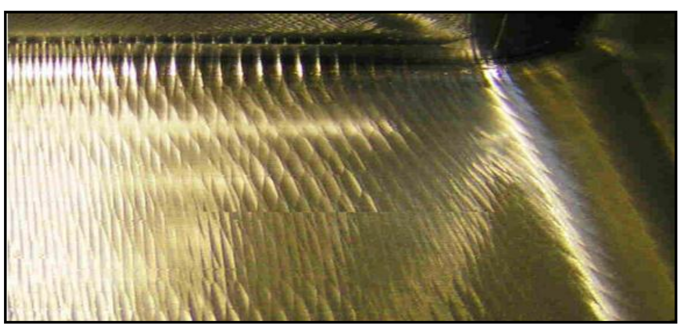


Figure 1.1: Poor surface finish of the product caused by the chatter of machining

Source: http://www.google.com.my/imgres

This project used the accelerometer to measures vibration and proper acceleration, also called the four-acceleration. The mounting of an accelerometer is easy but it is location must be carefully chosen. Indeed, if the sensor is close to a vibration node, signal amplitude would be very low. During the milling process, nodes can move, so it is very difficult to predict an optimal location. It is very difficult to put accelerometer on a rotating part. Beside that, the sensor tachometer (RPM gauge) is an instrument measuring the rotation speed of a tool milling machine. The device usually displays the revolutions per minute (RPM) on a calibrated analogue dial, but for this project the software of DasyLab that used can convert to revolution per second (RPS).

Specially, a chatter identification system to be applied in industrial conditions should have the following characteristics; (Kuljanic and Sortino, 2009)

1) It should not reduce stiffness and damping of the machine tool

2) It should be compatible to pallet changer and tool changer

3) It should not limit cutting parameters, tool dimension, work pieces dimensions and tool geometry.

4) The functioning of the chatter detection systems should not rely on the knowledge of the actual cutting conditions and on prior knowledge of the machining systems dynamics.

5) The system should be insensitive to environmental noise and it should be robust against the malfunctioning of one of its components.

1.2 PROBLEM STATEMENT

Study of the chatter and non-chatter vibration occurrences due to interaction of end mill cutter tool and workpiece. This project also to study about higher percentage of chatter vibration in end milling process as a function to increase metal removal rate.

1.3 OBJECTIVE OF PROJECT

1) To integrate tachometer with accelerometer for measure sensor chatter.
2) To analyze operation chatter at condition once per revolution and vibration in machining

1.4 SCOPE OF PROJECT

Scope of this project is to operation chatter at condition once per revolution and vibration in machining. For the next step, experiment will go through testing used the DasyLab. The project was used accelerometers to measures vibration and sensor tachometer (RPM gauge) is an instrument measuring the rotation speed of a tool milling machine. For many material that are easy to machine, this research activity has helped to motivate the development of operation machining, where very high material rate can be combined with good chatter stability and high quality surface finish. For this project, we used aluminum 7075 as a material.

This systems was programmed by DasyLab and used a National Instrument High Speed USB Carrier NI USB-9162 to measure the once per revolution. The signal from accelerometers and tachometer will be send to laptop. This signal for once per revolution will get and see from the laptop. Taken and analysis the data. The sequence of work has been planned as shown in Figure 1.2 in order to achieve the objectives of this research, while Gantt Charts can refer to Appendix A. This flow chart is useful as guideline to ensure that the experiment is carried out smoothly**.**

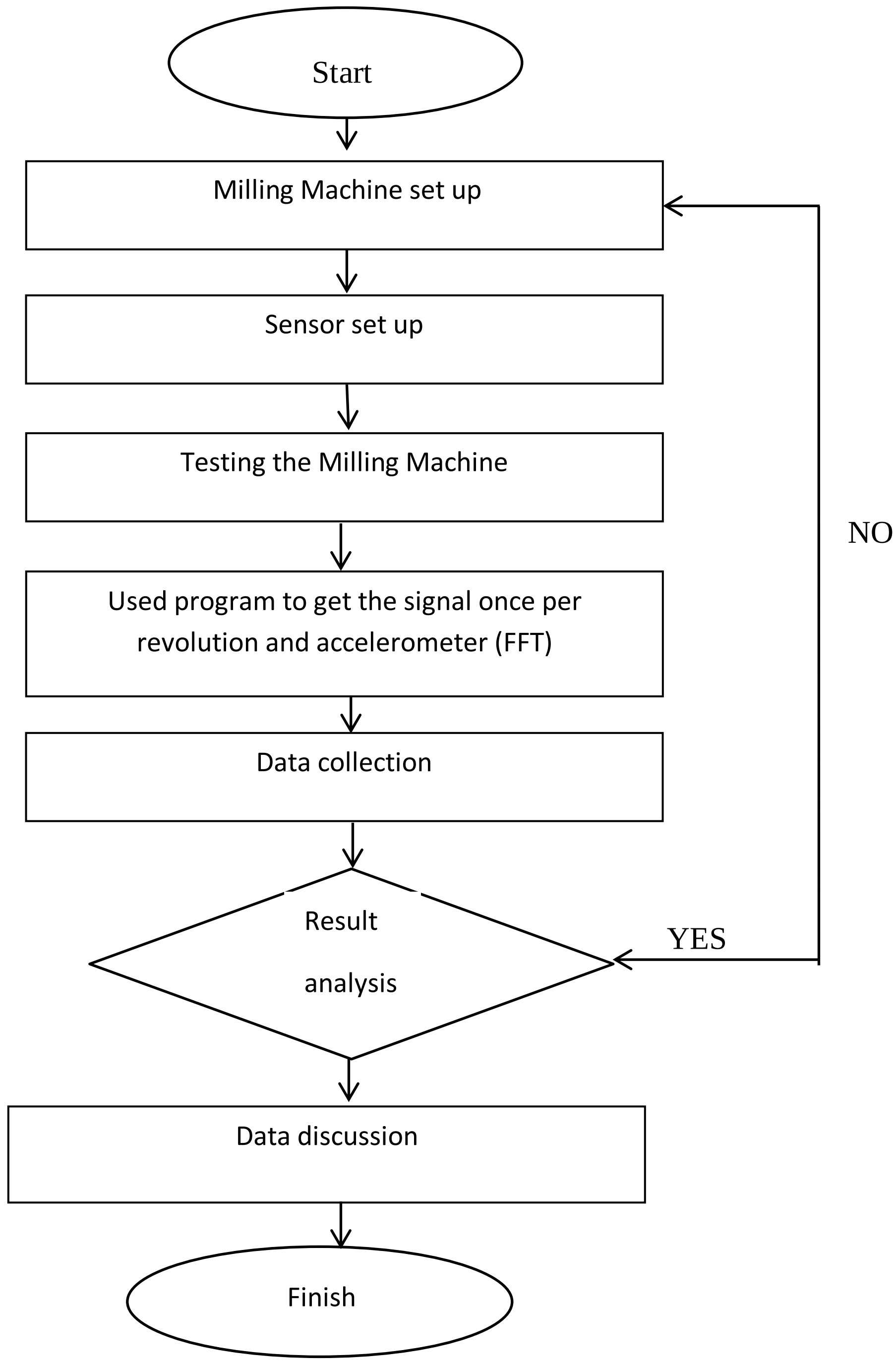


Figure 1.2: Project flow chart.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Technologies involved in machining operations have advanced greatly in the recent decades and machines have experienced significant changes such as the incorporation of numerical control. Every year, it's possible to observe in fairs, conference and of course, in the market, how production capabilities have increased thanks to development of new concept, devices, materials, tools, coatings, structures and so on. Accuracy, flexibility and productivity are enhanced constantly with innovative solutions to achieve market demands on even raise them to higher levels. In the end, all these improvements are possible thanks to the generation of knowledge (Quintana and Ciurana, 2011).

Manufacturing is very important because it provides high-wage jobs, commercial innovation, a key to trade deficit reduction, and a disproportionately large contribution to environmental sustainability. Manufacturing is the production of goods for use or sale using labor and machines, tools, chemical and biological processing or formulation. The term may refer to a range of human activity, from handicraft to high tech, but is most commonly applied to industrial production, in which raw materials are transformed into finished goods on a large scale. Such finished goods may be used for manufacturing other, more complex products, such as aircraft, household appliances or automobiles, or sold to wholesalers, who in turn sell them to retailers, who then sell them to end users.

Manufacturing takes turns under all types of economic systems. In a free market economy, manufacturing is usually directed toward the mass production of products for sale to consumers at a profit. In a collectivist economy, manufacturing is more frequently directed by the state to supply a centrally planned economy.

2.2 MACHINING

Machining is the broad term used to describe removal of material from a work piece. In terms of annual dollars spent, machining is the most important of the manufacturing processes and it is defined as the process of removing material from a work piece in the form of chips. The term metal cutting is used when the material is metallic. Most machining has very low set-up cost compared to forming, molding, and casting processes. However, machining is much more expensive for high volumes.

The many processes that have this common theme, controlled material removal, are today collectively known as subtractive manufacturing, in distinction from processes of controlled material addition, which are known as additive manufacturing. Machining is necessary where tight tolerances on dimensions and finishes are required. The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planning, boring, broaching and sawing. It is important to view machining, as well as all manufacturing operations, as a system consisting of the work piece, the tool and the machine.

The recent introduction of new and difficult to machine materials (e.g. aerospace alloys and reinforced plastics), as well as new tool materials (e.g. ceramics, and CBN inserts), has reduced considerably the predictability of cutting process. According, on-line tool failure detection is becoming a critical requirement for improving the utilization and flexibility of present-day CNC machine tools. It is estimated that fracture will be the dominant failure mode for more than 25% of all advanced tooling materials by, the year 1995. Therefore, tool breakage detection will be essential to the realization of untended machining (Di Yan and Elbestawi, 1995).

(a) Machining processes of turning

(b) Machining processes of drilling

(c) Machining processes of milling

Figure 2.1: Three principal machining processes are classified as turning, drilling and milling.

Source: http://www.google.com.my/imgres

2.3 MILLING MACHINE

For this project, the milling machine is used because to get the vibration and signal from the spindle tool for once per revolution sensor chatters. A milling machine is a machine tool used to machine solid materials. Milling machines are often classed in two basic forms, it is horizontal and vertical. The basic forms which refers to the orientation of the main spindle. Both types range in size from small, bench-mounted devices to room-sized machines. Work piece and cutter movement are precisely controlled to less than 0.001 in (0.025 mm), usually by means of precision ground slides and lead screws or analogous technology. Milling machines also can manually operate, mechanically automated, or digitally automated via computer numerical control.

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. For this project, milling machine used for drilling the side milling of material. This machine can also be used for cutting keyways, racks and gears and for fluting taps and reamers. These milling machines are also classified as knee-type, ram-type, manufacturing or bed type and planer-type milling machines. Most these machines have self-contained electric drive motors, coolant systems, variable spindle speeds, and power operated table feeds.

In machining, boring is the process of enlarging a hole that has already been drilled (or cast), by means of a single-point cutting tool (or of a boring head containing several such tools), for example as in boring a gun barrel or an engine cylinder. Boring is used to achieve greater accuracy of the diameter of a hole, and can be used to cut a tapered hole. Boring can be viewed as the internal-diameter counterpart to turning, which cuts external diameters.

Slot milling is an operation in which side and face milling are often preferred to end milling.

1) Slots or grooves can be short or long, closed or open, straight or non-straight, deep or shallow, wide or narrow.

2) Tool selection is normally determined by the width and depth of the slot and, to some extent, length.

3) Available machine type and frequency of operation determine, whether an end mill, long edge cutter or side and face milling cutter should be used.

4) Side and face cutters offer the most efficient method for milling large volumes of long, deep slots, particularly when horizontal milling machines are used. The growth of vertical milling machines and machining centres, however, means that end mills and long edge cutters are also frequently used in a variety of slot milling operations.

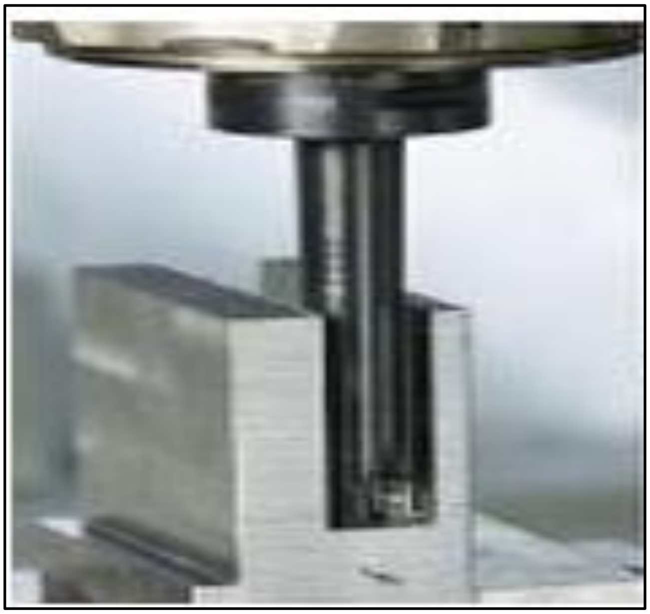


Figure 2.2: Slotting for milling machine.

Source: http://www.google.com.my/imgres

An indexing head, also known as a dividing head or spiral head, is a specialized tool that allows a workpiece to be circularly indexed; that is, easily and precisely rotated to preset angles or circular divisions. Indexing heads are usually used on the tables of milling machines, but may be used on many other machine tools including drill presses, grinders, and boring machines. Common jobs for a dividing head include machining the flutes of a milling cutter, cutting the teeth of a gear, milling curved slots, or drilling a bolt hole circle around the circumference of a part.

Since a milling machine can perform exact positioning, a drilling process can be carried out to an exact position. It is more efficient to process it using a drilling machine, if it is easy drilling process. However, when correctness is required of the position of the holes, or when there are many holes, the milling machine is suitable. Moreover, it is also the characteristics of the drilling with the milling machine that the taper drill of a large diameter can be used.

Figure 2.3: Drilling for milling machine.

Source: http://www.google.com.my/imgres

A milling cutter is a cutting tool that is used on a milling machine. Milling cutters are available in many standard and special types like forms, diameters and widths. The teeth maybe straight (parallel to the axis of rotation) or at a helix angle. The helix angle helps a slow engagement of the tool distributing the forces. The cutter may be right-hand (to turn clockwise) or left-hand (to turn counterclockwise). Below is example for features of milling cutter:

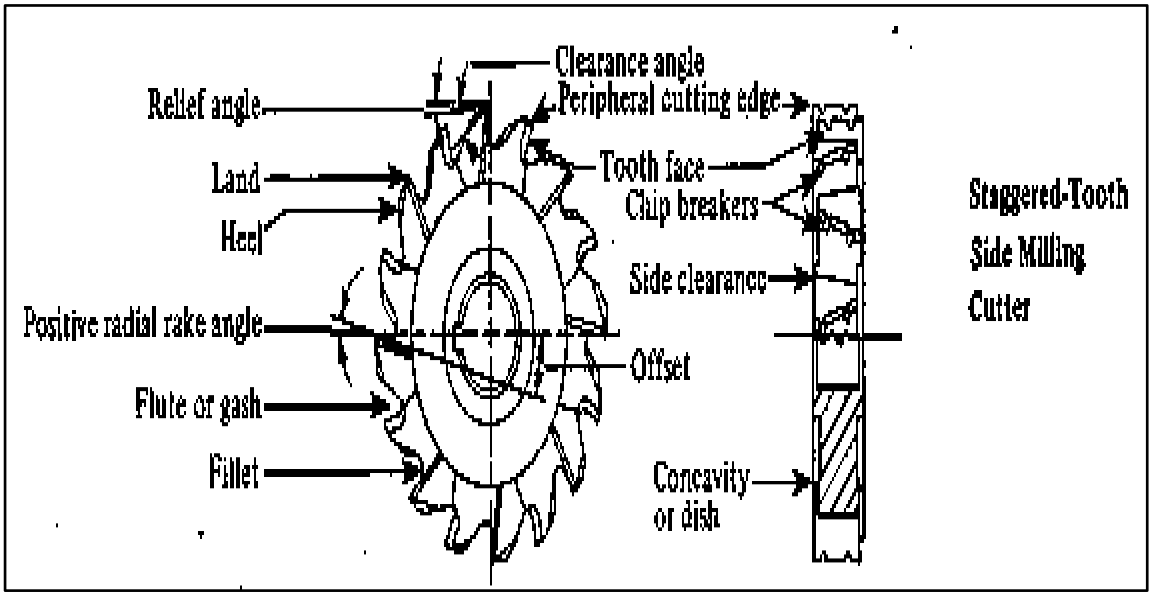


Figure 2.4: Features of milling cutter

Source: http://www.google.com.my/imgres

There are also many type of milling cutter. It is like for the example below:

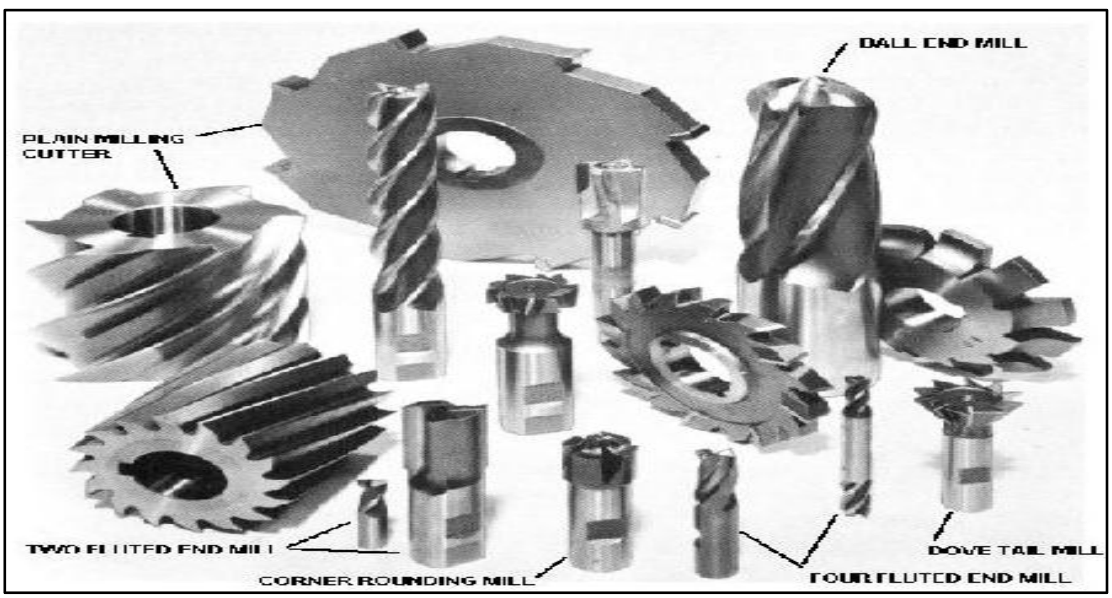


Figure 2.5: Type of milling cutter

Source: http://www.google.com.my/imgres

Metal cutting is a complex nonlinear dynamical process. The machine, the cutting tool, and the work piece form a complex system which has infinite number of degrees of freedom. The cutting process under dynamical conditions can behave in different ways for different modes of vibration. Instability of cutting process causes self-excited large-amplitude vibrations of the tool relative to the work piece. This phenomenon, known as chatter, adversely affects the performance and efficiency of the cutting process, quality of the product and produces high level of noise. This has negative influence on surface finish and dimensional accuracy of the work piece, tool life, and even machine life. Hence, it is important to detect the occurrence of chatter at an early stage so that corrective measures can be adopted by changing the cutting conditions. Various factors leading to chatter onset are increase in depth of cut, variation in cutting speed and variation in feed rate (Nair and Nampoori, 2010)

The characteristics of the identification system are similar for tool breakage detection systems, as follows: reliability, robustness, responsiveness, flexibility and practicality. In addition, the application in industrial conditions implies the following requirements (Kuljanic and Sortino, 2009).

1) It should not modify the modal parameters of the machining system, in particular it should not reduce the stiffness of the machine tool.
2) It should be compatible to pallet changer and to tool changer.
3) It should not put constraints on the selection of cutting parameters and on any other machining condition (tool dimensions, workpiece dimensions, tool geometry, and others)
4) The functioning of the chatter detection system should not rely on the knowledge of the actual cutting conditions and on a priori knowledge of the machining system dynamics.
5) The system should be insensitive to environmental noise

2.4 CHATTER IN MACHINING

Nowadays, the need of increasing the productivity and reducing the production costs is pushing towards fully automatic, unmanned machining centers or intelligent machining systems. In the new conditions, machine tool should be able to perform automatically the following activities, collision detection and prevention, tool condition monitoring, optimization of cutting parameters, detection and suppression of chatter vibrations. Specifically, the integration of chatter detection systems into control unit of machine tool would be a great improvement in precision machining. In this project, a new real-time sensor system has been developed to detect chatter in milling operations.

Actually chatter means the occasional unwanted vibration between components. Chatter decreases productivity and can cause wear. The features on the cutting force spectrum are fed into the sensor system to classify the milling operation process with or without chatter. The experimental results indicate that the proposed sensor system can accurately detect milling chatter regardless of the variation in cutting conditions and give signal from the vibration.

Machine tool chatter is an unfavorable phenomenon during metal cutting, which results in heavy vibration of cutting tool. With increase in depth of cut, the cutting regime changes from chatter-free cutting to one with chatter (Nair, and Nampoori, 2010).

One of the major limitations on productivity in metal cutting is chatter vibration, which causes poor surface finish and tool damage. Although there are several sources of chatter in metal cutting, the wave regenerative mechanical is usually the most dominant in milling operation. Regenerative chatter develop when the axial and radial depth of cut are larger than stability limit allowed by the structural compliance between the tool and the work pieces. Chatter is assumed to be present when the maximum magnitude exceeds the low frequency spectrum average by a factor greater than the threshold factor (Altintas and Philip, 1992).

In recent years, many researchers have investigated the application of sensors for chatter detection in machining operations. Table 2.3 illustrates some research works focused on chatter identification systems. The table is organized to indicate the machining process considered in the research, the sensor or sensors used, the applied signal processing techniques or classification methods and the authors' reference. Several contributions have investigated chatter identification systems in milling. The sensors which are mostly applied are the plate dynamometer, the microphones, and the displacement and acceleration sensors.

A dynamometer or dyno for short is a device for measuring force, moment of force (torque), or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (RPM). During milling test, these cutting forces were measured with Kistler Model 9257A dynamometer. With the work pieces, the bandwidth of the dynamometer was about 100Hz. The displacements of the cutter were monitored by a stationary proximity sensor, which was located close to a steel sleeve fitted to the cutter just above the cutting depth.

As proposed by Smith and Delio, a remotely positioned microphone was also used the measure the sound pressure during cutting. The spindle A.C motor was controlled by an in-house developed Intel 8096 microprocessor based variable speed drive system. The spindle speed parameters are sent from a personal computer (PC) to the variable speed control computer via a RS-232 serial connection. Due to the high inertia of the spindle, speed variation is limited to a maximum of 60 rev/min amplitude and 3 Hz frequency (Altintas and Philip, 1992).

Table 2.1: Summary of chatter identification systems research.

Process	Sensors	Signal processing and Classification methodology	Reference
Milling	Microphone	PSD	T. Delio and S. Smith, (1992)
Turning	Accelerometer	Cross coherence of acceleration in two directions	X.Q. Li and Nee,1996.
Milling	Eddy current displacement sensors and plate dynamometer	PSD and qualitative analysis of time trajectories	M.Hashimoto and S. Kato,1996.
Milling	Laser displacement sensor	Qualitative analysis of tool vibration in time	O. Ryabov and N. Kasashima, 1998
Turning	Plate dynamometer under the turret	Coarse-grained entropy rate—CER of the force signals	J. Gradisek and I. Grabec,1998.
Turning	Plate dynamometer under the turret	Time series analysis of the force signals	J. Gradisek, E. Govekar, I. Grabec,1998
Milling	Microphone	Variance of OPRS	T.L. Schmitz and J. Snyder,2001
Milling	Plate dynamometer	WT	C.S. Suh and B. Yang,2002
Milling	Eddy current displacement sensors	OPRS, PS, PSD of tool trajectory (quantitative chatter indicators not specified)	B.P. Mann and G. Ste´pa´ n,2003
Milling	Plate dynamometer	PSD	R.P.H. Faassen

	and microphone (harmonizer)		and H. Nijmeijer, 2003
Milling	Plate dynamometer	FFT	C.K. Toh,2004
Milling	Laser displacement sensor	OPRS, PS, PSD of tool trajectory (quantitative chatter indicators not specified)	J. Gradisek and I. Grabec, 2005
Milling	Microphone	PSD	W.L. Weingaertner and J.de Oliveira Gomesc,2006

OPRS = Once per revolution sampling; PS = Poincare´ sections; PSD = power spectral density; FFT = fast Fourier transform; WT = Wavelet transform.

Source: Department of Electrical, Managerial and Mechanical Engineering, University of Udine, Via delle Scienze, 2008.

2.5 SENSOR

An experimental procedure for calculating stable spindle speeds and axial engagement is developed and tested for once per revolution. The effect of cutting milling operation conditions on the chatter frequency is observed. So that, the results is to get from the sensor. This project is used two sensors; it is accelerometer and tachometer sensor.

The sensor accelerometer is a device that measures proper acceleration. It is proper acceleration measured by an accelerometer is not necessarily the coordinate acceleration (rate of change of velocity). For this project, the sensor is put on the work piece, aluminum. Actually this sensor has multiple applications in industry and science. The highly sensitive accelerometers are components of inertial navigation systems for aircraft and missiles. For this project, accelerometers sensor are used to detect and monitor vibration in rotating machinery. It’s detecting the rotating tool of Milling Machine.

The accelerometers sensors are available to measure acceleration in one, two, or three orthogonal axes. They are typically used in one of three modes, its is like as an inertial measurement of velocity and position; as a sensor of inclination, tilt, or orientation in 2 or 3 dimensions, as referenced from the acceleration of gravity (1 g = 9.8m/s2); and as a vibration or impact (shock) sensor.

This project is use the type of accelerometer is piezoelectric sensor. A piezoelectric sensor is a device that uses the piezoelectric effect to measure pressure, acceleration, strain or force by converting them to an electrical charge. Piezoelectric sensors have proven to be versatile tools for the measurement of various processes. They are used for quality assurance, process control and for research and development in many different industries. The rise of piezoelectric technology is directly related to a set of inherent advantages. The high modulus of elasticity of many piezoelectric materials is comparable to that of many metals and goes up to 106 N/m². Even though piezoelectric sensors are electromechanical systems that react to compression, the sensing elements show almost zero deflection. This is the reason why piezoelectric sensors are so rugged, have an extremely high natural frequency and an excellent linearity over a wide amplitude range. Additionally, piezoelectric technology is insensitive to electromagnetic fields and radiation, enabling measurements under harsh conditions.

Most accelerometers are Micro-Electro-Mechanical Sensors (MEMS). The basic principle of operation behind the MEMS accelerometer is the displacement of a small proof mass etched into the silicon surface of the integrated circuit and suspended by small beams. Its consistent with Newton's second law of motion (F = ma), as an acceleration is applied to the device, a force develops which displaces the mass. The support beams act as a spring, and the fluid (usually air) trapped inside the IC acts as a damper, resulting in a second order lumped physical system.

The development of a chatter detection system for application in industrial conditions was investigated. Several sensors—rotating dynamometer, accelerometers, acoustic emission and electrical power sensors—were compared to determine which signals are most sensitive to chatter onset. The signal characteristics both in time and frequency domain were condensed into a set of chatter indicators, which were further elaborated by means of statistical basic concepts, in order to obtain a chatter identification system. Single-sensor systems and multisensor systems were compared both in terms of accuracy and robustness against malfunctions. Among single sensor systems, the cutting torque signal proved to be a superior signal for chatter identification. Multisensors systems composed of three or four sensors are the most promising solution for reliable and robust chatter identification. The best results were obtained by the multisensor system composed of the axial force sensor and accelerometers (Kuljanic and G. Totis, 2009).

2.6 MATERIAL

Material that used for this project is Aluminium. Aluminium (or aluminum) is a chemical element in the boron group with symbol Al and atomic number 13. It is silvery white, and it is not soluble in water under normal circumstances. Aluminium is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. Structural components made from Aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. The most useful compounds of Aluminium, at least on a weight basis, are the oxides and sulfates.

Table 2.2: Specification of Aluminum.

Symbol	: Al
Melting point	: 660.3° C
Electron configuration	: Ne 3s2 3p1
Atomic number	: 13
Boiling point	: 2,519° C
Atomic mass	: 26.981539 ± 0.0000008

Aluminium is a relatively soft, durable lightweight, ductile and malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. It is nonmagnetic and does not easily ignite. A fresh film of Aluminium serves as a good reflector (approximately 92%) of visible light and an excellent reflector (as much as 98%) of medium and far infrared radiation. The yield strength of pure Aluminium is 7–11 MPa, while Aluminium alloys have yield strengths ranging from 200 MPa to 600 MPa. Aluminium has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded.

Table 2.3: Density and tensile strength Aluminum

SUBSTANCE	GRAMS PER CUBIC (cm)	TENSILE STRENGHT IN MPa
Water	1.0	Liquid
Aluminum	2.7	40-50, 310 in alloy
Titanium	4.5	240-434
Zinc	7.1	110-200
Nickel	8.9	140-195
Copper	8.9	210
Lead	11.3	12
Mercury	13.6	Liquid
Gold	19.3	100

2.7 FAST FOURIER TRANSFORM (FFT)

A fast Fourier transform (FFT) is an algorithm to compute the discrete Fourier transform (DFT) and it is inverse. There are many different FFT algorithms involving a wide range of mathematics, from simple complex-number arithmetic to group theory and number theory.

Changes the Fourier are very useful because they reveal the period of the input data and the relative strengths of any periodic components. The result means the FFT operation, periodic functions will include changing the peak is not one, but two places. However, both these components are symmetric, so it was only necessary to see one to obtain frequency information. And providing information about the frequency, the FFT can be used to apply signal processing techniques such as filtering the signal and image compression is much easier to implement in the frequency domain.

In relation to the signal processing and classification methods, the methods of analysis in the frequency domain (power spectral density—PSD, fast fourier transform—FFT and wavelet transform—WT) are the most common. All these classification methods are based on the analysis of the energy distribution in the signal spectrum (E. Kuljanic, M. Sortino and G. Totis, 2008).

2.8 SUMMARY

In this chapter, chatter is to need of increasing the productivity and reducing the production costs is pushing towards fully automatic, unmanned machining centers or intelligent machining systems. In the new conditions, machine tool should be able to perform automatically the following activities, collision detection and prevention, tool condition monitoring, optimization of cutting parameters, detection and suppression of chatter vibrations.

This project used milling machine to get the vibration and signal from the spindle tool for once per revolution sensor chatters. The sensor used is accelerometers sensors and tachometer. Accelerometers sensors are available to measure acceleration in one, two, or three orthogonal axes. They are typically used in one of three modes, its is like as an inertial measurement of velocity and position; as a sensor of inclination, tilt, or orientation in 2 or 3 dimensions, as referenced from the acceleration of gravity (1 g = 9.8m/s2); and as a vibration or impact (shock) sensor.

Material that used is Aluminum is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation.

CHAPTER 3

METHODLOGY

3.1 INTRODUCTION

This chapter presents the overall methodology of the experiments. Research methodology is usually that are planned and also guideline system for solving a problem. The experimental methods and producers are will discussed step by step and clearly. This chapter will be discussed based on the objective and scope of the research.

3.2 EXPERIMENT PROCEDURE

The experiment will be conducted based on the scope of the project. This project need use the sensor accelerometer and tachometer. Starting with the first requirement, build a single degree of freedom flexural. This project also used the material as aluminum. This aluminum needs the actual size. The actual size is 150 x 50 x 30 mm^3. To get this actual size, this aluminum needs to cut with horizontal band saw. After that, fit the size with CNC vertical milling machine. Next, CNC vertical milling machine need to running with software DasyLab to get graph for chatter and non-chatter. From this process, the data is different because the experiment is conducted to compare analytical prediction, depth of cut material with different speed (RPM) and feed rate (mm/min). Finally, analysis the data and process will be continued to get more data and also signal from vibration.

3.2.1 Build a Flexure

This project, a single degree of freedom flexure as shown in Figure 3.1, has to build as the first requirement in the project. During the machining experiment to validate the chatter stability prediction, flexure will be clamped to the worktable of the machine, while the workpiece have to tight on the top of flexure.

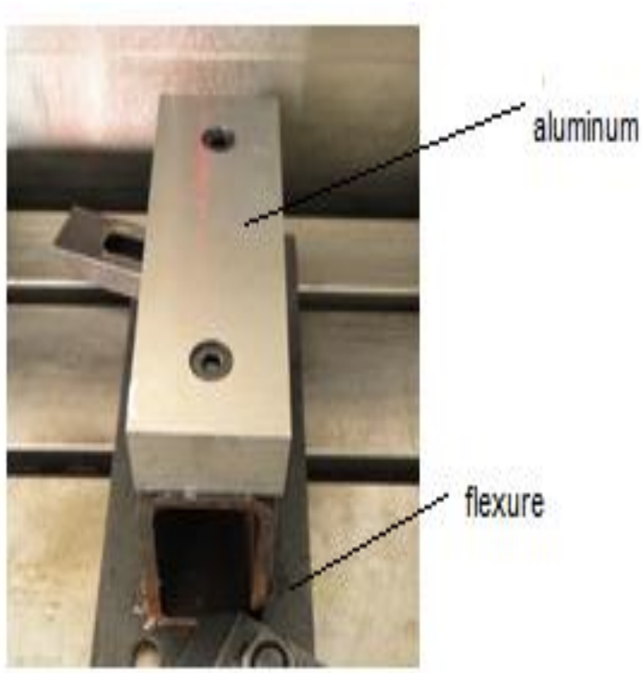


Figure 3.1: Flexture of Experiment.

3.2.2 Preparation of Material (Wokpieces)

After finishing chatter stability prediction, the project continued by preparing the materials which are aluminum that available at FKM Laboratory. In this stage, horizontal band saw machine as shown in Figure 3.2, have been used for this purposed to cut aluminum 7075 bars with dimension of 150 x 50 x 30 mm^3 each (Figure 3.3). The quantities of workpieces are based on the points on the stability lobes diagram that wanted to be tested.

Figure 3.2: Horizontal Band Saw Machine

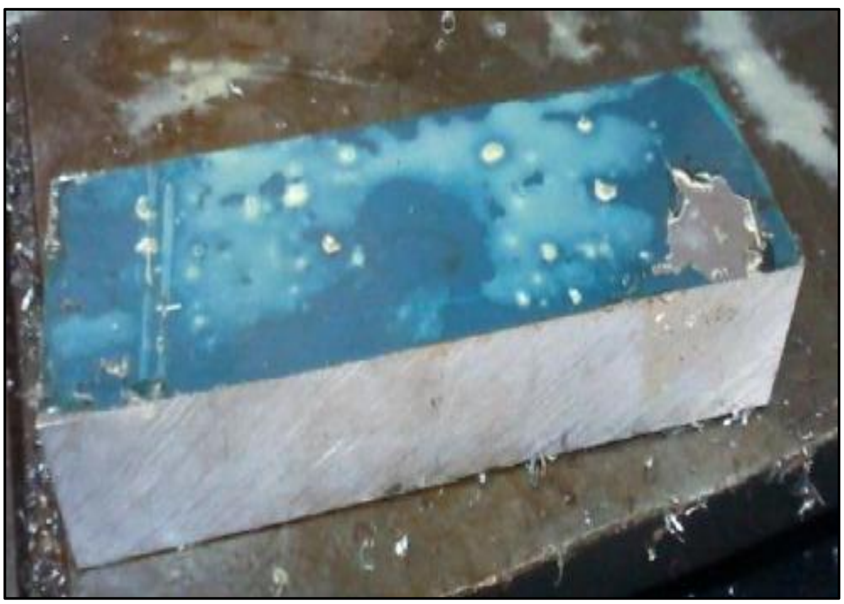


Figure 3.3: Aluminum 7075 specimen.

3.2.3 Machining Experiment

The machining was performed on a CNC vertical milling machine, as shown in Figure 3.4.

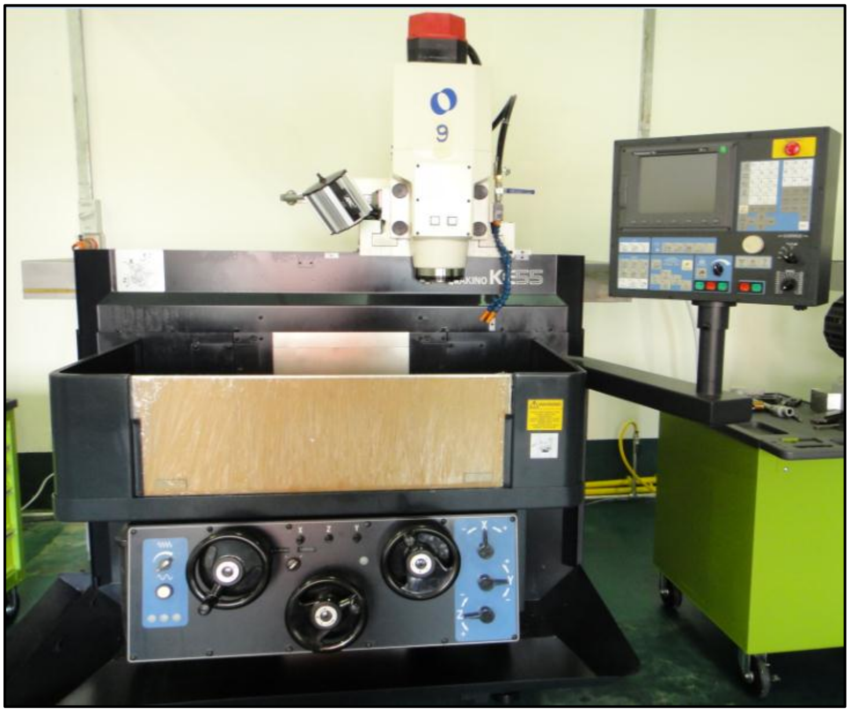


Figure 3.4: CNC vertical milling machine

During the experiment, the acceleration response was captured by piezoelectric accelerometer (PCB 352C33), refer to Figure 3.5 and tachometer refer Figure 3.6 which located on the flexure and connected to a National Instrument High Speed USB Carrier NI USB-9162 (refer to Figure 3.7) and laptop. The connection from both of sensor can see like Figure 3.8. This figure shows that cutting experiment setup for schematic diagram for both of the sensor location on the milling machine. After the experiment is done, the graphs of FFT spectrum, tachometer and acceleration signal that obtain on the laptop can be collected. The experiment studies the effect of Depth of Cut, Feed Rate and Spindle Speed to machining chatter.

Figure 3.5: Piezoelectric accelerometer (PCB 352C33)

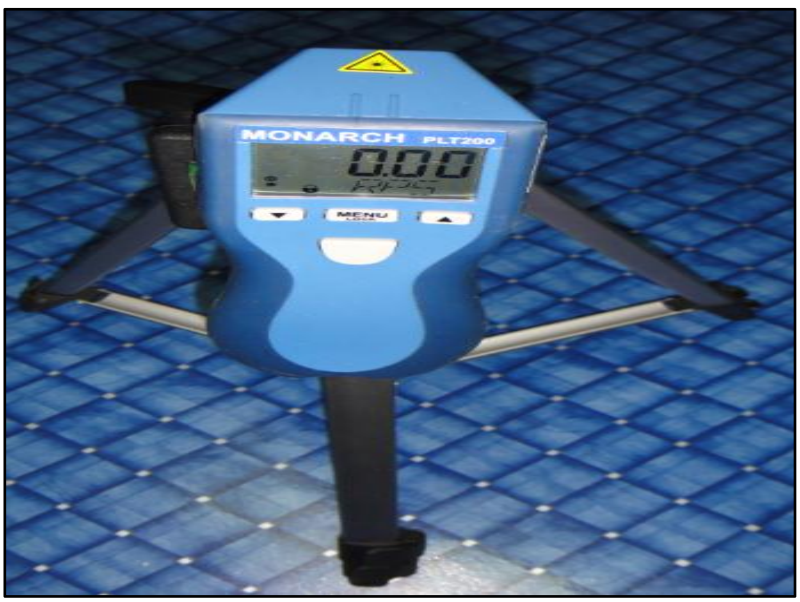
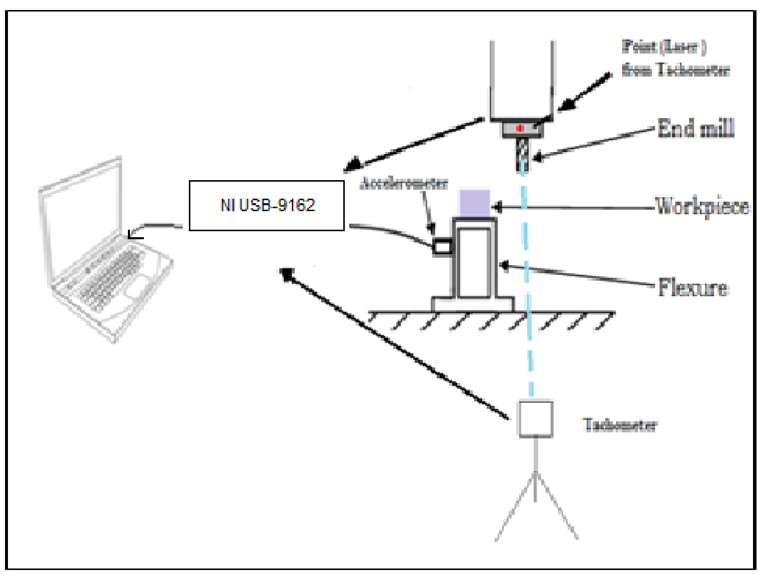
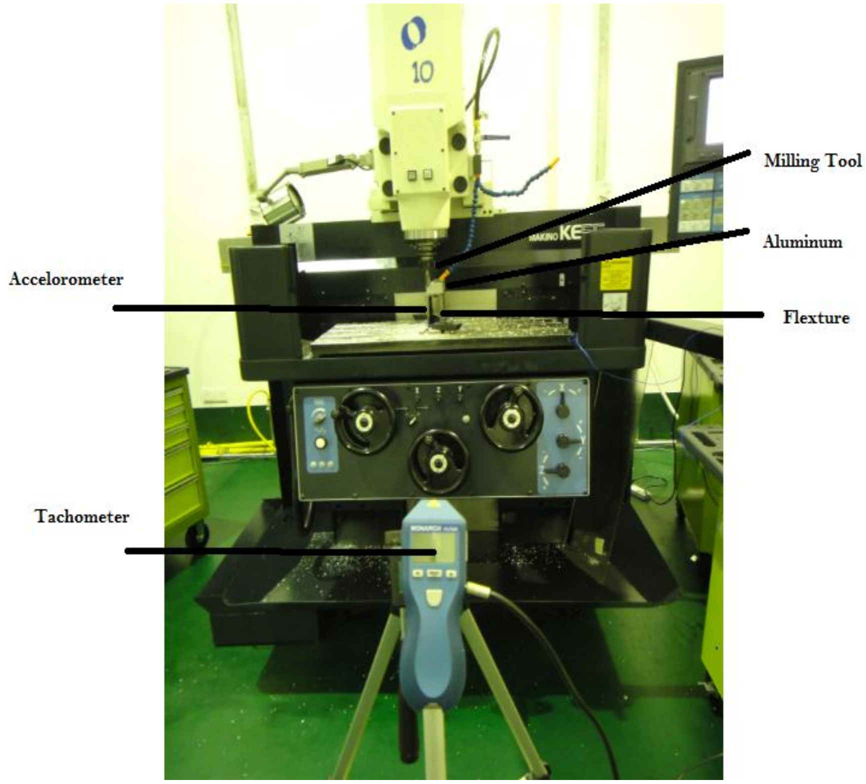


Figure 3.6: Tachometer

Figure 3.7: National Instrument High Speed USB Carrier NI USB-9162



(a)



(b)

Figure 3.8: Cutting experiment setup: (a) schematic diagram and (b) Sensor accelerometer and tachometer location.

3.3 DASYLAB

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems (abbreviated with the acronym DAS or DAQ) typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

1) Sensors that convert physical parameters to electrical signals.
2) Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.

3) Analog-to-digital converters, which convert conditioned sensor signals to digital values.

Data acquisition applications are controlled by software. The software used is DasyLab. Figure 3.9 show the worksheet of DasyLAb that used for this project. Based on the worksheet, the graph will display as like below:

- y/t chart 00 = Roughness data.
- y/t chart 01 = FFT
- y/t chart 02, channel 0 = Time domain accelerometer
- y/t chart 02, channel 1 = Time domain tachometer
- digital meter = Revolution per second

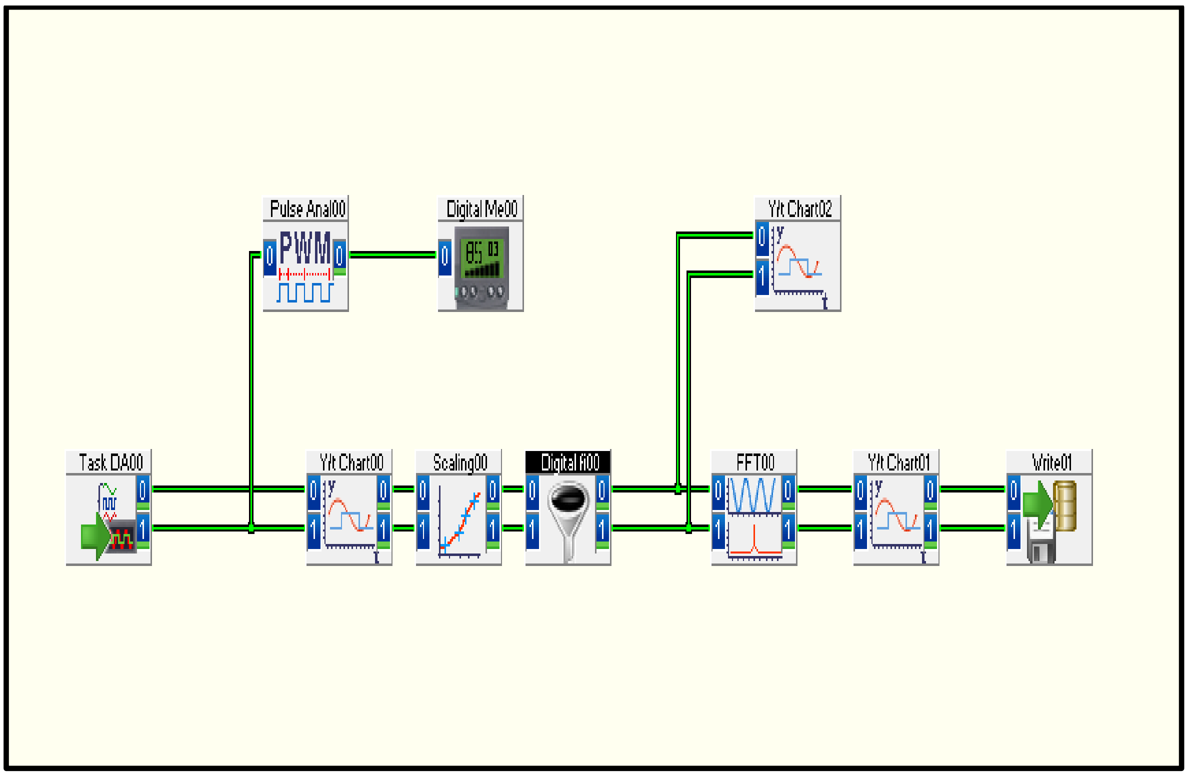


Figure 3.9: The worksheet of DasyLAb.

3.4 SUMMARY

The result from sensor chatter and non-chatter once per revolution signal will be get from the machining experiment using CNC vertical milling machine will be defined and classify it vibration condition. The others findings or journals will be used as the comparison to the results to make sure that the result is acceptable and follow the theoretical behavior. This project needs the data from frequency, spindle speed, feed rate and depth of cut. From this data, the signal from chatter and non-chatter once per revolution signal will be getting. Conclusion and recommendation will be made based on the result and discussion that being got from the machining experiments. The conclusion becomes as a summary of overall procedures of research, and recommendation will be suggested to improve any weakness founded during the experiment.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter generally discussed about the results and the analysis that obtained throughout the experimental development of once per revolution sensor chatter. The performance of depth of cut, feed rate and spindle speed will be investigated in the experiment. The experiment will show where a data get from the graph to avoid chatter from happen. Then, the machining experimental results will be compared with different type; it is depth of cut, feed rate and spindle speed.

4.2 CHATTER IDENTIFICATION

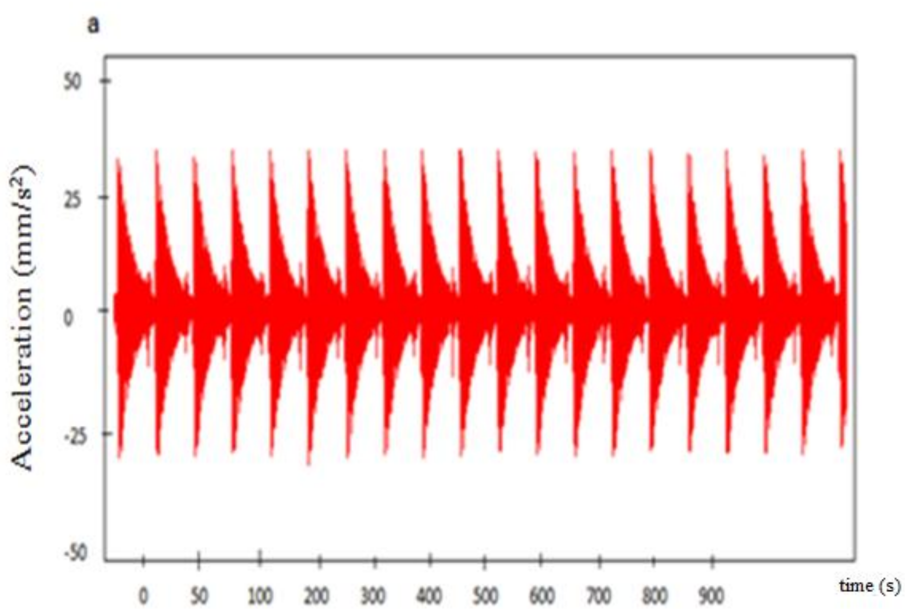
The FFT spectrum, acceleration and tachometer signals were measured from sensor accelerometer and tachometer for different type that used to compared the chatter on the graph like it is depth of cut, feed rate and spindle speed. For 16mm diameter tool used, the cutting tests were carried out in 3 cases: depth of cut (1 mm, 2 mm, 3 mm), feed rate (120 mm/m, 140 mm/m) and spindle speed (500 rpm, 1000 rpm. 1500 rpm, 2000 rpm). For stable, unstable and marginal stable, the result for accelerometer, FFT and once per revolution can get based on graph from DasyLab.

The cases for depth of cut, feed rate and spindle speed as shown in Figures 4.1, 4.2 and 4.3, respectively, represent the chatter, non-chatter and marginal chatter condition. For the figure 4.1 show the non-chatter was happen because the acceleration signals in stable at 25mm on 15 minute. At the FFT spectrum, the frequency also stable. It is happen because used the spindle speed at 1000 rpm, feed rate 120 mm/m and depth of cut 2 mm.

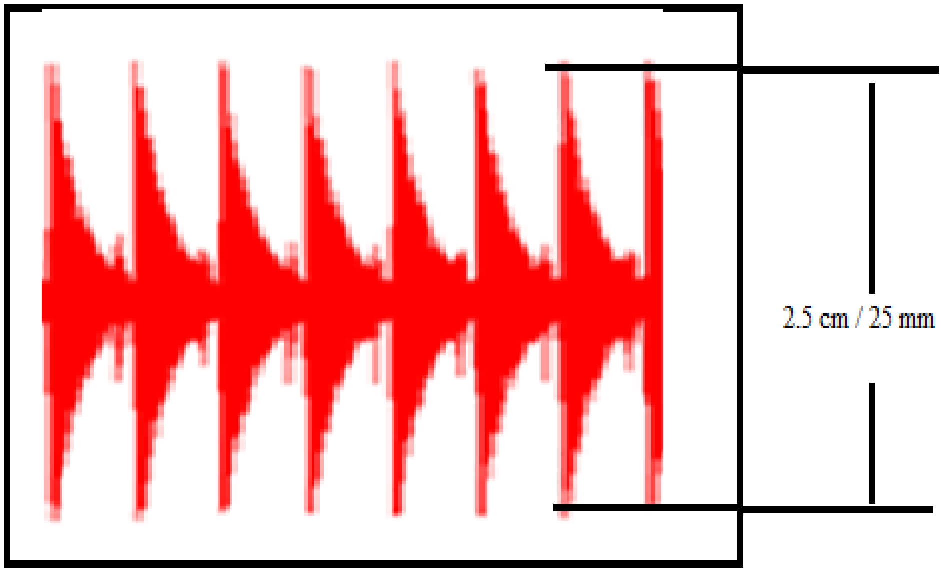
. For the figure 4.2 show the marginal chatter was happen because the acceleration signals in stable 5 mm and after that unstable at 10 mm on 2 minute. At the FFT spectrum, the frequency also marginal stable. It is happen because used the spindle speed at 1500 rpm, feed rate 120 mm/m and depth of cut 1 mm.

For the figure 4.3 show the chatter was happen because the acceleration signals in unstable 38 mm on 15 minute. At the FFT spectrum, the frequency also unstable. It is happen because used the spindle speed at 2000 rpm, feed rate 120 mm/m and depth of cut 3 mm.

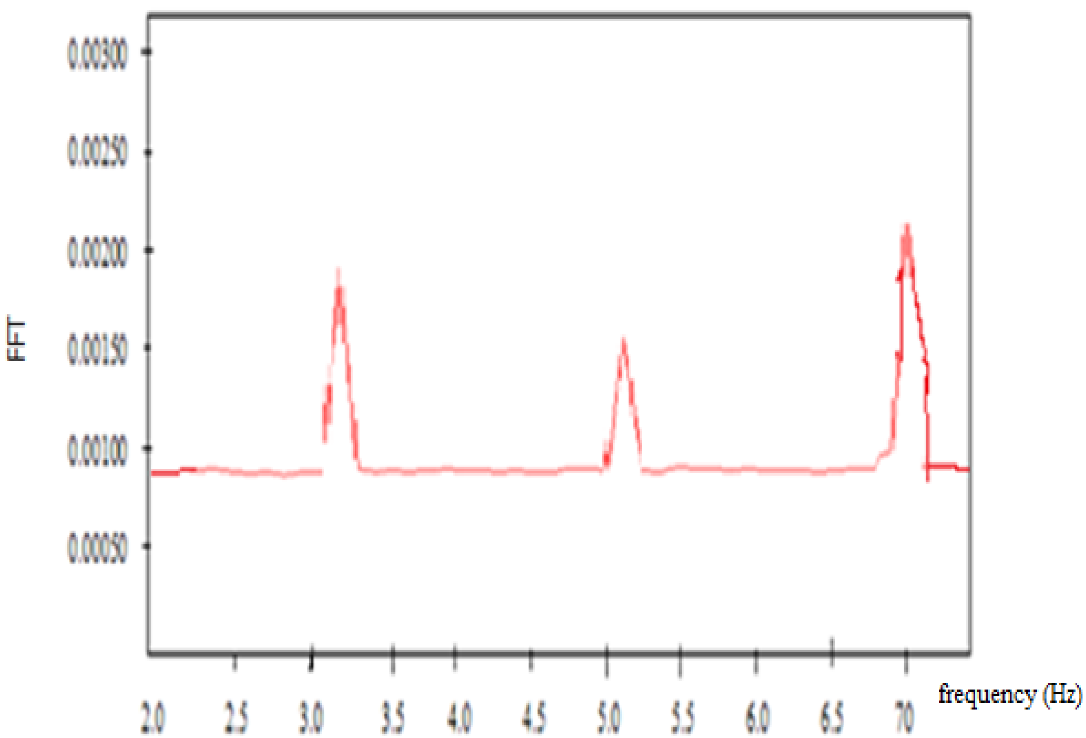
(a)



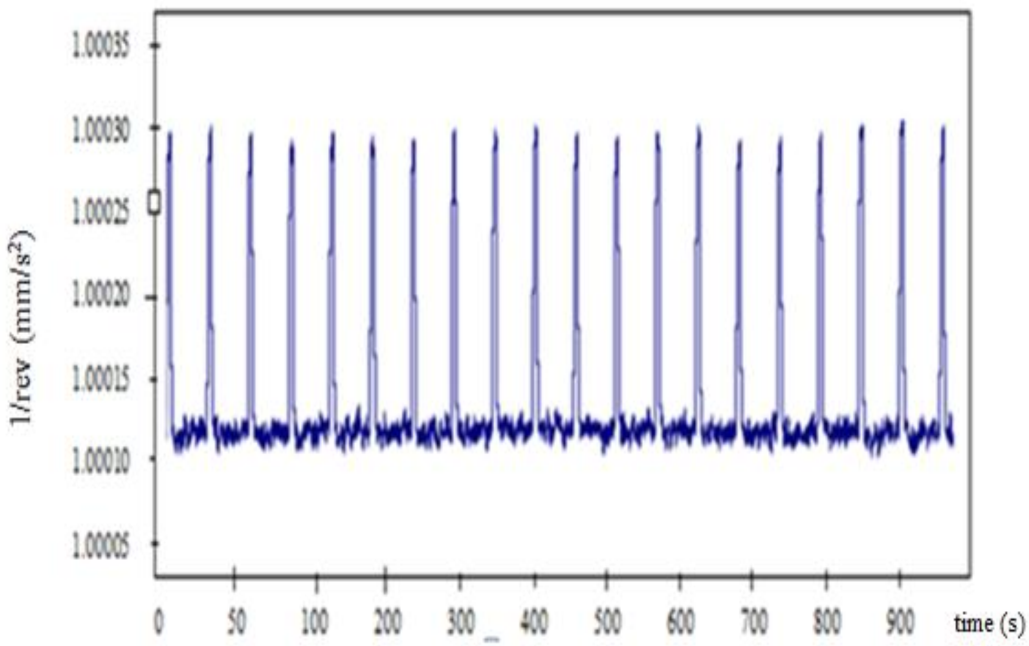
(b)


2.5 cm / 25 mm

(c)

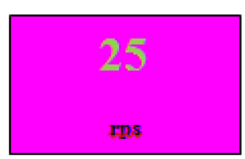

0.00300
0.00250
0.00200
0.00150
0.00100
0.00050
FFT
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
frequency (Hz)

(d)

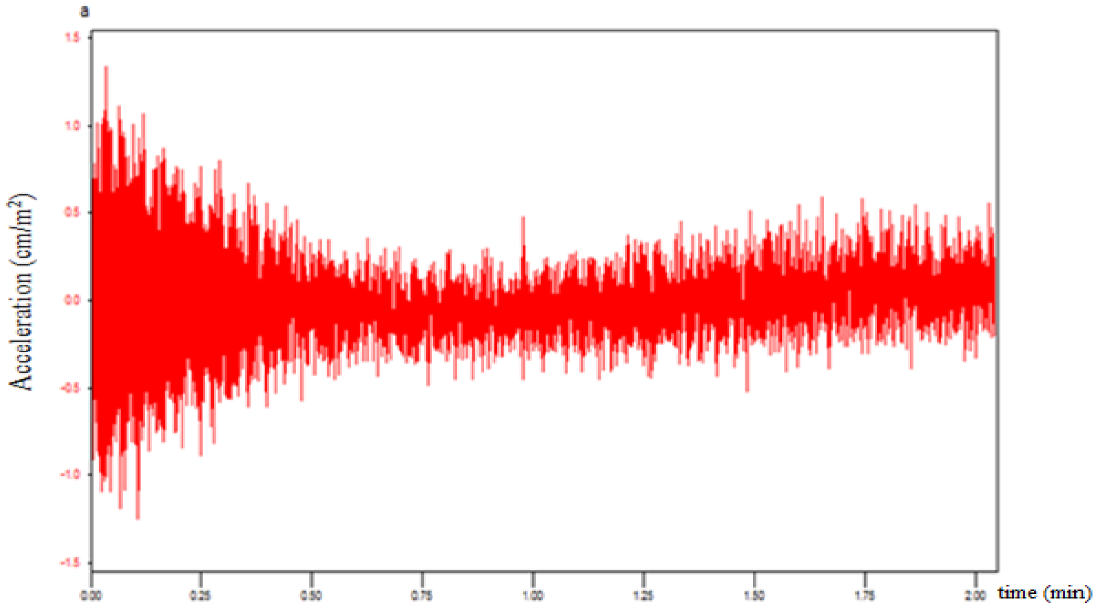


(e)

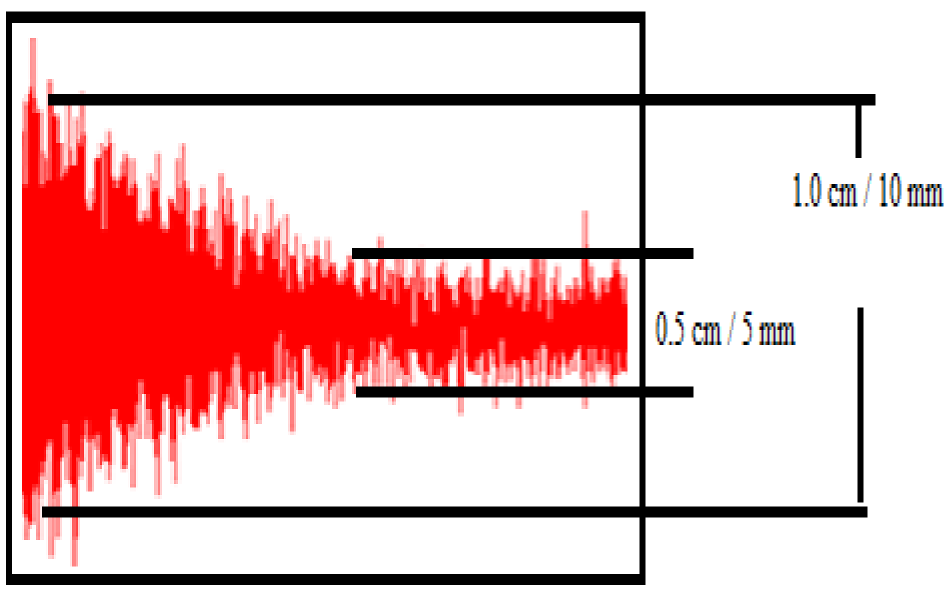
Figure 4.1: Experiment stable result for speed rate 1000 rpm, feed rate 120mm/m, depth of cut 2 mm. (a) digital meter 16.66 rps / 1000 rpm (b) time domain acceleration signal (c) non-chatter on 2.5 mm at the acceleration signal (d) FFT spectrum (e) 1/rev for tachometer signal



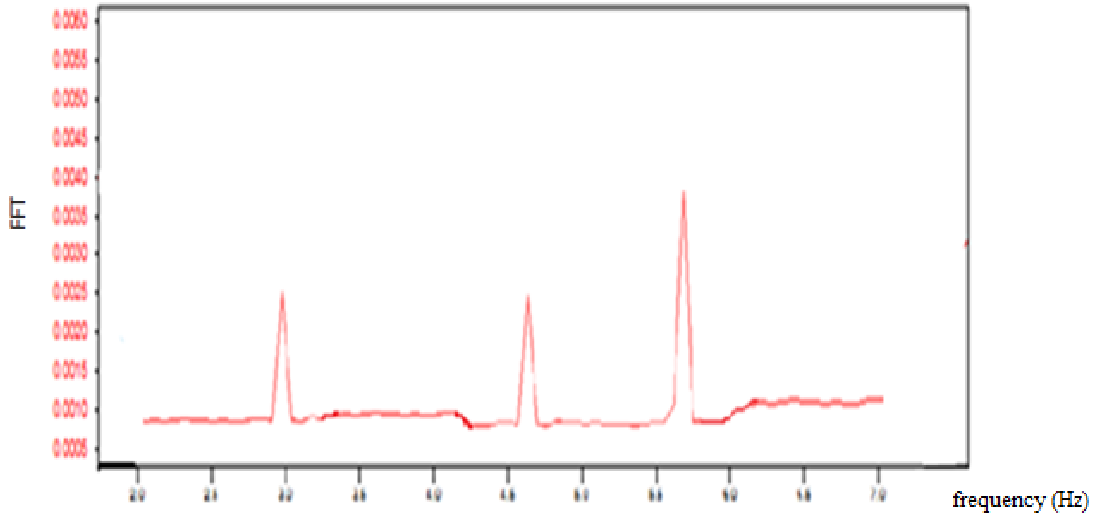
(a)



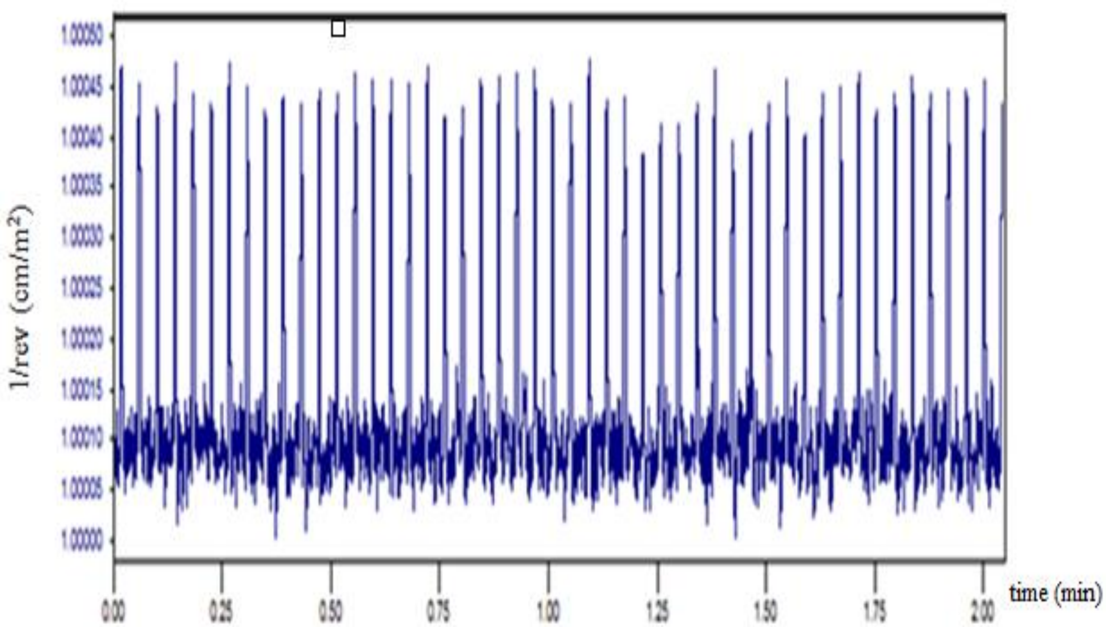
(b)



(c)



(d)

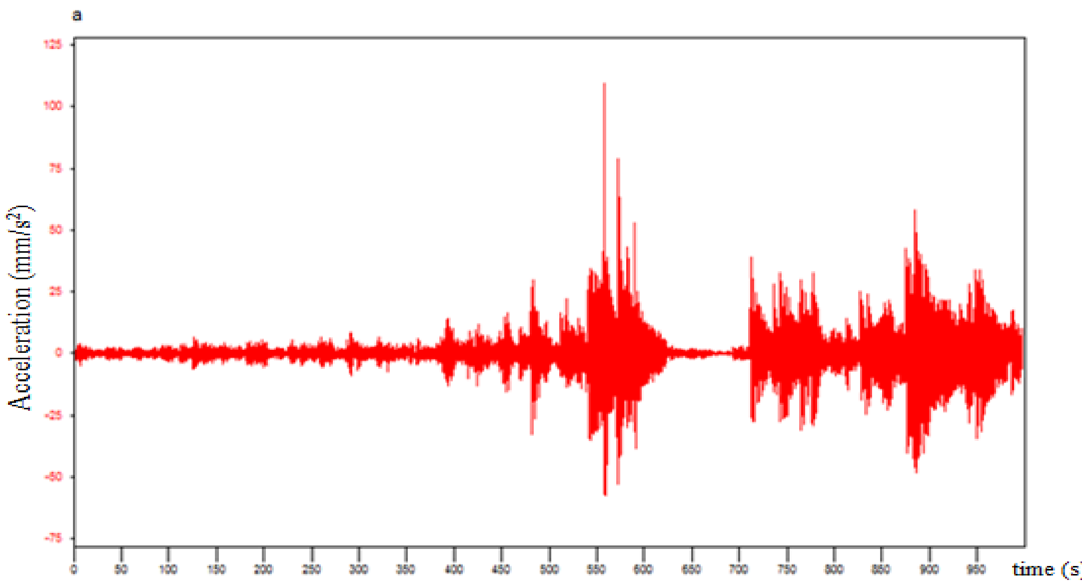


(e)

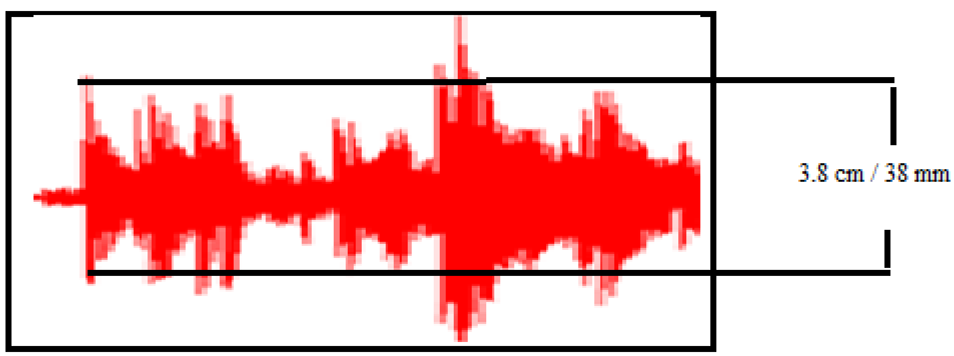
Figure 4.2: Experiment marginal stable result for speed rate 1500 rpm, feed rate 120mm/m, depth of cut 1 mm. (a) digital meter 25 rps / 1500 rpm (b) time domain acceleration signal (c) marginal chatter on 5 mm at the acceleration (d) FFT spectrum (e) 1/rev for tachometer signal


33.33
rps

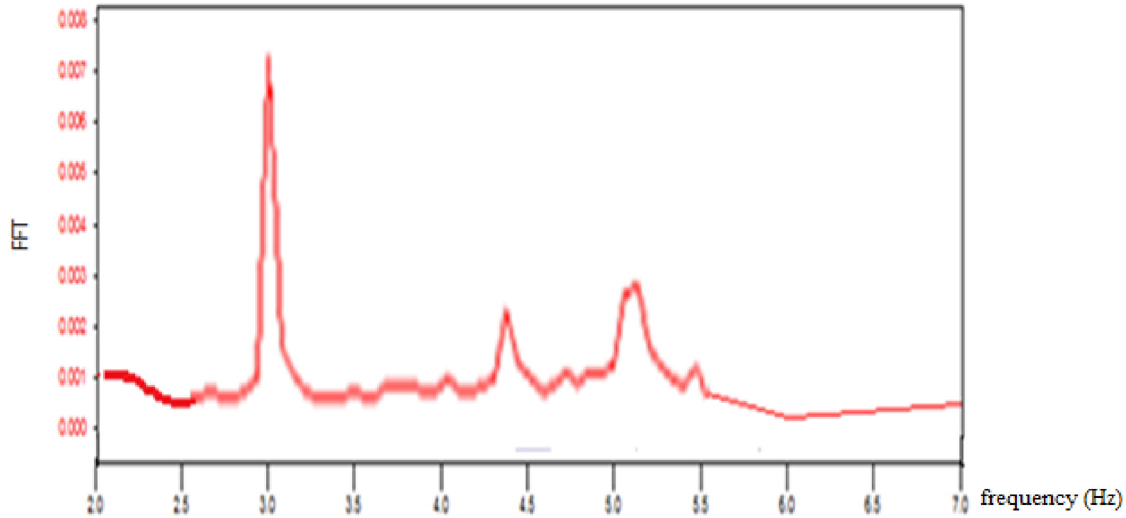
(a)


a
Acceleration (mm/s²)
125
100
75
50
25
0
-25
-50
-75
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
time (s)

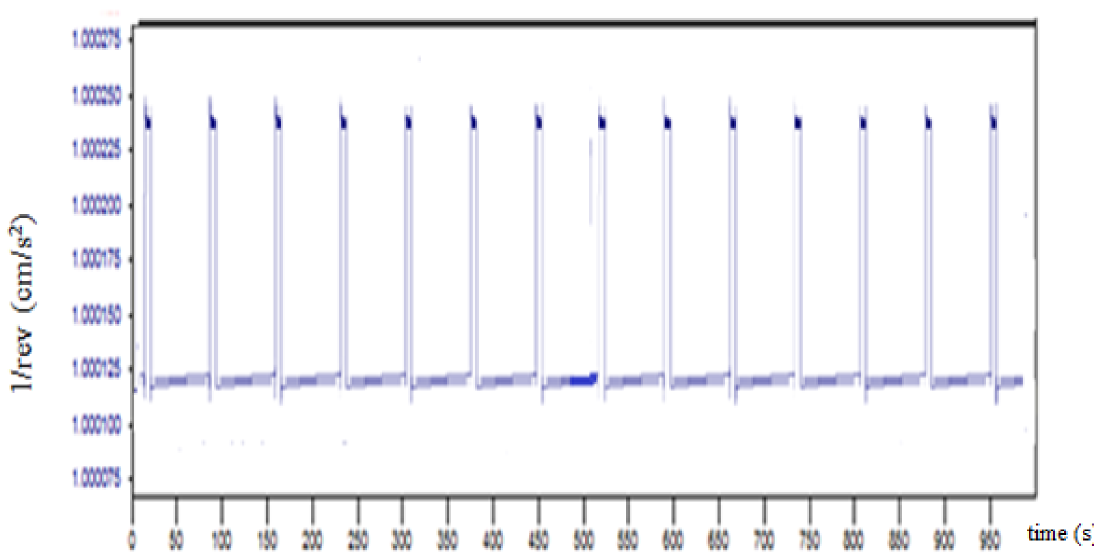
(b)


3.8 cm / 38 mm

(c)



(d)



(e)

Figure 4.3: Experiment unstable result for speed rate 2000 rpm, feed rate 120mm/m, depth of cut 3 mm. (a) digital meter 33.33 rps / 2000 rpm (b) time domain acceleration signal (c) marginal chatter on 38 mm at the acceleration (d) FFT spectrum (e) 1/rev for tachometer signal

4.3: CHATTER STABILITY COMPARISON

Based on the FFT spectrum, acceleration and tachometer signal, vibration condition during experiment for each case was identified. The 3 cases for this experiment depth of cut, feed rate and spindle speed were compared its theoretical prediction and machining experimental results, in order to present their stable, unstable and marginal stable for chatter.

From the Table 4.1, the result from 3 cases will be getting for chatter, non-chatter and marginal chatter.

Table 4.1: The result for chatter, non- chatter and marginal chatter

DEPTH OF CUT		FEED RATE		SPINDLE SPEED	
1 mm	Stable	12O mm/m	Stable	500 rpm	Stable
2 mm	Marginal Stable	14O mm/m	Unstable	1000 rpm	Stable
3 mm	Unstable			1500 rpm	Marginal Stable
				2000 rpm	Unstable

4.4 SUMMARY

The chatter for depth of cut, feed rate and spindle speed that used in machining was validated in cutting experiment. The vibration conditions of machining were identified using acceleration, tachometer signals and FFT spectrum. The comparisons showed there was good agreement for machining results.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In conclusion, all the objectives of the research, 'development of once per revolution sensor chatter' is achieved. Firstly, the project is to prepare specimens of material aluminium 7075. The material for machining experiment was cut using the Horizontal Band Saw Machine according to dimension of 150 x 50 x 30 mm3 each.

The first objective is to integrate tachometer with accelerometer for measure sensor chatter. The project was used accelerometers to measures vibration and sensor tachometer (RPM gauge) is an instrument measuring the rotation speed of a tool milling machine. The mounting of an accelerometer is easy but it is location must be carefully chosen. Indeed, if the sensor is close to a vibration node, signal amplitude would be very low. During the milling process, nodes can move, so it is very difficult to predict an optimal location. It is very difficult to put accelerometer on a rotating part. Beside that, the sensor tachometer is the device usually displays the revolutions per minute (RPM) on a calibrated analogue dial, but for this project the software of DasyLab that used can convert to revolution per second (RPS). The chatter condition was identified when analysis the vibration signals and FFT spectrum, results of machining.

The second objective of the project is to analyze operation chatter at condition once per revolution and vibration in machining. Sensor tachometer is used to detect once per revolution because it's can measure the once rotation speed of a tool milling machine. Then, get the graph from tachometer for the time domain. When the sensor accelerometer and tachometer was synchronous together, the graph will get from Dasylab when it's detect the vibration on the process machining for chatter, non-chatter and marginal chatter. It is depend for the feed rate, spindle speed and depth of cut that used for this machining.

5.2 RECOMMENDATION

There is always room for further improvements for every study and researches that has been done. For further improvements, there are several suggestions that could be implanted when running this experimental of Development of Once per Revolution Sensor Chatter for research next time. Firstly, the next researchers can select more parameters and levels when running the experiment. It can be helping to reduce the errors occur and also can lead to get better accuracy.

Secondly, for Development of Once per Revolution Sensor Chatter, used the variable tool to determine the vibration. Thirdly, in order for better analysis results, a Hall-effect probe can be used to capture a periodic pulse signal matching the tool revolution. Lastly, need more time to learn software of Dasylab. It is can be easier to get more result. Beside that, the equipment or instrument to do the research need improved for make sure student can complete their research on time.

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APPENDIX A

GANTT CHART

A1: Final Year Project 1

PROJECT ACTIVITY		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Discuss about appointment day	P														
	A														
Find and read the journal based on the tittle of project	P														
	A														
Discuss the suitable journal with supervisor	P														
	A														
Do the chapter 1	P														
	A														
Discuss the chapter 1 with supervisor	P														
	A														
Draft chapter 1	P														
	A														
Draft chapter 2	P														
	A														
Draft chapter 3	P														
	A														
Complex chapter 1 (Introduction)	P														
	A														
Complex chapter 2 (Literature Review)	P														
	A														
Complex chapter 3 (Methodology)	P														
	A														
Presentation	P														
	A														

PLAN

ACTUAL

A2: Final Year Project 2

PROJECT ACTIVITY		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Order the sensor	P															
	A															
Prepared the material	P															
	A															
Cut the material for the actual size	P															
	A															
Learn the software DasyLab	P															
	A															
Setup the milling machine	P															
	A															
Testing the milling machine	P															
	A															
Setup the sensor	P															
	A															
Get the data	P															
	A															
Used program to get data of FFT and once per revolution	P															
	A															
Analysis data	P															
	A															
Continuous the process to get more data	P															
	A															
Final report	P															
	A															
Presentation	P															
	A															

PLAN

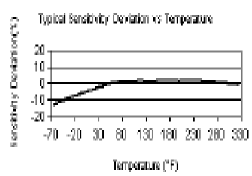
ACTUAL

APPENDIX B

PIEZOELECTRIC ACCELEROMETER (PCB 352C33) SPECIFICATIONS

Model Number 352C33	ACCELEROMETER, ICP®	Revision H ECN #: 28610

Performance	ENGLISH	SI	
Sensitivity (±10 %)	100 mV/g	10.2 mV/(m/s^2)	
Measurement Range	±50 g pk	±490 m/s^2 pk	
Frequency Range (±5 %)	0.5 to 10000 Hz	0.5 to 10000 Hz	
Frequency Range (±10 %)	0.3 to 15000 Hz	0.3 to 15000 Hz	
Resonant Frequency	≥50 kHz	≥50 kHz	
Broadband Resolution (1 to 10000 Hz)	0.00015 g rms	0.0015 m/s^2 rms	[1]
Non-Linearity	≤1 %	≤1 %	[4]
Transverse Sensitivity	≤5 %	≤5 %	[5]
Environmental			
Overload Limit (Shock)	±5000 g pk	±49000 m/s^2 pk	
Temperature Range (Operating)	-65 to +200 °F	-54 to +93 °C	[3][3]
Base Strain Sensitivity	0.003 g/µε	0.029 (m/s^2)/µε	[1]
Electrical			
Excitation Voltage	18 to 30 VDC	18 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤200 Ohm	≤200 Ohm	
Output Bias Voltage	7 to 12 VDC	7 to 12 VDC	
Discharge Time Constant	1.0 to 2.5 sec	1.0 to 2.5 sec	
Settling Time (within 10% of bias)	<10 sec	<10 sec	
Spectral Noise (1 Hz)	39 µg/√Hz	380 (µm/sec^2)/√Hz	[1]
Spectral Noise (10 Hz)	11 µg/√Hz	110 (µm/sec^2)/√Hz	[1]
Spectral Noise (100 Hz)	3.4 µg/√Hz	33 (µm/sec^2)/√Hz	[1]
Spectral Noise (1 kHz)	1.4 µg/√Hz	14 (µm/sec^2)/√Hz	[1]
Physical			
Size (Height)	0.62 in	15.7 mm	
Weight	0.20 oz	5.8 gm	[1]
Sensing Element	Ceramic	Ceramic	
Size (Hex)	0.44 in	11.2 mm	
Sensing Geometry	Shear	Shear	
Housing Material	Titanium	Titanium	
Sealing	Hermetic	Hermetic	
Electrical Connector	10-32 Coaxial Jack	10-32 Coaxial Jack	
Electrical Connection Position	Side	Side	
Mounting Thread	10-32 Female	10-32 Female	
Mounting Torque	10 to 20 in-lb	113 to 226 N-cm	



CE [6]

All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.
ICP® is a registered trademark of PCB group, Inc.

Optional Versions (Optional versions have identical specifications and accessories as listed for standard model except where noted below. More than one option maybe used.)

HT - High temperature, extends normal operation temperatures			[3]
Frequency Range (5 %)	6 to 10000 Hz	6 to 10000 Hz	
Frequency Range (10 %)	4.5 to 15000 Hz	4.5 to 15000 Hz	
Broadband Resolution (1 to 10000 Hz)	0.0009 g rms	0.009 m/s^2 rms	
Temperature Range (Operating)	-65 to +325 °F	-54 to +163 °C	
Excitation Voltage	22 to 30 VDC	22 to 30 VDC	
Discharge Time Constant	0.07 to 0.15 sec	0.07 to 0.15 sec	
Spectral Noise (1 Hz)	107 µg/√Hz	1050 (µm/sec^2)/√Hz	
Spectral Noise (10 Hz)	58 µg/√Hz	570 (µm/sec^2)/√Hz	
Spectral Noise (100 Hz)	41 µg/√Hz	400 (µm/sec^2)/√Hz	
Spectral Noise (1000 Hz)	9.8 µg/√Hz	96 (µm/sec^2)/√Hz	
Output Bias Voltage	10 to 15 VDC	10 to 15 VDC	[2]

Supplied Accessory: Model ACS-68 Single Axis Amplitude Response Calibration from 5 Hz to upper 5% plotted on dB scale replaces Model ACS-1

J - Ground Isolated		
Frequency Range (5 %)	9 kHz	9 kHz
Frequency Range (10 %)	14 kHz	14 kHz
Resonant Frequency	≥40 kHz	≥40 kHz
Electrical Isolation (Base)	$>10^8$ Ohm	$>10^8$ Ohm
Size (Hex x Height)	0.44 in x 0.67 in	11.2 mm x 17.0 mm
Weight	0.21 oz	6.0 gm

T - TEDS Capable of Digital Memory and Communication Compliant with IEEE P1451.4

TLA - TEDS LMS International - Free Format

TLB - TEDS LMS International - Automotive Format

TLC - TEDS LMS International - Aeronautical Format

TLD - TEDS Capable of Digital Memory and Communication Compliant with IEEE 1451.4

Temperature Range	-10 to +200 °F	-23 to +93 °C
Excitation Voltage	20 to 30 VDC	20 to 30 VDC
Output Bias Voltage	7.5 to 13 VDC	7.5 to 13 VDC

W - Water Resistant Cable		
Electrical Connector	Sealed Integral Cable	Sealed Integral Cable
Electrical Connection Position	Side	Side

Notes

[1] Typical.
[2] TEDS option adds 1.0 VDC to bias voltage.
[3] 200°F to 325°F data valid with HT option only.
[4] Zero-based, least-squares, straight line method.
[5] Transverse sensitivity is typically <= 3%.
[6] See PCB Declaration of Conformance PS023 for details.

Supplied Accessories
080A Adhesive Mounting Base (1)
080A109 Petro Wax (1)
081B05 Mounting Stud (10-32 to 10-32) (1)
ACS-1 NIST traceable frequency response (10 Hz to upper 5% point). (1)
M081B05 Mounting Stud 10-32 to M6 X 0.75 (1)

Source: PCB Piezotronics Incorporation, 2012

APPENDIX C

TACHOMETER SPECIFICATIONS

Specifications

General Specifications				
Accuracy	±0.02% v. reading ±1 Digit			
Measuring Ranges rpm	optical	1 ... 99999 min		
	mechanical	1 ... 19999 min		
Speed		Ø 01 m	Ø6"	Ø 12"
	m/min	0.10 ...1999	0.10 ...1524	0.40 ...609.6
	ft/min	0.40 ...6550	0.40 ...5000	0.40 ...2000
	in/min	4.00 ...78700	4.00 ...60000	4.00 ...24000
	m/sec	0.10 ...33.30	0.10 ...25.40	0.10 ...10.16
	ft/sec	0.10 ...109	0.10 ...83.33	0.10 ...33.30

Length	0 ...99999 m / 0...99999 ft / 0...99999 in
Sensing Distance (optical)	max. 600 mm (24 in)
Operation	
Battery type	2x AA 1.5V Battery LR6 (ALKALINE) or rechargeable
Operating Temperature	0 ... +50°C (32...122°F)
Storage Temperature	-20...+70°C (0...160°F)
Housing	
Material	ABS
Weight	250 g (0.55 lb)
Size	175x60x28 mm (7x2.5x1 in)
Agency Approvals & Certifications	CE

Source: http://content.amprobe.com/DataSheets