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SUPPRESSION OF CHATTER IN HIGH SPEED MILLING USING MICROCONTROLLER BASED SPEED CONTROLLER BY SPINDLE SPEED VARIATION METHOD

(REDAMAN GELATUK PADA HALAJU TINGGI MENGGUNAKAN PENGAWAL MIKRO BERPANDUKAN KEPADA KAEDAH VARIASI HALAJU SEPINDA)

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Suppression of chatter in high speed milling using microcontroller based on spindle speed variation

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ABSTRACT

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(Keywords: chatter; high spindle speed; microcontroller; spindle speed variation)

High speed milling process is the most common and versatile technology compared with conventional milling process for machining productivity of metal cutting industry**.** However, the productivity of machining is often limited by chatter at high signed in milling process. Chatter is a wavy mark on a product surface finish that occurs when self-excited vibration develops during the process, which results in poor surface finish, increase the rate of tool wear and reduce the spindle lifetime. The aims of this study are to suppress chatter by spindle speed variation method at high speed machinery and a better surface finish is also achieved. This research PID controller was developed to give on-line feedback to the machine based on data fed by the microphone sensor. The data received from microphone sensor is analysed in time and frequency domain. Furthermore, after machining, result also was compared with the surface roughness of all cutting conditions. Results showed improvement the surface roughness of the machined material after spindle speed variation has been implemented together with high speed milling technique.

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ABSTRAK

REDAMAN GELATUK PADA HALAJU TINGGI MENGGUNAKAN PENGAWAL MIKRO BERPANDUKAN KEPADA KAEDAH VARIASI HALAJU SEPINDA

(Keywords: redaman gelatuk; halaju tinggi; pengwal mikro; kaedah variasi halaju tinggi)

Proses pengisaran berkelajuan tinggi merupakan teknologi umum dan serba boleh jika dibandingkan dengan kaedah konvensional untuk tujuan pemesinan dalam industri pemotongan logam. Walau bagaimanapun, pemesinan kerap kali terganggu disebabkan oleh gelatuk semasa proses pengisaran. Gelatuk menghasilkan kesan bergelombang pada permukaan produk akhir berpunca dari getaran pengujaan sendiri yang terhasil sepanjang proses, menyebabkan permukaan produk buruk, meningkatkan kadar haus alat dan mengurangkan jangka hayat gelendong mesin. Matlamat kajian ini adalah untuk menyekat gelatuk dengan kaedah mevariasikan kelajuan gelendong pada pemesinan berkelajuan tinggi seterusnya menghasilkan permukaan yang lebih baik pada produk akhir. Kajian ini dijalankan dengan membangunkan pengawal PID untuk menyampaikan maklum balas secara terus atau atas talian kepada mesin berdasarkan data yang disalurkan oleh senson mikrofon. Data yang diterima dari sensor mikrofon akan dianalisis dalam bentuk masa dan frekuensi. Selain itu, kekasaran pada permukaan selepas pemesinan dalam semua keadaan pemotongan turut diperoleh. Hasil analisis menunjukkan penambah baikan pada permukaan pemotongan selepas mengimplimentasikan kaedah variasi kelajuan gelendon mesin dalam proses pengisaran berkelajuan tinggi.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Current modern manufacturing industry, the machine tool manufactures, aiming for the development of their product and the machine tool users. They also try to find the best machine tool suitable for their tasks; both need a qualitative measure to check performance of newly developed machine tools. 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. In the aspect of development of a manufacturing company, the utmost profit and the reputation of the company are considered seriously. At the same time, consumers have high demand on better quality of the final product in short period of time (Wiercigroch, 2001). These feedbacks unknowingly motivate the manufacturers to control their product so that it satisfied their customers.

During developments of the products, often milling is used for this purpose. Moreover, in mass production, high speed milling has to be considered high to increase the production rate (Seguy , 2008). High speed milling is most efficient when a high material removal rate is attained. The most important parameters that influence the material removal rate are the spindle speed, the feed per tooth and the axial and radial depth-of-cut. The performance of the machine tool during high speed milling is affected by the accuracy of the machine tool itself as well as its working accuracy. The working accuracy of the machine tool is often affected largely by the vibrations produced which known as dynamic behavior of the machine during the cutting operation. Every designer who has a machine tool in the development stage is concerned with its vibration behavior, and every production is fully aware that vibration leads to shorter tool life, poorer surface finish on the work produced and lowers output (Seguy, 2011).

Generally, in a milling process, three different types of mechanical vibrations may rise in machine tools due to a lack of dynamic stiffness or rigidity of the machine tool system comprising tool, tool holder, work- piece and machine tool itself as explained by Tobias (Seguy, 2011). There are free vibration, forced vibration and self-induced vibration. Furthermore, free vibrations are induced by shock and forced vibrations are due to unbalance effects in machine tool assemblies like gears, bearings, spindles. In addition, free and forced vibrations can be easily identified and suppressed by vibration isolation but self-induced vibrations where generated within the machine tool itself are referred as chatter and are the result of the dynamic instability of the cutting process. Chatter becomes a common limitation to productivity and part quality. For this reason, it has been a topic of industrial and academic interest in the manufacturing sector for many years. A great deal of research has been carried out since the late 1950s to solve the chatter occurrence. (Seguy, 2009)

During mass production, high speed machining and material removal rate (MRR) could lead to self-induced vibrations called as chatter, between the cutting tool and the work piece. This phenomenon characterized by violent vibrations, loud noise and poor quality of the machined surface where this type of surface finish has wavy patterns (Altintas & Chan, 1992). On the other hand, chatter also contributes to dimensional inaccuracy, and chipping of cutter teeth. Additionally, chatter reduces the life of the tool, breakage of machine tool components and the productivity of the manufacturing process by interfering with the normal functioning of the machine (Dijk, 2010).

Hence, prevention of resonance problems is a vital factor in the design of machining system and since prototype testing is not usually possible within the development cycle, vibration considerations must be resolved at the design stage. These problems have been investigated by the manufacturing community for long time. Chatter control method where the indisputable technique is to find the optimal parameter which is quick enough to increase the production rate. With considerably high material removal rate (MRR) in conjunction with the product surface finish is good enough before the chatter starts to develop (Insperger, 2004). Besides, those set of parameters can be deduced as a guideline.

The research of chatter on the particular of parameter selections in machining to avoid the built-up of these undesired oscillations becomes focus after the early research

(Seguy, 2008). The presence of negative damping that is believed as the only source of chatter. In the same way to avoid chatter, the material removal rate is often reducing, abdicating the power and torque available on the spindle. Besides that, spindle speed variation method was introduced to control chatter during machining. Spindle Speed Variation (SSV) is a well-known technique to suppress machine tool vibrations where the continuous modulation of the spindle speed breaks the energy injection that flows from the cutting process to the machine tool due the chatter effect thus avoiding the vibration growth.

Spindle Speed Variation (SSV) is a well-known technique to suppress regenerative chatter vibration both in turning and milling operations but a lack of knowledge regarding the effects of non-stationary cutting conditions is still limiting its diffusion in the industrial scenario, but it is usually considered to be effective only for low spindle speeds. In this paper an experimental study regarding the effects of Spindle Speed Variation technique on tool wear in steel turning is presented and the effect of spindle speed variation is analyzed in the high-speed domain, for the spindle speeds corresponding to the first flip (period doubling) and to the first Hopf lobes. The optimal amplitudes and frequencies of the speed modulations are computed using the semi-discretization method. It is shown that period doubling chatter can effectively be suppressed by spindle speed variation, while the technique is not effective for the quasi-periodic chatter above the Hopf lobe (Albertelli, 2012).

This method allows machinist to maintain or increase depth of cut without worry with the correct spindle speed and chatter is then kept under control. In this research project, experiment is set up by collecting the particular data using the microphone sensor to find the optimum spindle speed that give a positive result in high speed milling operation before chatter is develop.

The main problem of the research is obviously the chatter or self-exited vibration that occurred between cutting tool and the work piece which result in poor surface finish. As the problem develops, it leads to another problem that are increasing the rate of tool wear and damaging the work piece (Insperger, 2004). With conjunction of these problems and effects, manufacturer and machinist have to bear with the high cost of maintenance and repairing.

With regard to the first factor, chatter is a highly complex phenomenon due to the diversity of elements. It can compose the dynamic system and its behavior: the cutting tool, the tool holder, the work piece material, the machine tool structure and the cutting parameters (Dijk, 2010). Predicting its occurrence is still the subject of much research, even though the regenerative effect, the main cause of chatter, was identified and studied very early on. Moreover, chatter can occur in different metal removal processes.

Regarding the causes, chatter occurrence has several negative effects such as poor surface quality and dimensional inaccuracy (Davies, 2009). Chatter also produces excessive loud noise. Furthermore, chatter contributes for disproportionate tool wear and machine tool damage. Due to those problems, increased costs in terms of production time and maintenance issues. In addition, there are environmental impact in terms of materials and energy. Even costs for recycling damage machined final parts also very high.

1.3 Research Objective

These following are the objectives of the project to study the influences of high speed machining technique in conventional milling machine and the effectiveness of spindle speed variation method:

(i) To study the offer of in high speed machining technique using conventional milling machine for cutting 7075, including different material of mold steel P20 comparison tool wear and surface roughness.

(ii) To analyze the spindle speed variation using PID controller for chatter suppression based on microphone signal.

(iii) To verify experimental in the spindle speed variation in different feed rate and depth of cut using surface roughness and surface topography analyse.

By achieving those objectives, the chatter occurrence during machining can be cured and improve the final output of the machined parts.

1.5 Report Overview

In Chapter 2, reviews of high speed milling, chatter and spindle speed variation were carried out. This review was done on the design and application of the experiments, the principles of PID controller, the tuning method of the PID parameters as well as their limitations and improvements. The experiment begins with the implementation of high speed milling technique in conventional milling machine, represented by Chapter 3. Then, the experiment continues with mini three axes milling machine to study about chatter occurrence and suppression chatter using spindle speed variation method with microphone feedback PID controller. All Chapter 4 presents results from the experiments recorded and analyzed in time and frequency domain using Dasylab and Matlab software. Moreover, the surface roughness of final machined parts for both experiments were measured using portable surface roughness tester and the tools used for high speed milling technique experiment used to measure tool life using metallurgical microscope machine. Finally, in chapter 5, there will be completer summary of the whole research project described in details and stated some recommendations for future developments.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Manufacturing process plays a big role in the world various industries. As the world becomes more advance, people tend to build or invent gadget and parts. The science behind it continues to move rapidly and give major impact in the financial system of people. Machine tool chatter is characterized by large vibrations in machining, which cause poor surface finish, reduce the lifetime of machine tool components and increase tool wear (Wiercigroch, 2001). The feedback between the outer modulation of the chip to the current cutting force, and consequently, the inner modulation of the chip is called regenerative effect. Hence, the productivity of stable machining without disadvantageous vibrations depends on the time delay as the time between two subsequent cuts and is limited by the so-called stability lobes of the regenerative effect.

Machining is a removing the unwanted material from a given work piece to create the required shape (Quintana, 2011).After being formed into a specific shape and size, the parts will undergo further manufacturing process which is machining. In this process, the work pieces are cut to create a detail profile using a specific cutting tool. This process is described a group of process that consist of the removal of material and modification of the surface of work piece after it has been produce by various methods. In general machining consists of several major types of material removal process. Cutting process typically involving a single-point or multipoint cutting tools where each with clearly defined shape. Abrasive processes, such as grinding and advance machining process which utilizing electrical, chemical, laser, thermal, and hydrodynamic method to accomplish the task (Olgac, 1968).

Manufacturing have a great relationship with business, where the manufacturer compete each other to produce better quality of products. To achieve such condition, a suitable types of process is required to match with the time constrain without neglecting the quality of the product such as the surface finish (Jensen, 1999).In the meantime, manufacturers also have to consider the cost of manufacturing the product. Besides the cost of the material itself, manufacturer have to constantly monitor the quality and allocate funds for a research on the problem occur when they are involves in high speed machining.

2.2 High Speed Machining

Machining with high speeds (HSM) is one of the modern technologies, which in comparison with conventional cutting enables to increase efficiency, accuracy and quality of work pieces and at the sometime to decrease costs and machining time. The first definition of HSM was proposed by Carl Salomon in 1931 (Weck, 2011). He has assumed that at a certain cutting speed which is 5 –10 times higher than in conventional machining, the chip tool interface temperature will start to decrease. Figure 2.1 explains the fact of hard competition causes rapid development of the machining technology and design of new solutions. High Speed Machining is proposed as an example. HSM ensures high metal removal rates, boost productivity, improve surface finish and eliminates the need of coolant (Zhang, 1995). In spite of high requirements of machining tools, HSM gives numerous benefits. It allows shortening the production time and eliminates some treatment (e.g. manual finishing) besides simultaneously retaining the accuracy. These advantages are decisive for the use of HSM for machining the press dies. Even though HSM has been known for a long time, the researchers are still being developed for further improvement of quality and minimization of costs (Endres, 1996).

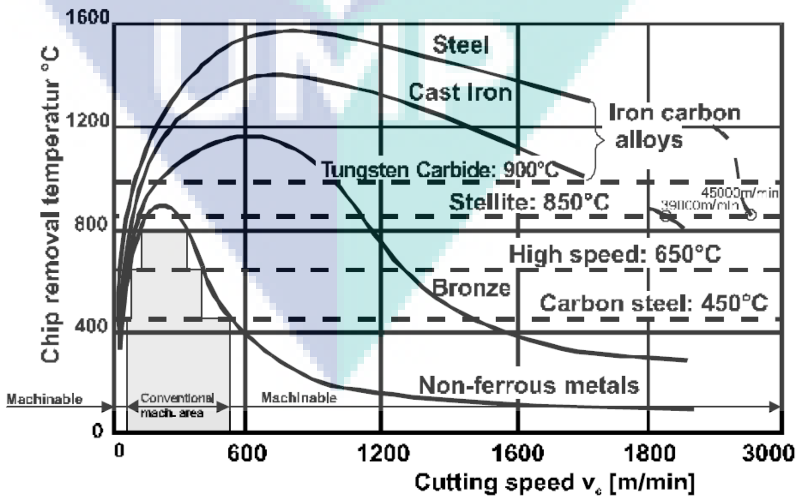


Figure 2.1: Temperature as a function of cutting speed.

Source: Pasko, R. et al., (2010)

High speed machining (HSM) refers to the speed of the cutting process takes place. In most cases, high speed machining always referred as high spindle speed (Slavicek, 1965). The truth about high speed machining is the material removal rate, MRR which consists of the product of the feed rate, axial depth of cut and diameter of cutting tool, as shown in Figure 2.2 with Equation (1.1). Any of this parameter can be combined to produce high rate of material removal which means it can accelerate the productivity. A research by Schultz and Moriwaki (1992) found that an optimum HSM could reduce time taken of the cutting process up to 50%.

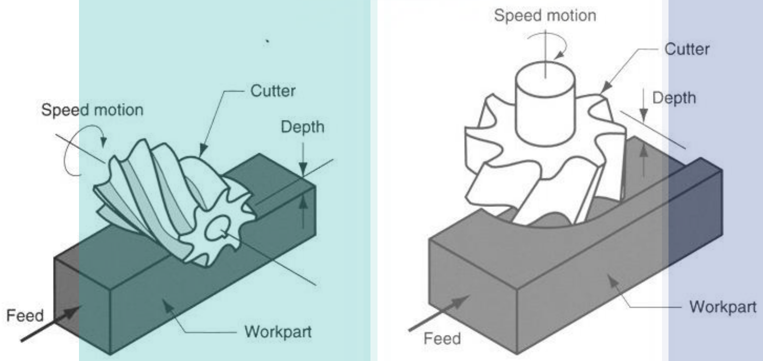


Figure 2.2: Face vertical milling

Source: Narnarayan Shastri Institute of Technology Presentation Transcript. (1998).

$$MRR = \frac{lwt}{ct} \tag{1.1}$$

where

w is width of cut (may be full cutter or partial cutter)

t is depth of cutter engagement

l is length of pass or cut

HSM is often used in finishing in hardened steels with both high speeds and feeds (Wiercigroch, 2001). HSM can be called rather the high productive machining when machining components in roughing to finishing and also in finishing to super-finishing in components of all sizes. The uses of HSM allow us to shorten the production time and to increase the accuracy of machined parts. The first category is industry which deals with machining aluminium to produce automotive components (Olgac, 1968) small computer parts (Delio, 1992) or medical devices (Stoferle, 1972). This industry needs fast metal removal, because the technological process involves many machining operations. The second category which is aircraft industry involves machining of long aluminium parts, often with thin walls. The third industry sector is the die mould industry which requires dealing with finishing (Jensen, 1999) of hard materials. In this category it is important to machine with high speed and to keep high accuracy (Paris, 2004).

There are some critical parameters for HSM, as for instance the depth of cut. The cutting tool manufacturers provide recommendations regarding the machining parameters that should be used. HSM ensures high metal removal rates, boost productivity, improve surface finish and eliminates the need of coolant (Pratt, 2009). In spite of high requirements of machining tools, HSM gives numerous benefits. It allows shortening the production time and eliminates some treatment (e.g. manual finishing) besides simultaneously retaining the accuracy (Paris, 2004). These advantages are decisive for the use of HSM for machining the press dies. Even though HSM has been known for a long time, the research is still being developed for further improvement of quality and minimization of costs.

2.2.1 High Speed Milling Technique

Machining technique using high spindle speed, high feed rate and shallow depth of cut utilize in High Speed Milling (HSM) machines offer several benefits such as increase of productivity, elimination of secondary and semi-finishing process, reduce tool load, small chips produced and ease of cleaning (Hoshi, 1977). An increase of cutting speed to HSM values give several benefits such as enlarging of the removal rate and improving of the final surface as shown in Figure 2.3. Moreover, below in Table 1 can found some comparisons of speeds during machining for some chosen material using conventional and HSM methods.

2.2.2 High Speed Milling Technique Application in Normal Machining

When manufacturing engineers and machine shop owners come across reports of such fantastic increases in productivity, many wonder whether their operations can reap the same benefits. In fact, it is easy once you understand that high-speed machining is different from conventional machining and that you must adopt a completely new philosophy to make it work. This understanding begins with the definition of high – speed machining. In general, 8000 per/mm is considered minimum ante for the rotational aspect of high speed machining. That is not to say some high speed machining benefits cannot be derived at slower speeds. But, very basic equipment will limit the incremental improvements that can be made. Machining technique with the combination of high spindle speed, high feed rate and shallow depth of cut by high speed milling (HSM) machine is one of the new production technology (Olgac, 1968). By comparing this high productivity machine with conventional machine has a number of advantages, such as high efficiency, accuracy, quality of final workpieces, eliminate the secondary or semi-finishing process, increase of productivity, cut off costs and machining time, better surface finish, eliminates the needs of coolant, reduce tool load for finishing operation and last but not least small chips are produced for easily cleaning purposes (Radulescu, 1997).

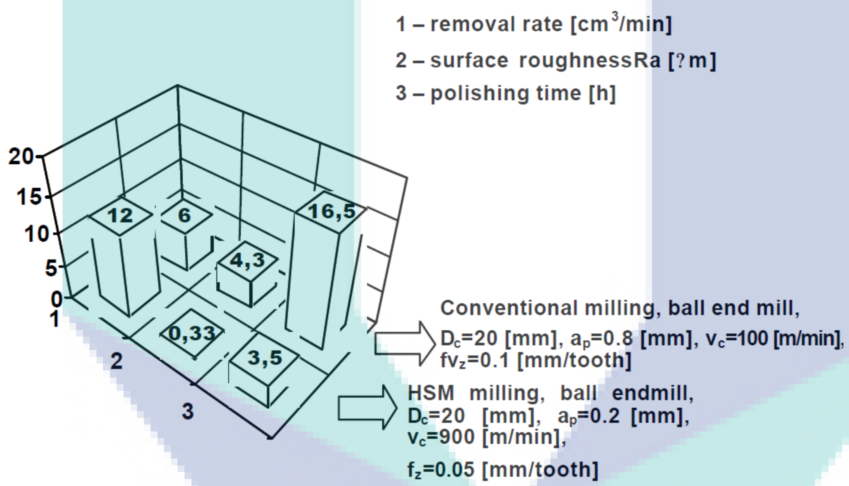


Figure 2.3: Comparison of production indexes during machining of a punch.
Source: Hoshi etal, (1977)

2.3 Chatter in Machining Process

The machining of metals is often accompanied by a violent relative vibration between work and tool which is called chatter. Chatter is undesirable because of its adverse effects on surface finish, machining accuracy and tool life. Apart from that, chatter is also responsible for reducing output because if there are no remedy can be found, metal removal rates have to be lowered until vibration-free performance is obtained (Al-Regib, 2003). Figure 2.4 shows clear picture of chatter formed on machined part surface.

Table 2.1: Conventional vs. High Speed Machining

		Solid Tools (end mills, drills) ***WC, Coated WC, PCD, ceramic***		**Indexable Tools (shell mills, face mills)** ***WC, ceramic, sialon, CBN, PCD***	
Work material		Typical cutting speed (m/min)	High cutting speed (m/min)	Typical cutting speed (m/min)	High cutting speed (m/min)
Aluminium		>305 (*WC, PCD*	>3050 (*WC, PCD*	>610	>3658 (*WC, PCD*
Cast iron	**Soft**	152	366	366	1219 (sialon, ceramic)
	ductile	107	244	244	914 (ceramic)
Steel	**Free mach. Steel**	107	366	366	610
	Alloy	76	244	213	366
	stainless	107	152	152	274
	Hardness HRC65	24	122	30 (WC) 91 (CBN, ceramic)	30 (WC) 91 (CBN, ceramic)
Titanium		38	61	46	91
Super alloy		46	76	84 (WC) 213 (sialon)	366 (sialon, ceramic)

Figure 2.4: Chatter vibration marks.

Source: Tobias(1965).

As we know, chatter is not the only vibration phenomenon occurring under practical conditions. In machining process, three different types of mechanical vibrations are present due to a lack of dynamic stiffness/rigidity of the machine tool. This system comprising tool, tool holder, work piece and machine tool itself as explained by Tobias (Paris, 2004). These are free, forced and self-induced vibrations. In addition, free vibration where induced by shock and forced vibration. The unbalance effects, gear and bearing errors either arising in the machine itself or transmitted through the foundation from other machines are frequently encountered and are difficult to avoid. The last-mentioned types of vibration, however, do not present any basically new problems and can be overcome. As soon as the causes responsible for inducing free and forced vibration have been identified, it is always possible to find methods of eliminating or reducing vibration

The total scenario of the chatter is totally different. The physical causes underlying the mechanism are still not fully understood. It is so often extremely difficult, despite a diagnosis which accords with the facts. For reducing metal-removal rates, it is lowering the output. Additionally, chatter is so inconsistent in character that the tendency of a machine to exhibit chatter effects is often not observed during the development stage (Stoferle, 1972). Moreover, modern machines only chatter under certain conditions, namely when a simultaneous combination of several cutting conditions occurs. Apart from that, the most important characteristic property of chatter vibration is not induced by external periodic forces, but rather that the forced, it is bringing and maintain to generate the vibratory process itself by (Doolan, 1975). The vibration concerned is therefore of the self-induced type which draws the energy for its own maintenance from the cutting operation and hence from the machine tool drive.

Generally, two mechanisms are responsible for self-induced vibration. There are mode coupling and regeneration of surface waviness (Dijk, 2010). The friction between tool and work piece classified as thermo-mechanical effects or by mode coupling. On the other hand, the regeneration of surface waviness is by far the most common cause of chatter. The theory of regenerative machine tool chatter is based on the work of Tobias and Fishwick (1958). Moreover, each tooth pass leaves a modulated surface on the work piece due to the vibrations of the tool and work piece structure, causing a variation in the expected chip thickness.

In other words, chatter is caused by the so-called regeneration of surface waviness during successive cuts; the wavy surface caused by previous cuts influence the chip thickness during the following cut (Merdol, 2004). This again causes a wavy surface, which in turn influences the chip thickness in the successive cuts. By the way, under certain cutting conditions such as feed, depth of cut and spindle speed, large chip thickness variations and hence force and displacement variations occur and the resulting instability is called regenerative chatter (Merdol SD, 2004). Machine tool operators often select conservative cutting condition to avoid chatter, thus decreasing productivity. Consequently, practical guidance to machine tool users for optimal process planning of depth of cuts and spindle speed in machining operation were derived (Cossalter, 2008).

2.3.1 Chatter in High-Speed Milling process

Within the few past decades, there had been a marked increase in the industrial use of the so-called high-speed machining technology. These decades have been the development of machining centres capable of spindle and slide speeds that are higher than those available on conventional machining centres. One of the promising machining technologies with high industrial relevance is high-speed milling. It allows high material removal rates, distinctly improved surface finish and higher work piece quality which are expected from modern machining centres (Durand, 2010).

However, in high-speed milling operations, regenerative chatter is often the dominant factor limiting the attainable rates of material removal and work piece quality. One of the structural modes of the machine tool and work piece system is the excited by cutting force initially during milling process. Due to structural vibrations, an oscillatory surface finish left by one of the tooth is removed by the succeeding oscillatory tooth. The resulting chips thickness becomes also oscillatory, this in turn produces oscillatory cutting forces whose magnitudes are proportional to the time varying chip load (Pratt, 2009). This condition makes the self-excited cutting system becomes unstable. Then, under excessive cutting forces, chatter vibrations grow until the tools jumps out of the cut or break (Altintas and Budak, 1995).

There are two main methodologies have been developed in order to avoid and suppress chatter on-fine. In details, the first methodology exploits the stability lobes by selecting the cutting speed so that the depth of cut allowed by the cutting system is more but this methodology has two drawbacks (Bartolini, 1989).

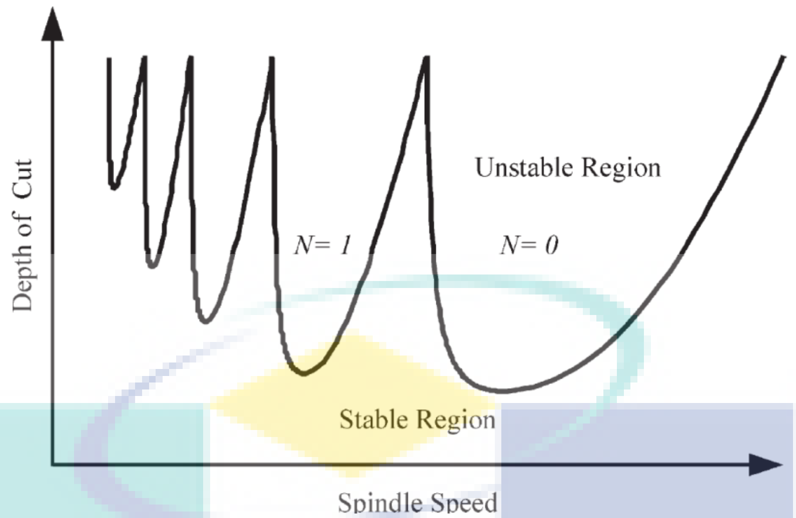


Figure 2.5: Exploits the stability of lobes

Source*: Al-Regib, Ni, (2003)*

The first drawback is that detecting high stability zones is not a simple task especially for machine structures with several coupled modes. This is due to a speed of cutting that allows a large depth of cut by avoiding chatter at a certain mode does not necessarily avoid chatter at the other modes (Seguy, 2009). Also, finding the speed that avoids chatter at all modes requires many interruptions to the cutting process either by stopping the process completely or by decreasing the feed rate drastically. The second drawback is that these zones can move during the cutting process either due to the feed motion of the machine table or headstock or due to changes in the work piece geometry upon cutting (Radulescu, 1997).

The second methodology depends on sinusoidal modulating the cutting speed around a mean value. The rationale behind this methodology is to disturb the mechanism of regeneration of waviness which procreates chatter. Altintas and Chan designed a system that used spindle speed modulation to suppress chatter in milling. The system was designed to sense chatter by analysing the frequency spectrum of the cutting force signal as shows by Figure 2.5. When chatter was detected spindle speed modulation was invoked (Al-Regib, 2003). Otherwise, cutting proceeded at a constant speed. This method showed great success in suppressing chatter under different cutting conditions. But, it was not clear how the modulation parameters, amplitude and frequency of speed modulation were selected (Al-Regib, 2003). Although the speed modulation methodology has shown a considerable success in suppressing chatter it has not yet been accepted in industry for two reasons. The first reason is that modulating the spindle speed requires modifying existing drives and it results in a very complex system that is not easy to analyse as shown in Figure 2.6. Another reason is that some research has shown that speed modulation can result in an adverse effect and may even propagate chatter for an otherwise stable process.

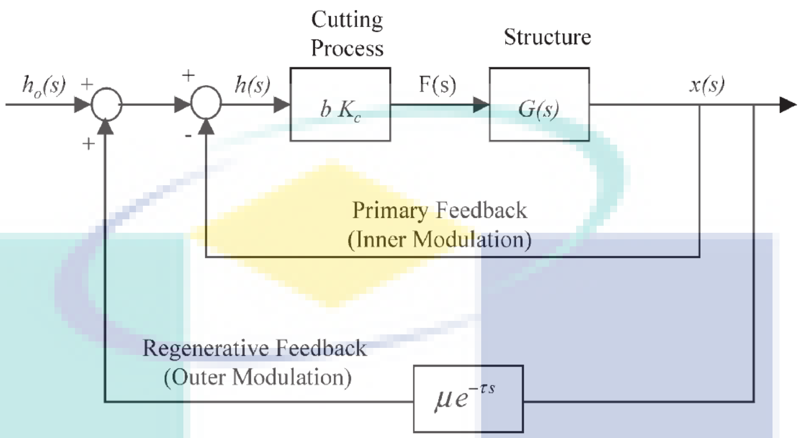


Figure 2.6. Block diagram of regenerative chatter loop

Source: *Al-Regib, Ni, (2003)*

2.3.2 Development of chatter suppression method

The chatter suppression method that has received attention from researchers in every corner of the world in recent years is spindle speed variation method. Spindle speed variation is a better technique to suppress regenerative machine tool vibration. Machining technique using high speed milling technique with the combination of high feed rate and low immersion results high productivity and eliminate the secondary or semi-finishing process (Wiercigroch, 2001). This technique can also reduce tool loading during finishing operation with a small chips production. By implementing high speed milling technique to conventional milling may contribute to some vibration known as chatter which needs to be suppressed by using spindle speed variation.

Later on, the method which enables working with several degrees of freedom models is presented by Altintas and Budak (1995). Analysis for the geometrical non-linearity's of the milling process obtain an approach to the solution by using a Fourier series development of the directional factors and solved the system by considering the zero order terms only. Next three years, Budak and Altintas (1998) worked out the system by considering several terms of the Fourier development, which gives rise to solution very close to those obtained by using fundamental terms only. Next three years, Budak and Altintas (1998b) worked out the system by considering several terms of the Fourier development, which gives rise to solution very close to those obtained by using fundamental terms only.

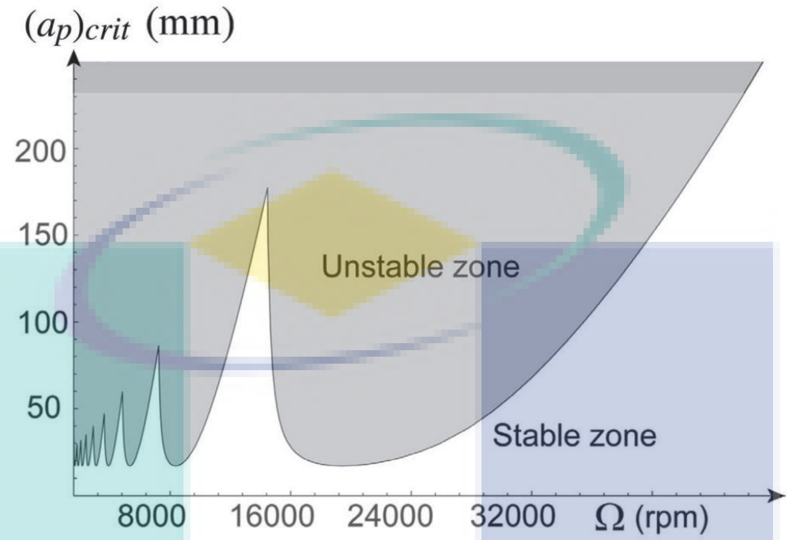


Figure 2.7. Layout of linear stability lobes

Source: *Insperger and Stepan*, 2000

Analytical methods that explicitly account for the interrupted nature of milling and have generated stability diagrams analogous to the classical 'lobes' have been proposed by researchers. The intermittent was captured by many harmonics in the Fourier series of the time carrying coefficients (Corpus and Endres, 2000). This approach loses accuracy as the relative time in the cut decreases. The single frequency approach has been shown to be very precise, but when radial immersion of the mill is small, the existence of additional stability lobes was found. A discrete map model for highly interrupted milling process was used by Davies et al, 2002), where the time in the cut is infinitesimal and the cutting process is modelled as an impact. An approximate expression was derived for the time delay form of an integral, time-periodic matrix differential equation, and use Floquet theory to determine stability boundaries (Insperger and Stepan, 2000).

The technique of semi-discretization was developed later Insperger and Stepan (2004), while the similar results using temporal finite elements was obtain by Bayly et al. (2003). The multi-frequency resolution is also able to present accurately the flip instability phenomenon was showed (Merdol and Altintas, 2004). In specific research, just a few papers analyzed the chatter in milling with the inclusion of the effect of helix angle. Without associated with the helix angle of milling, some papers present some instability regions with ‘lenticular’ shape (Govekar et al, 2005). Most commonly chatter research has focused to increase the material removal rate while avoiding the onset of chatter. A natural progressive trend is to increase the productivity to simultaneous machining. This process can be further optimized by determining the best combination of the chip loads and spindle speeds with constrain chatter instability (Olgac and Sipahi 2005).

2.4 Chatter suppression by spindle speed variation

There are few possible ways to suppress chatter. It includes the Application of variable tool pitches. Other than that, the continuous spindle speed variation also an option which it can effectively be used in a wider spindle speed range, since the frequency and amplitude of spindle speed variation can be easily adjusted in CNC machines even during the machining process. In facts, this technique becomes focus of interest in 1970’s.

Spindle speed variation method can serve two purposes, which to avoid machine-tool self-excited vibration associated with existing depth of cuts, and improvement of productivity through higher depth of cut as written by Yilmaz et al. (2002) and Zatarain et al. (2008) . They proposed the multi-level random spindle speed variation technique that will randomly change the spindle speed in fixed time interval as shown in Figure C. This type of spindle speed variation represent a stand-alone controller that generate continuous signal with amplitude range usually not exceeding of 40 % of nominal speed based on the spindle speed limitation.

Takamura et al. (1974) presented first simple model to study the stability of variable speed machining. Predicted a significant shift of the stability lobes to higher depth of cut, but the experimental test only show small improvements. Sexton et al. (1977) developed more realistic model. The research found some improvements in stability properties for low spindle speeds. The research concludes that the method of spindle speed variation (SSV) is shown to increase stability, in general, for single point cutting. However, the methodology used in the research is just only the numerical simulation. Next, Sexton and Stone (1980) showed that the presence of transient vibrations may drastically reduce these gains Sexton and Stone (1980).

Research by Jemielniak and Widota (1984) found that the variation of the frequency of self-excited vibration is the main mechanism of the influence of the SSV on the stability of the system. The influence on the stability limit is exercised by the relative amplitude of SSV. The value of this amplitude can result in efficient suppression of chatter. He agrees that one must find the root cause to a problem before solving it. As chatter develop with presence of self-excited vibration, the frequency of the self-excited vibration itself must be detected, then SSV suppression technique can be implemented. At the beginning of the 1990s, the technique for automatic regulation or selection of a stable spindle speed was introduced by Smith and Tlusty (1992) and operated in recent years to produce monolithic Aluminium parts.

The effects of variable speed cutting was studied and it is found that sinusoidal wave is more suitable than other periodic function such as triangular wave and square wave in terms of both traceability by the spindle servo system and the performance in terms of vibration suppression. It is concluded that variable speed cutting using sinusoidal speed trajectory increase the stability of machining system against self-excited vibration over the wide range of nominal speed and machining system dynamics (Lin et al. 1990 and Zatarain et al. 2008). However, other types of waves also can be used with different interest and accuracy. Despite of this very powerful technique, the relation of nominal speed and dominant frequency must be considered when designing speed trajectory for a specific application. Analysis of data must include on how the frequency change with spindle speed and with other influence.

At high spindle speed machining, the optimum sinusoidal spindle speed variation amplitude ratio is very high and beyond the allowable range by available spindle-drive system as stated by Al-Regib et al. (2003). Thus the feasible method is applying spindle speed selection method. Smith and Tlusty (1992) described the basic theory of eliminating milling chatter by automatic spindle speed regulation. The system they proposed does not require any knowledge of the system dynamics, and selects a stable speed where chatter does not emerge (Bediaga et al. 2009).

Delio et al. (1992) came out with a research of used of audio signal for chatter detection and control. They found that using an microphone sensor such as microphone capable of detecting chatter arising from tool, work piece, and machine flexibilities. One more advantage is it can collect chatter signal even in low-immersion cut. This gives a significant value as it provides a validation of the project, which is to detect chatter in low depth of cut.

To avoid chatter, the spindle speed has to be controlled as the material removal rate can be increase substantially. A technique was proposed to control machine spindle speed by means collecting the frequency data of the cutting process and feed them back to controller to adjust the spindle speed by Bediaga et al. (2009). They agreed that the knowledge required for spindle speed variation method is the chatter frequency and spindle speed of the machine.

Later on, many researches regarding spindle speed variation to suppress chatter is conducted. In 2011 a further research of spindle speed variation in chatter suppression was conducted. The research focus on to verify the efficiency of the optimal-linear spindle speed control by determine the best interval of time between subsequent changes of the spindle speed after receiving commands from the controller (Kalinski and Galewski, 2011).

The mathematical analysis in this field also takes place. Tsao et al. (1993) developed model taking the angular coordinates as variables instead of time followed by Insperger and Stepan (2004). They showed the semi-discretization method can effectively be used for stability analysis of turning at variable speed. Critical depth of cut can be increase for low speeds, but for high speed domain, there were no improvements.

Modelling the spindle speed variation of milling is more complex than turning but there still mathematical techniques to determine approximate dynamic properties. Sastry et al. (2002) used Fourier expansion and apply the Floquet theory to derive stability lobe diagram for race milling as improvement for low spindle speed. Later, Zatarain et al. (2008) proposed a general method in the frequency domain to the problem. It is showed that varying spindle speed can effectively suppress chatter. It is recommended that the research of spindle speed variation requires knowledge of the chatter frequency and the spindle speed. Another approach to suppress chatter is to use time domain simulation which makes it possible to obtain more detailed information like amplitude of vibration, chip thickness or cutting forces. The results of all these suppression techniques give a clear fundamental for the further research.

This research takes advantage of the rotating-frame approach and the constant angle delay in the angle domain to investigate the effect of SSV on system stability for rotating-bar boring, a case of no intermittent rotating-tool machining. The results show that the effectiveness of SSV on the stability lobes of rotating-bar boring is not as large as that on stationary bar boring. However, the SSV effect on rotating-bar boring flattens the stability lobes and lifts the tangential stability limits, such that the system stability becomes robust relative to spindle speeds.

A phenomenon commonly encountered during machining operations is chatter. It manifests itself as a vibration between work piece and cutting tool, leading to poor dimensional accuracy and surface finish of the work piece and to premature failure of the cutting tool. A chatter suppression method that has received attention in recent years is the spindle speed variation method, whereby greater widths of cut are achieved by modulating the spindle speed continuously. By adapting existing mathematical techniques, a perturbative method is developed in this paper to obtain finite-dimensional equations in order to systematically study the mechanism of spindle speed variation for chatter suppression. The results indicate both modest increase of stability and complex nonlinear dynamics close to the new stability boundary. The method developed in this paper can readily be applied to any other system with time-delay characteristics.

2.5 Summary for Chapter 2

To eliminate chatter, it must be detected first. Based on the research there were a lot of studies regarding chatter detection by using various type of sensor. The most frequently used sensor in the research is an accelerometer. Accelerometer provides great information as its data have a close relationship with vibration and displacement. Oppositely, microphone sensor is rarely used. Surprisingly, microphone sensor do gives a very good data on chatter detection because it can react even for low immersion cut provided the sensitivity of the sensor is good enough.

Chatter occurs because of the self-excited vibration. For chatter suppression, vibration damper or absorber is needed. It can be done in passive or in active approach. Passive suppression technique involves the manual modification of machines parameter to suit the particular cutting condition whereas active technique involves automatic adjustment.

Furthermore, active suppression technique consists of on-line and off-line technique. On-line technique is the method of collecting the real-time data during cutting process using sensor to give feedback for parameter re-adjustment (Insperger, 2004). Offline method, oppositely, be made up of stand-alone controller, that programmed beforehand to vary the parameter. However, it will be more practical to control the spindle speed rather than other parameter for active chatter suppression. This is because in a real situation, changing the spindle speed doing not interrupt the machining time and productivity rate as compared to depth of cut and feed rate (Al-Regib, 2003). Although a lot of techniques have been done and studied, spindle speed variation method is proven as the modest technique to suppress chatter that die to self-excited vibration of the machine.

In conjunction with this project, the technique of on-line spindle speed variation is use and combined with closed-loop PID controller system. The research is expected to contribute to high productivity through higher depth of cut, or faster feed rate of the process. On the other hand, cost of re-work the product and repairing the tool can be reduce, increase product surface quality through surface roughness, and also increase the machine lifespan.

CHAPTER 3

METHODOLOGY

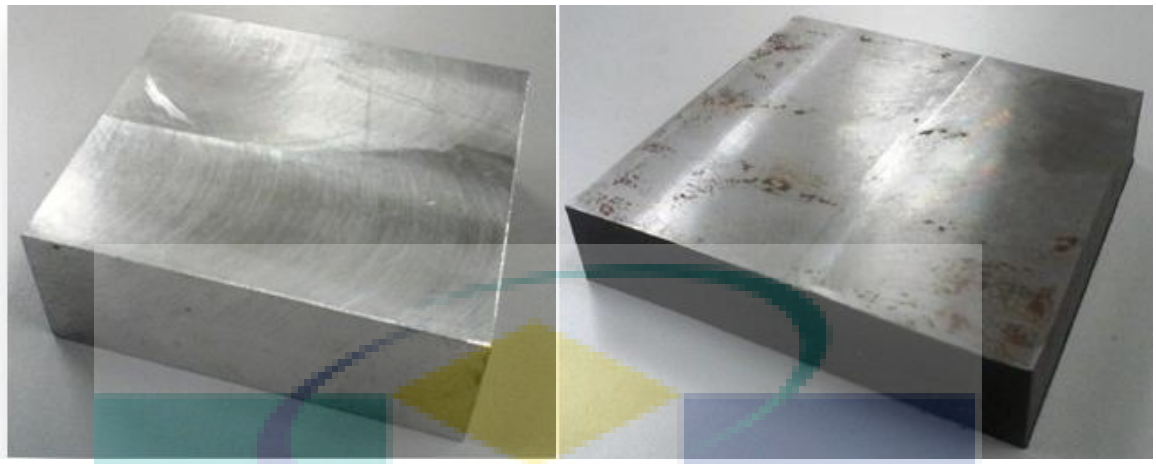
3.1 Introduction

This chapter explain the methods and techniques used to conduct this research project are deliberated step by step. The experiments are carried out to give a clear picture about the objectives mentioned in Chapter 2. First experiment was conducted by applying the high speed milling technique to conventional milling machine. PID controller in second experiment, an experimental system was designed to study about chatter detection and suppression respectively as manually and also automatically.

3.2 Machining for HSM application to normal machining

3.2.1 Design of Experiment

Two different types of materials are used in this experiment. There are aluminium and P20 steel materials as shown in Figure 3.1 (a). Apart from that, Figure 3.1 (b) shows the design of machining material using Catia 5V 60 software. The size of the machining material is 130mm x 810mm x 310mm.



a) b)

Figure 3.1: (a) Aluminium alloy 6061 (b) P20 Steel

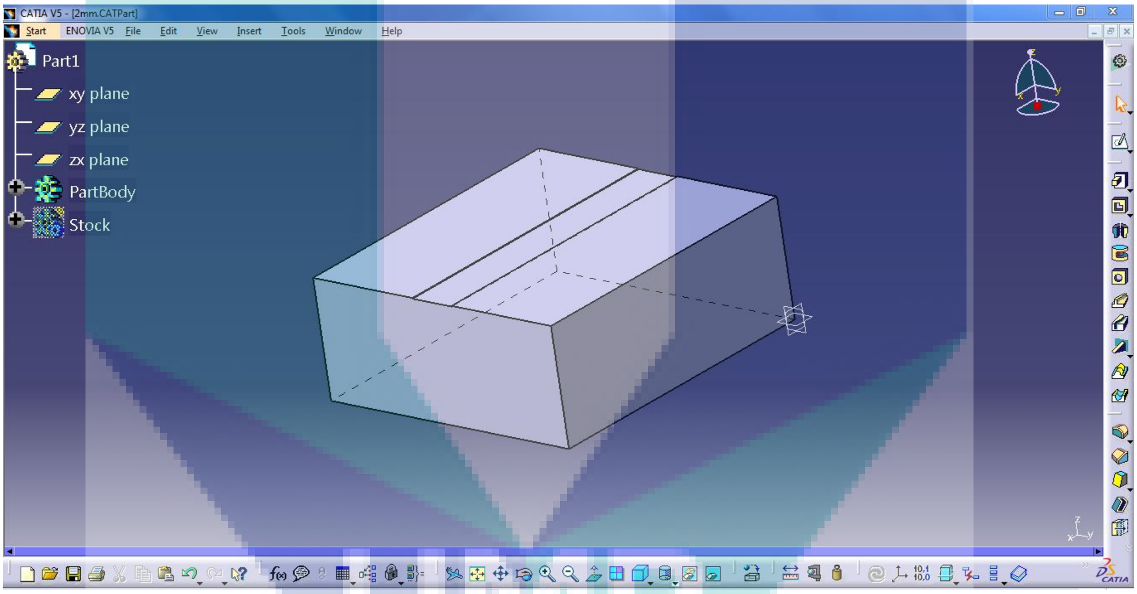


Figure 3.2: Design of machining material using Catia 5V60 software

Table 3.1: Description of aluminium and P20

Aluminium alloy 6061	P20
• Specifications	• Plastic mould steel
• AKA: aluminium square bar, aluminium key stock	• Standard: AISI
• Applications: frame work, braces, supports, trim, shafts	• Place of Origin: Guangdong, China (Mainland)
	• Brand Name: SONGSHUN

• Workability: Easy to Weld, Cut and Machine. • Mechanical Properties: Tensile = 45,000+/-, Yield = 40, 000 +/-	• Model Number: P20/1.2311/3Cr2Mo • Technique: hot rolled or machined • Application: Die steel Bar • Alloy or not; Is Alloy • Special use: Mold Steel • Type: Alloy steel Bar • Material: steel material 2738 • Tolerance: 0/+5mm • Quenching hardness: HRC 45-65 • Surface: black or machined

After conducting squaring machining process using conventional milling machine on both materials, the experiment was beginning with single slot of pocket. The machining parameters used in the first experiment for aluminium, began with depth of cut of 2mm and feed rate of 45 mm/min. It is finished at depth of cut and feed rate of 0.08mm and 1500 mm/min respectively. For P20 steel material, the machining parameters began with the same depth of cut as aluminium until least depth of cut but the feed rate began with 55 mm/min until the highest feed rate of 1100 mm/min. The spindle speed is constant for both materials that are 3000 rev/min. The size of pocket to be machined for both materials aluminium and P20 are 73mm x 81mm x 30mm and 102mm x 104mm x 15mm respectively.

3.2.2 Different Cutting Speed

In the second experiment, the machining parameters began with ten slots of pocket with the same depth of cut and feed rate for both types of materials. In first experiment one but extended until the least depth of cut and highest feed rate of 0.03mm and 3000 mm/min respectively. In fact, there is an increment of spindle speed to 3500 rev/min and kept constant for both materials. Other machining parameters were set to be constant which are radial depth of cut of 60% overlap ratio and material removal rate. Apart from that, constant material removal rate was determined from tool path simulation using Catia V5R20 (Paris H, 2004) software. It recommended various depth of cut and feed rate combination in order to get same machining time which too means the same material removal rate for each set of experiments. The actual machining time were checked after each completion of machining experiment to verify constant material removal rate after actual machining with the tolerance of ±5 minute.

After that, the generated NC code from Catia V5R20 then transferred to the conventional milling machine used which known as Makino KE55, 3-axis milling machine with maximum spindle speed of 4000 rev/min and feed rate of 5000 mm/min respectively. Moreover, the insert used was flat end mill TiAIN coated carbide from Ceratizit, 20 mm in diameter with three flutes. In addition, only one insert was used because considering single tool for analytical purposes. Other than that, to avoid the influence of tool run out and facilate the tools wear measurement. The experiment setup of tool and material was displays in Figure 3.3 Each experiment was conducted about three times and then used the final average value. The size of pocket was machined for both materials aluminium and P20 are 73mm x 81mm x 30mm and 102mm x 104mm x 15mm respectively is shown in Figure 3.5. The experiment setup is shown in Figure 3.4.

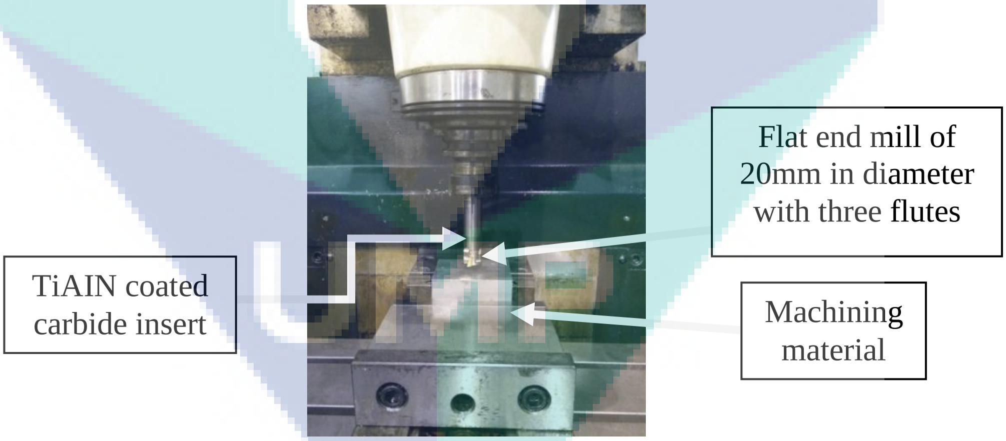


Figure 3.3. Experiment setup of tool and material

(a)

(b)

Figure 3.4. Experimental setup (a) before machining; (b) during machining

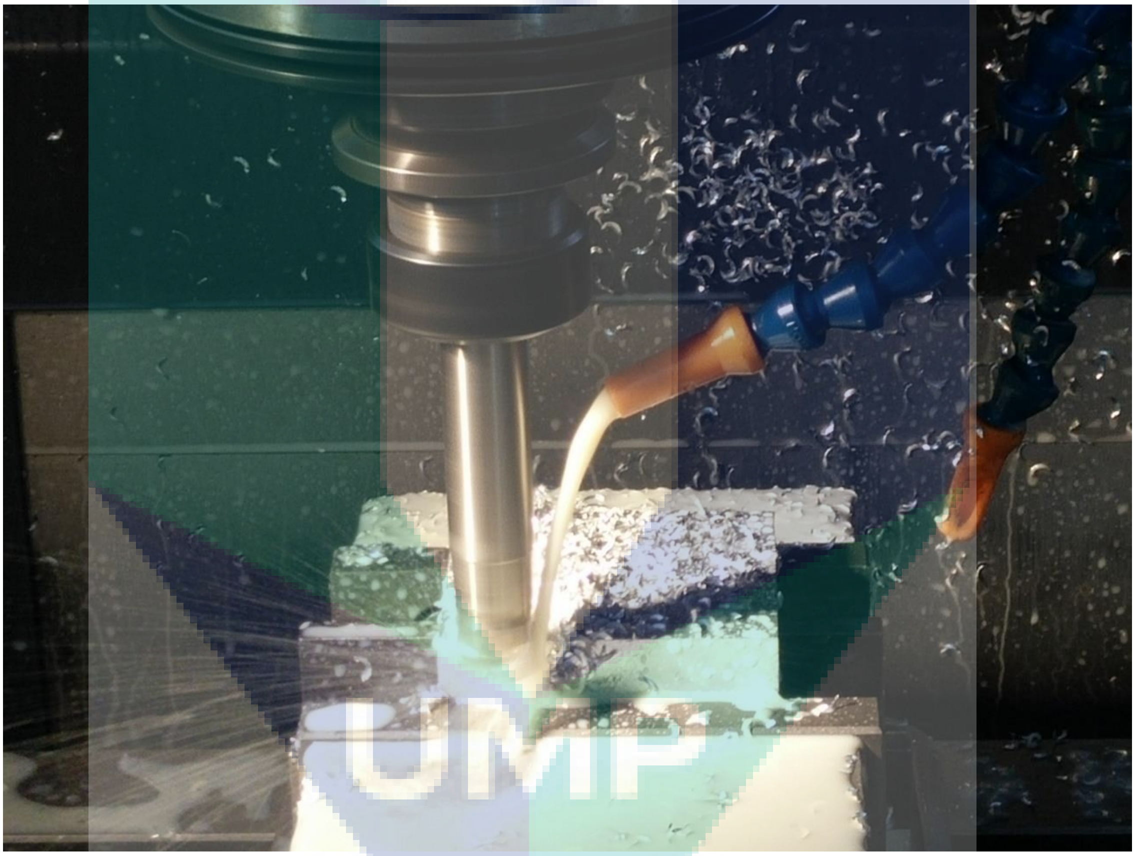


Figure 3.5: During pocket cutting process

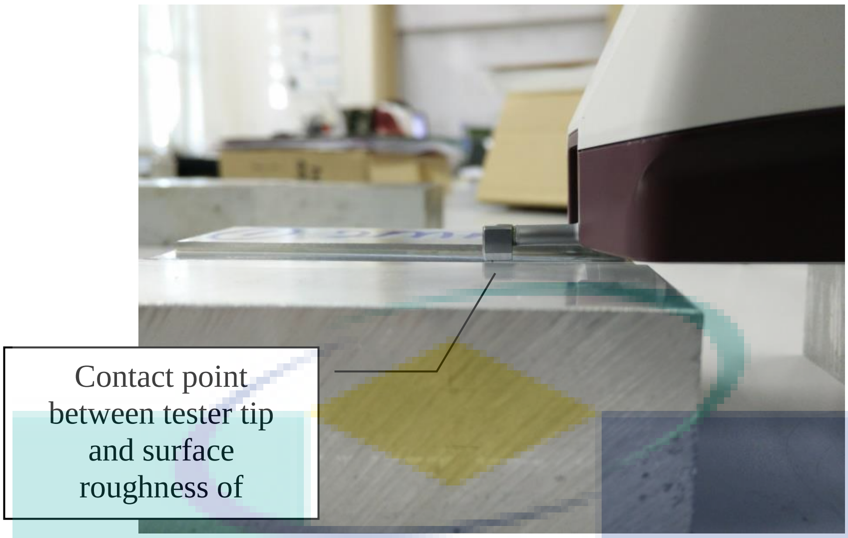
3.2.3 Surface Roughness and Tool Wear Measurement

After the machining experiment, the machined block surface roughness and tool wear of these inserts were measured by using Mitutoyo portable surface roughness tester model SJ210 series as show in Figure 3.6 (a). This portable device comfortable to use surface roughness measurement that let to view surface roughness waveforms and record the Ra value of the surface roughness. Moreover, this device also capable of performing in any orientation, including vertical and upside-down. On the other hand, metallurgical microscope machine as shown in Figure 3.6 (b) was also used to observe the tool wear length of those inserts for clearer micrograph image (Davies Pratt, 2009) and in order to make pictures to subsidize the study of wear mechanisms.

(a) (b)

Figure 3.6**:** (a) Mitutoyo portable surface roughness tester model SJ210 series; (b) Metallurgical microscope machine

(a)



(b)

Figure 3.7: (a) Surface roughness measurement (b) Contact point at machining area Machining Experiment for HSM application to high speed machining.

3.3 Experiment for Spindle Speed Modulation

The experiment will be conducted based on the scopes of the project, and these will be now introduced. The experiment is mainly focused on detecting chatter occur due to a specific range of spindle speed, which in range of 3000 – 20000 revolutions per minute (rpm) using a desktop-CNC machine as shown in Figure 3.8 (a). This machine used with the PC parallel port and controlled by Mach 3 software. The answer is yes, if you can justify the right machine for the job and learn to use it correctly. In fact, it is easy once you understand that high-speed machining is different from conventional machining and that you must adopt a completely new philosophy to make it work, according to Adam Schaut, a manufacturing engineer at Boeing's St Louis facility. He explains that this understanding begins with the definition of high-speed machining. Rather than using the conventional definitions based on spindle speeds (rpm), tooltip speeds (sfm), or bearing ratings (DN), the researches prefer to define it in terms of frequency.

Smith mentioned that high-speed machining occurs when the tooth-pass frequency approaches a substantial fraction of the dominant natural frequency of the machine and tool system. Smith developed his definition after showing a relationship between this natural frequency and the frequency of chatter, which is the vibration induced by the regeneration of waviness as a tooth recuts a portion of the work already cut by the previous tooth. Because the wavelength of chatter increases with cutting velocity, there is less friction along the clearance face of the tool to damp the vibration (Koelsch, 2001). Consequently, Smith and his followers deduced that high-speed machining involves more than just high spindle speeds and requires a definition that accounts for this fact. In this project, the detection of chatter is done by using a microphone sensor (microphone) mounted on the machine to collect signal during the cutting process. Experiment will be conducted as depth of cut; feed rate and spindle speed will become the variable. Signal is transferred to the Data Acquisition Card (DAQ) by using a device namely National Instrument NI USB-4431, then will be processed to identify whether chatter develop or not. The flow chat of project procedure is shown as figure 3.8 (b).

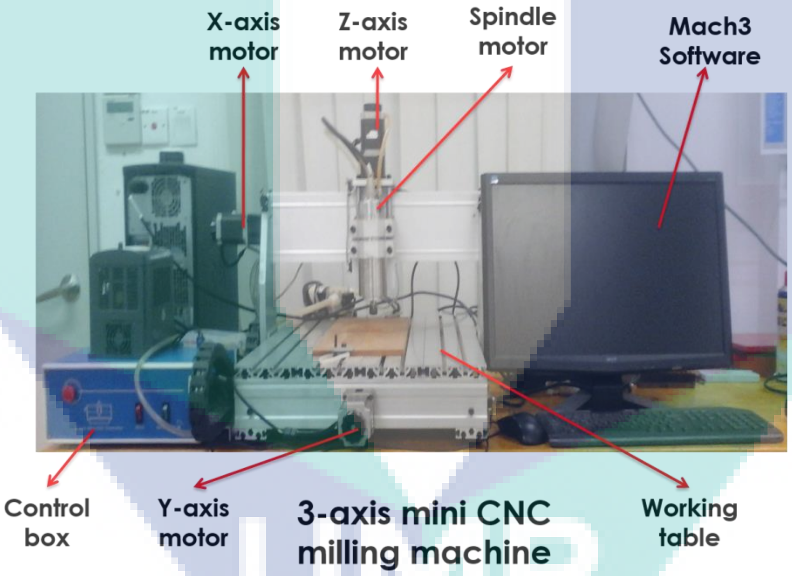


Figure 3.8. (a) Desktop-CNC machine

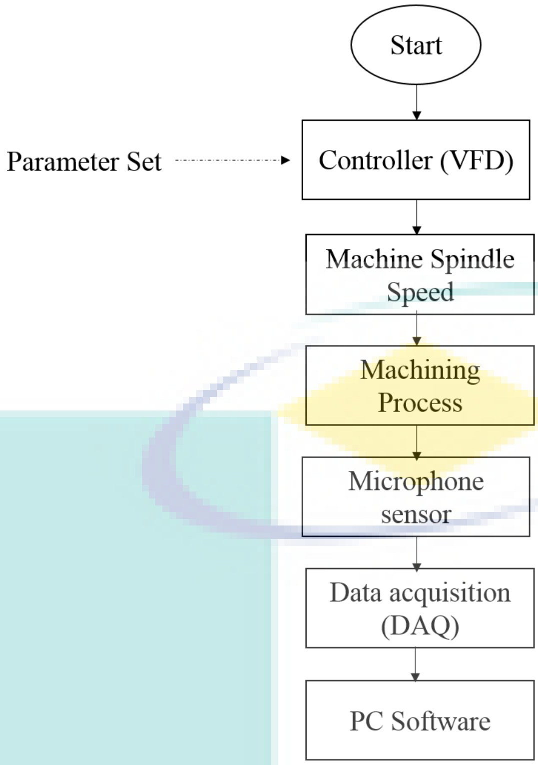


Figure 3.8. (b) Process flow for designed experiment

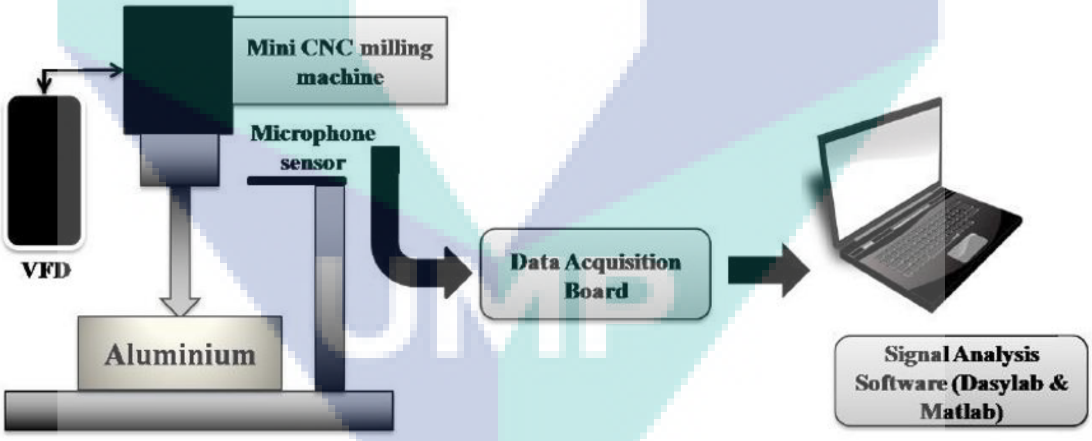


Figure 3.8. (c) Illustration of Experiment tools arrangement

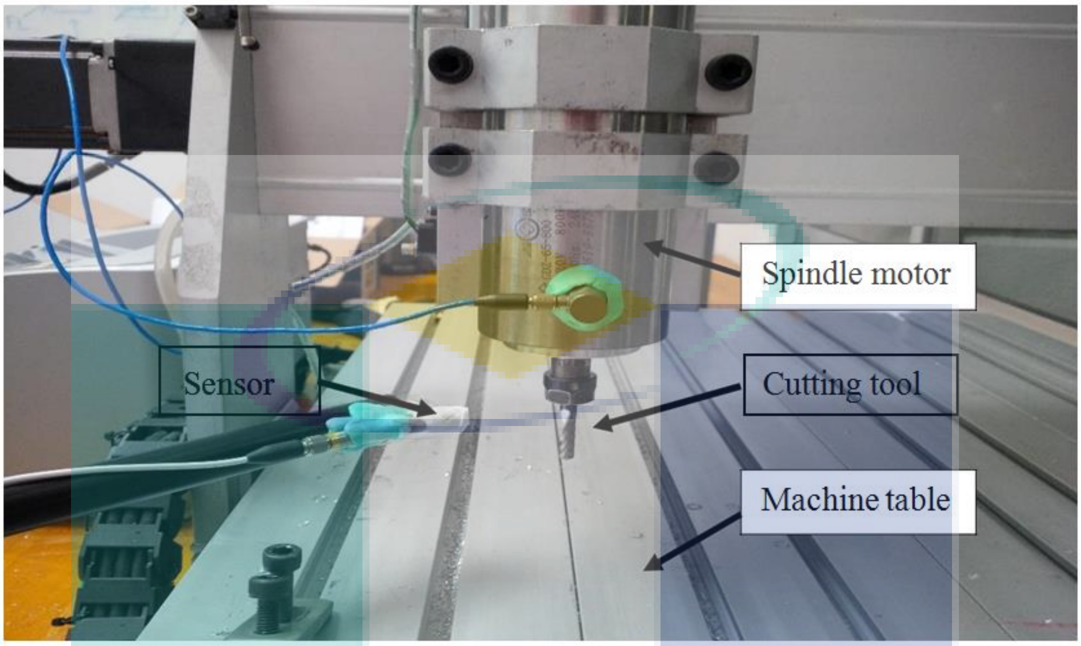


Figure 3.8. (d) Arrangement of experiment tools

3.3.1 Spindle motor control unit

A Variable Frequency Drive (VFD) as shown in Figure 3.5 unit model HY01D523B is use to drive a 220VAC, 7 ampere and 1.5 kW spindle motor as shown in Figure 3.9. The machine spindle speed is controlled by a potentiometer.

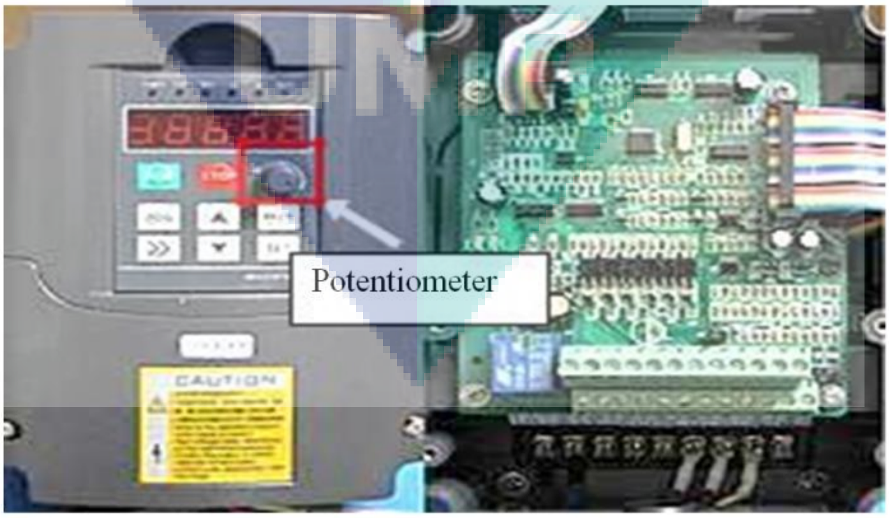


Figure 3.9. Variable Frequency Drive Unit (VFD) of the machine

Figure 3.10. Spindle motor

Figure 3.11: Control box

Table 3.2: The specification of the control box

Parameter	Descriptions / Specifications
Operating voltage	AC110V – AC220V (we also stock USA.UK.EU.AU.plugs and 110V – 240V power version for the country all over the world).
Control unit	2.5A stepping motor driver plus adjustable spindle speed controller
Computer connection	On board parallel port
Command code	G code
Acceptable software	Mach3, EMC2
Protection	Emergency stop button

3.3.2 Microphone sensor and DAQ instrument

Sensor is one of the most important devices in this project. It is function to collect the data or signal during the cutting process. This project makes a full use of ICP microphone System model 378C01 as shown in Figure 3.7 by PCB Piezotronics Inc. as an active sensor (Delio, 1992). To ensure a legible data collected throughout the experiment, sensor is separately mounted so that it has no contact with the machine (T. Delio, 1992). The crucial information of this sensor is tabulated in Table 3.3. Comparisons are made between the microphone and some other common sensors (dynamometers, displacement probes, and accelerometers) regarding sensing of unstable milling. It is shown that the signal from the microphone provides a competitive, and in many instances a superior, signal that can be utilized to identify chatter. Using time domain milling simulations of low-radial-immersion, low-feed, finishing operations it is shown that for these cuts (especially at relatively high speeds) chatter is not adequately reflected in the force signal because of the short contact time, but that it is clearly seen in the displacement signal. Using the dynamics of existing production milling machines, it is shown how the microphone is more suitable to chatter detection than other remotely placed displacement sensors, especially in cases that involve flexible tooling and work pieces. Aspects important for practical implementation of a microphone in an industrial setting are discussed. Limitations of the microphone are addressed, such as directional considerations, frequency response, and environmental sensitivity (i.e., workspace enclosure, room size, etc). To compensate for expected unwanted noises, commonly known directionalization techniques such as isolation, collection, and intensity methods are suggested to improve the ability of the microphone to identify chatter by reducing or eliminating background and extraneous noises.

Figure 3.12. 378C01 microphone sensor by PCB Piezotronics

Using frequency domain processing and the deterministic frequency domain chatter theory, a microphone is shown to provide a proper and consistent signal for reliable chatter detection and control. Cutting test records for an operating, chatter recognition and control system, using a microphone, are presented; and numerous examples of chatter control are listed which include full and partial immersion, face and end-milling cuts (Delio, 1992).

Table 3.3 Characteristics of microphone

Item	Value
Open circuit sensitivity	2.0 mV/Pa
Open Circuit Sensitivity (+/-3.0 dB)	-54 dB re 1 V/Pa
Dynamic Range (3% Distortion Limit)	>162 dB re 20 µPa

Data acquisition in this project is using National Instrument sound and vibration data acquisition (NI-USB-4431) which is capable in collecting high speed data directly from the sensor. This DAQ system is a 24-bit four channel analogue input device as shown in Figure 3.13.

Figure 3.13. NI-USB-4431 DAQ

3.3.3 Work piece Preparation and Cutting Tool

The aluminium alloy 6061 used through this experiment and the specification use in this project is tabulated as in Table 3.4. The dimension of the work piece is 73mm x 81mm x 30mm prepared using standard machining process. Preparation is done using Makino KE-55 milling machine located at machining workshop in Faculty of Manufacturing Engineering involve the process of cutting and squaring the material into the desired shape.

Table 3.4 Characteristics of Aluminium

Items	Parameter
Another name	Aluminium square bar, aluminium key stock
Applications	Frame work, braces, supports, trim, shafts
Workability	Easy to weld, cut and machine
Tensile stress	45,000± psi
Yield stress	40,000± psi

The cutting tools use in this project is summarized in Table 3.6. Actual cutting tool is shown in Figure 3.14. This project used single flute cutting tool for observation and analytical purpose.

Table 3.5: Cutting tools

Brand name	Senyo
Product name	Senyo tungsten carbide single flute straight cut end mill cutters
Material	Carbide
Diameter	6mm
Type	End mill
Processing type	Metal
Coating	TiAIN
Overall length	38-100MM
End mill type	single flute end mill
Usage	General high-speed cutting

Figure 3.14. Single flute end mill

3.3.4 Machining Parameters

Machining parameters, such as depth of cuts (axial and radial) is set beforehand. It is to ensure valid data can be compared with controlled parameters. MRR of the operation can be obtaining by using Equation 1.1. Other than that, the surrounding parameters also must be taken into consideration. To collect data from an microphone sensor, the surrounding noise has to be suppressed (Seguy, 2009). This is to ensure only valid data is collected. Thus, experiment must be conducted in an isolated room. The Experiment parameter is summarized in Table 3.5.

Table 3.6 Parameters of Machining Experiment

Parameter	**Value (min)**	**Value (max)**
Depth of cut	0.1mm	0.3mm
Feed rate	2800 mm/min	3000 mm/min
Spindle speed	3000 rpm	2000 rpm
Sensor sampling rate	2000 Hz	

3.3.5 Software for Data Recording and Analysing

DASYLab version 10.1 is used to record the data collected by microphone sensor during cutting process. The software consists of several block charts to channel the data and saved in ASCII file format which contains the time domain value from the sensor in Pascal (Pa). Figure 3.15 shows the screen shot of the DASYLab workspace that is use in this project.

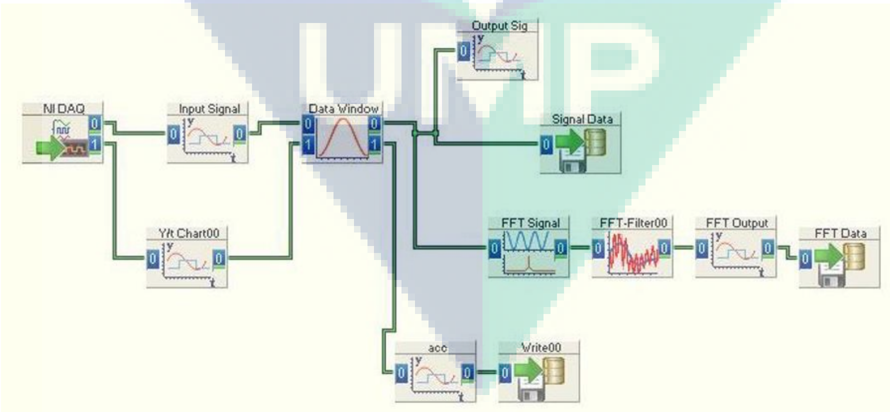


Figure 3.15. Dasylab workspace

Table 3.7: Description of functional icons used in EMA testing

Feature	Description
Task DAQ	Analog input with sampling rate 2000 Hz
Data Window	Hanning window with the block size 2048
Y/t Chart	Display fast data in graph presentation
Digital Meter	Display fast data in digit number presentation
Write Data	To save data

Matrix Laboratory (MATLAB) is software that is commonly used to compute mathematical data. This software is used to analyse the data saved from DASYLab to compute and show the data in graphical form using Fast Fourier transform technique. The Matlab script is attached in Appendix B.

3.4 Design for Active PID controller

Active PID controller where the whole system operates without any existence of external source. It operates with the signal gained by the sensor and give feedback accordingly. Here, the system works with the signal acquired from microphone sensor and varies the spindle speed accordingly to minize the vibration occurred during machining process. Chatter detection experiment is done to collect data and the machining parameter is controlled and set manually. Machining process is conducted at Faculty of Manufacturing Engineering (FKP) laboratory. The enclose laboratory is chosen, where the noise can be significantly reduced in order to collect legit data by the microphone sensor (Dijk, 2010).

For chatter detection experiment stage, machine's spindle speed is controlled using a potentiometer, which control the voltage supplied to the spindle motor. The spindle speed value is detected using a built-in rotary encoder. Few experiments were designed to collect sufficient data to develop the active controller. The experiments consist of three parameters, namely axial depth of cut, feed rate and spindle speed. For every experiment conducted, data is collected by microphone sensor by 2000 Hz sampling frequency. The actual experiment setup is shown in Figure 3.16.

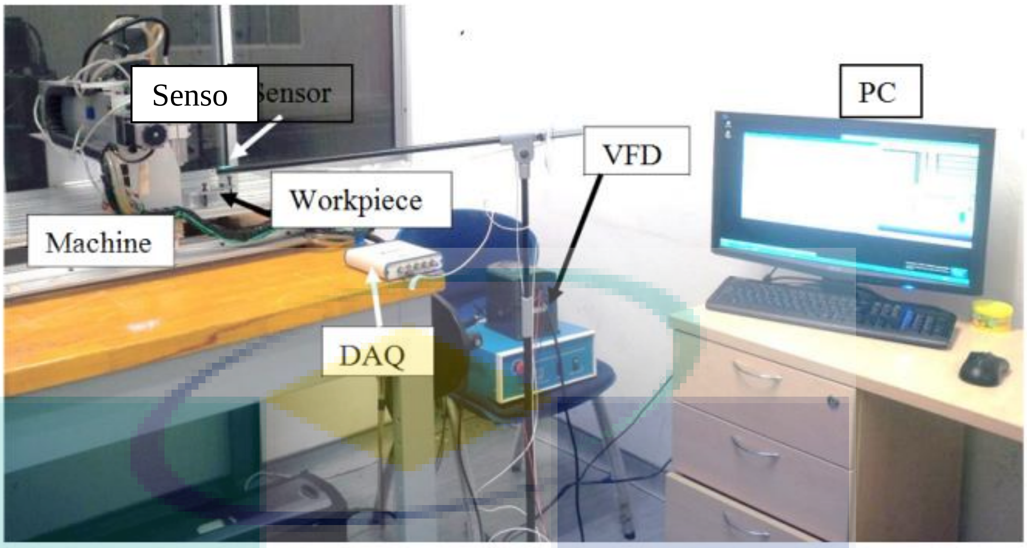


Figure 3.16 Actual setup of the designed experiment

Before main experiment is conducted, a pre-experiment is done to select the minimum parameter of the main experiment. MRR of 1680 mm^3/min is kept constant for this experiment. The experiment design is tabulated in Table 3.7. MRR of 1680 is chosen to make a full use of the machine capability, in which the feed rate is capped at 3000 mm/ min. The first experiment involves the cutting process at 3000 rpm and feed rate at 2800 mm/min. The depth of cut is varied from 0.1 mm until 0.3 mm with increment of 0.05 mm. Next experiment is done by varying the feed rate of the cutting process in range if 2800 mm/min until 3000 mm/min with increment of 50 mm/min. The last experiment consists of constant depth of cut and feed rate at 0.1 mm and 2800 mm/min respectively. Spindle speed is varied by 3000, 5000, 10000, 15000 and 20000 rpm.

Table 3.8: Pre-Experiment Parameters

Depth of cut (mm)	**Feedrate (mm/min)**	**Spindle Speed (rpm)**	**MRR (mm^3/min)**
0.1	2800	3000	1680
0.2	1400	3000	1680
0.3	933	3000	1680
0.4	700	3000	1680
0.5	560	3000	1680

A closed-loop active PID controller is set up using an Arduino board. The experiment methodology is re-arranged as shown in Figure 3.14, whereas the actual setup of the active control experiment is shown in Figure 3.15.

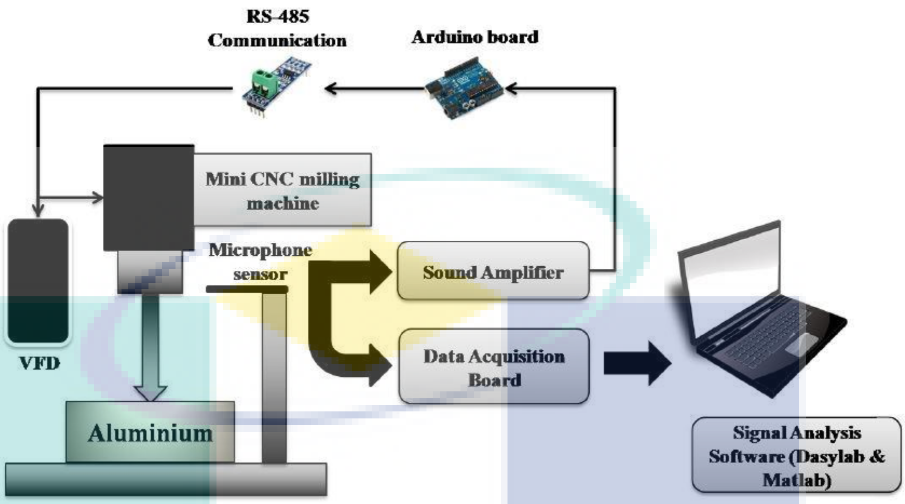


Figure 3.17. Active control system configuration schematic diagram

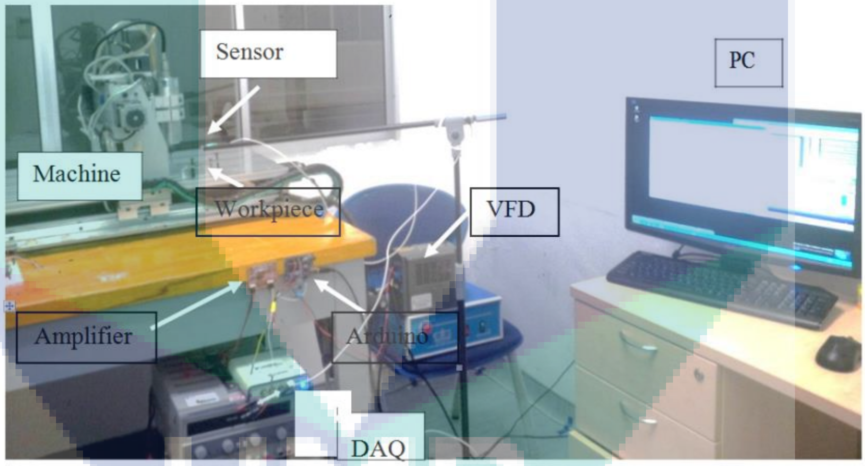


Figure 3.18. Active control system actual setup

Microphone sensor has a very small signal. It needs to be amplified to a significant value. In Figure 3.19, Arduino board can only receive analogue signal in range of 0 V to 5 V. The signal measures directly from the microphone shows a steady-state value at 40 millivolts and need to be amplified to 2.5 V. The amplification factor (gain) needed is 62.5. Amplification circuit is set up in non-inverting configuration as shown in Figure 3.20.

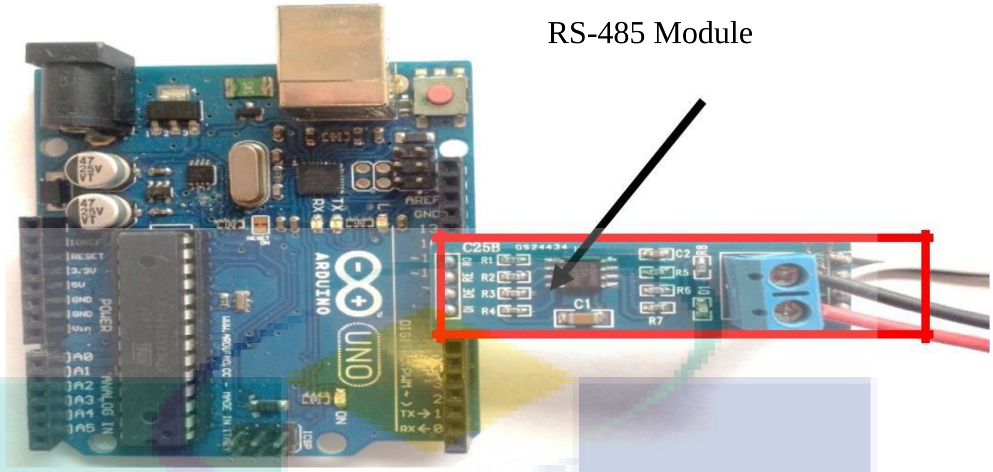


Figure 3.19. Arduino Board with RS-485 module

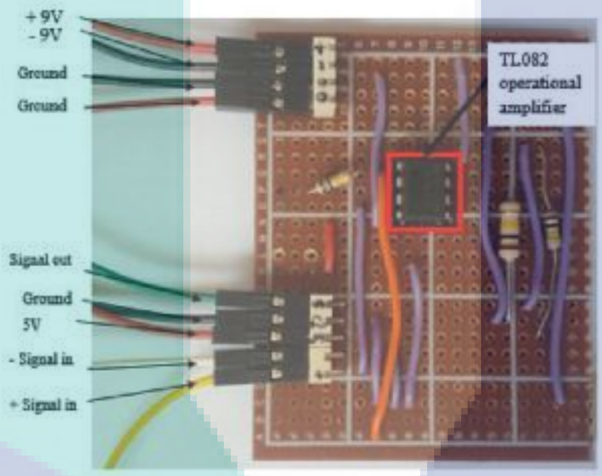


Figure 3.20. Microphone amplifier and DC offset circuit

Data receive from the microphone sensor with sensitivity 1.8mV/Pa was amplified using amplifier due to the signal is in mV. The data is in time domain. After amplified it transfer to Arduino where conversion from analog to digital occur. Since, the type of chatter classified into 5 types, the conversion begins with 1023 bit divided to 5. It is transform into frequency domain using Discrete Time Fourier Transform (DTFT) as shown in Equations 3.1 to 3.3 to calculate the amplitude of spectral density at 400 Hz.

Real Value	=	$\sum_{N=1}^{0} x[N] \cos{}'('\omega NTs)$	(3.1)
Imaginary Value	=	$-\sum_{N=1}^{0} x[N] \sin{}'('\omega NTs)$	(3.2)
Amplitude	=	$\sqrt{(Real\ Value)^2} + (\text{Imaginary Value})^2$	(3.3)

From here, amplitude is set as input. RS-485 module is used to communicate with VFD. RS-485 is serial communicators that communicate with half-duplex on a single pair of wires, at a distance up to 1200 meter. The module connects with VFD using twisted pair wire consist of (+) and (-) terminal Figure 3.17. Lines of codes is use to send a signal to VFD to change the spindle speed. The output range is 0 to 255. In this project, the microcontroller send data to VFD using 8N1 for ASCII MODBUS protocol that writes a function to override the current spindle frequency.

Table 3.10 shows the number of experiments has done to analysis the constant feed rate 2800 mm/min and the constant depth of cut 0.1 mm. It has been taken almost three times of experimental with various types of depth of cut and feed rate. In each depth of cut of 0.05 mm, it starts at 0.1 until 0.3 mm. In each feed rate of 50 mm/min, it starts at 2800 until 300 mm/min. Thus, from the table we could notify that it has been used 5 vary types of parameters which are in an ascending order to calculate and analysis the constant of the feed rate and depth of cut.

Table 3.9: Cutting Experiment with constant feed rate (1-5) and depth of cut (6-10)

No.	Depth of cut(mm)	Feedrate (mm/min)
1	0.1	2800
2	0.15	2800
3	0.2	2800
4	0.25	2800
5	0.3	2800
6	0.1	2800
7	0.1	2850
8	0.1	2900
9	0.1	2950
10	0.1	3000

3.4.3 Work piece measurement

After the machining experiment, the roughness of material was tested using portable Mitutoyo surface roughness tester model SJ210 for both active and initial experiment. Moreover, the material also tested using surface topography machine. Surface topography is the local deviations of a surface from a perfectly flat plane. The topography of a surface is known to substantially affect the bulk properties of a material. Despite the often nanoscale nature of surface irregularities, the influence they have may be observed by macroscopic measurements. The characterization of surface topography has become increasingly important in many fields, such as materials, tribology and machine condition monitoring. Surface topography also known as surface texture, surface finish or surface profile.

Surface topography is an important factor that controls friction and transfer layer formation during sliding. Surface topography can be either isotropic or anisotropic. Sometimes, stick-slip friction phenomena can be observed during sliding depending on surface topography. Each manufacturing process produces a surface topography. Many factors contribute to the surface topography in manufacturing. In general, the cost of manufacturing a surface increases as the surface finish becomes smoother. Due to the abstractness of surface topography parameters, engineers usually use a tool that has a variety of surface roughness's created using different manufacturing methods. The process is usually optimized to ensure that the resulting texture is usable.

3.5 Summary for Chapter 3

This project involves two stages of experiment; Chatter detection experiment and active controller testing experiment. The experiments are designed so that the data recorded during the process is legible and valid. The experiment involves machining process, data recording, data analysing, surface roughness testing, visual appearance and sound level observation. For every test, data is shown in graphical form to show trends and crucial value. The methodology is designed based on the limitation of apparatus and time constrain when conducting the project.

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

In the first experiment, the experiment carried on investigation of surface roughness and tool wear length with varying combination of depth of cut and feed rate of Aluminium alloy and P20 steel machining. This experiment investigates the effects of varying combination of depth of cut and feed rate to tool wear rate length using metallurgical microscope and surface roughness using portable surface roughness tester after end milling of Aluminium and P20 steel. Results showed that feed rate significantly influences the surface roughness value while depth of cut does not as the surface roughness value keep increasing with the increase of feed rate and decreasing depth of cut. Whereas, tool wear rate almost remain unchanged indicates that material removal rate strongly contributes the wear rate.

In addition, in second experiment by using the techniques of high speed milling chatter occurrence during machining was suppressed using spindle speed variation (SSV) method via microphone online detection techniques. The initial experiment begins with constant material removal rate (MRR) where varies depth of cut, feedrate and spindle speed were analysed using time and frequency domain.

Data collected from sensors are analysed in time domain and frequency domain using Fourier transform technique to develop PID controller in active mode. The material roughness was measured using portable surface roughness for both initial and active experiments. The validation of the result is done using roughness value, the signal from microphone sensor, sound, and visual inspection of the specimens.

4.2 High Speed Machining Results

There are many definitions for High Speed Machining (HSM). MMS Online uses the tagline Achieving high metal removal rates with quick milling passes or the HSM zone on their site. Another very high-tech definition of HSM is Machining at the Resonant Frequency of the Machine, which goes to HSM techniques for selecting spindle speeds that minimize chatter. Others argue that HSM is all about high material removal rates and leaving a surface finish good enough to call finished in one pass.

The dotted lines represent temperatures at various surface speeds. Note that all of the materials go steadily up and then eventually start dipping back down again as surface speed increases. Somehow, temperatures decrease beyond a certain spindle rpm. Steel and cast-iron taper down more gently than aluminium, but the effect is still alive and well. The same experiment showed that cutting forces also come down, and that will be at least one reason why the temperatures drop, and why for HSM machining in the right rpm ranges, you can achieve high MRR's with lower cutting forces.

4.2.1 Low Cutting Speed Result

Figure 4.1 shows that the average surface roughness value taken in first experiment for both materials, Aluminium and P20 Steel using single slot of pocket machining where different combination of depth of cut and feed rate were used under constant material removal rate. This figure obviously prove that feed rate strongly influences the surface roughness value to increase as when the feed rate is kept increasing while the depth of cut decreasing. Even the material properties are highly influences the pattern of graph where the average surface roughness value seems bigger in P20 compared with Aluminium. This is due to the P20 material is so solid and hardens compared with Aluminium. Figure 4.1 shows the end of experiment after cutting process of Aluminium.

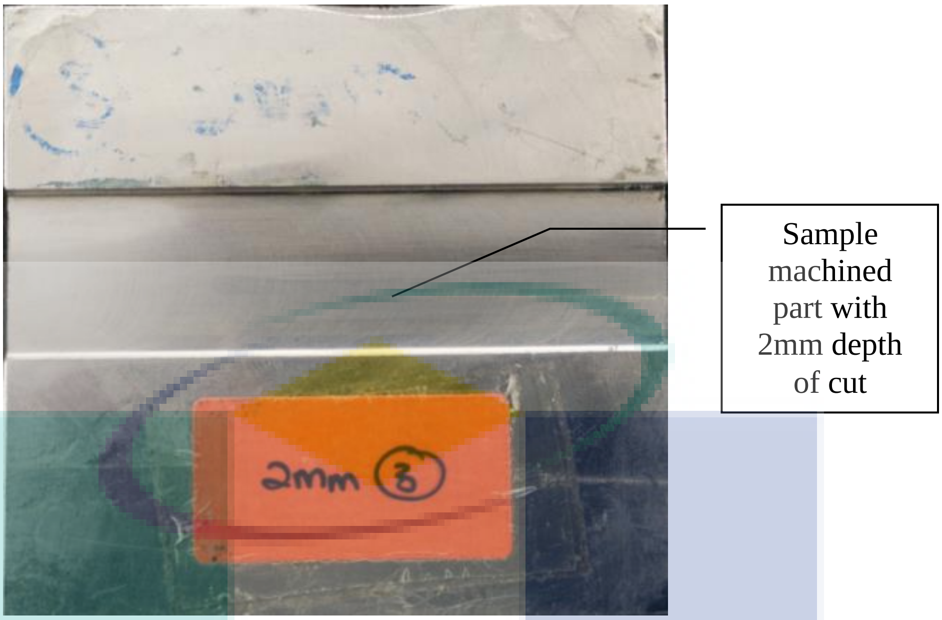


Figure 4.1 : Aluminium material after machining process

According to the Figure 4.2, the highest average surface roughness value for both materials is at lowest depth of cut 0.08mm and highest feed rate of 1500 mm/min for Aluminium and 1100 mm/min for P20 Steel. Furthermore, this also strongly proves that feed rate had contributed for the surface roughness value compare to depth of cut. This statement had agreed with Saikumar et al. (2012) that stated that as the cutting speeds and feed rates are increased, the rubbing action also become faster and more heat generated even though less contact time exists.

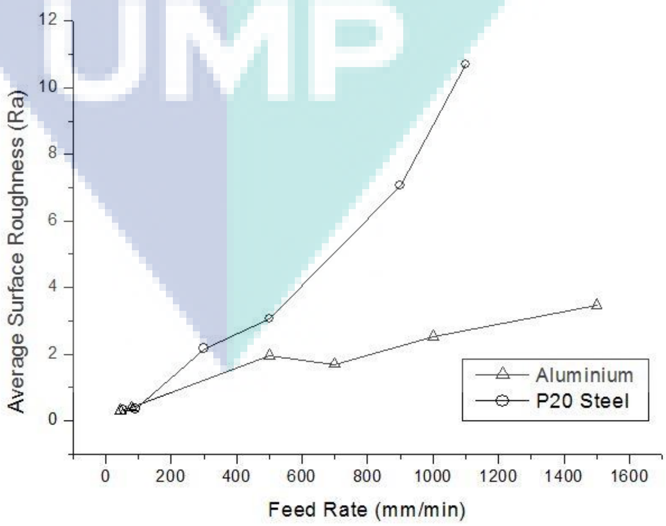


Figure 4.2: Average surface roughness at different feed rate 0-1600 mm/min for Aluminium and P20 Steel

4.2.2 High Cutting Speed Result

Figure 4.2 displays that the average surface roughness value taken in second experiment for materials, Aluminium and P20 Steel using ten slot of pocket machining where different combination of depth of cut and feed rate were used under constant material removal rate too. Figure 4.3 shows the machined surface of aluminium.

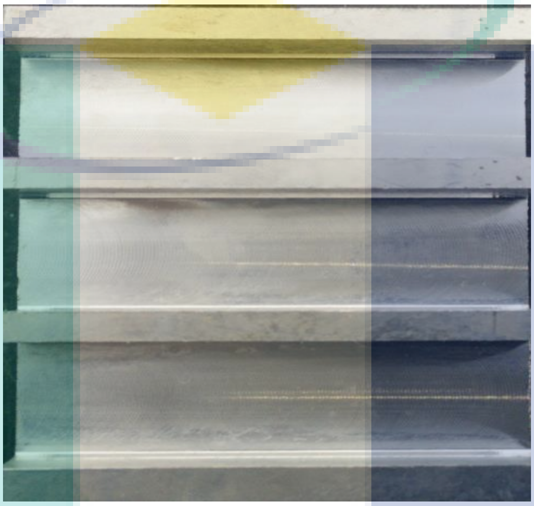


Figure 4.3: Aluminium after machining process

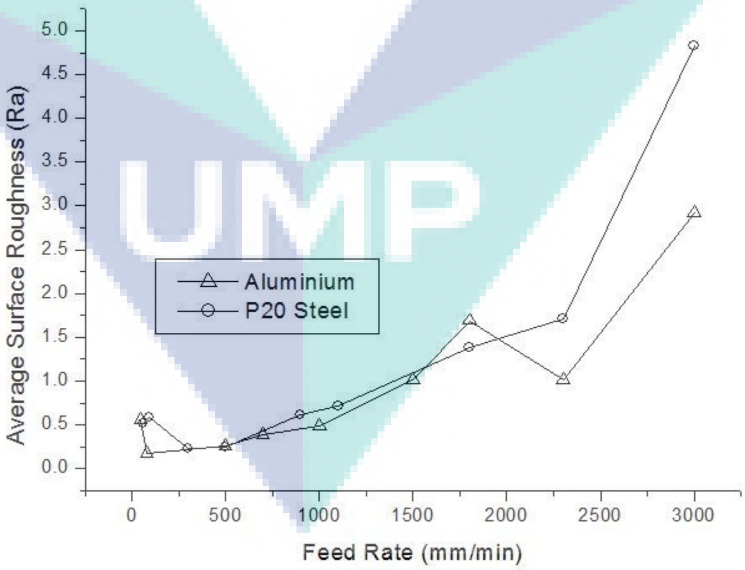


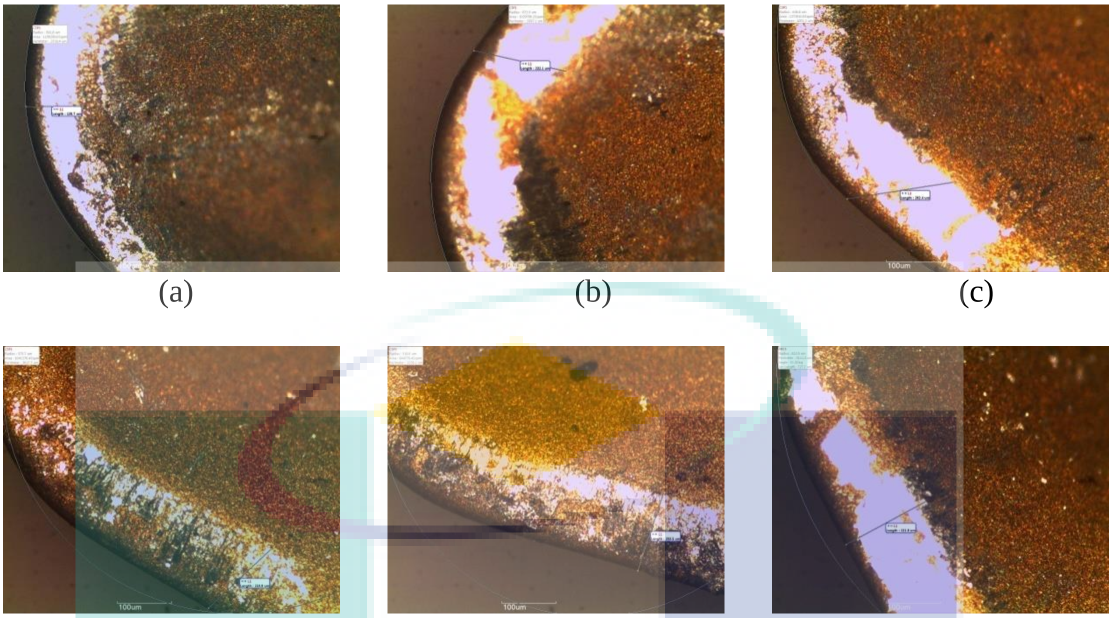
Figure 4.4: Average surface roughness at different feed rate of 0-3000 mm/min for Aluminium and P20 Steel

Based on the Figure 4.3 and 4.4, the average surface roughness value taken in second experiment for both materials, Aluminium and P20 Steel using ten slot of pocket machining where different combination of depth of cut and feed rate were used under constant material removal rate too. Obviously can see similar pattern from Figure 4.3 compare with Figure 4.4 where feed rate really influences the surface roughness value to keep increase as when the feed rate is kept increasing while the depth of cut decreasing. According to the figure, the highest average surface roughness value for both materials is at lowest depth of cut 0.03mm and highest feed rate of 3000 mm/min for Aluminium and P20 Steel. Although, the experiment is extended even to least depth of cut compare with first experiment, it still shows same pattern that the surface roughness value is keep increasing together with the increment of feed rate. Hence, this strongly proves that feed rate had contributed for the surface roughness value compare to depth of cut.

4.2.3 Discussions

Through the experiments, with constant material removal rate, radial depth of cut and spindle speed, surface roughness value have been influenced by feed rate while depth of cut does not contribute at all. From the both experiment results given, the surface roughness value keeps incrementing when higher feed rate was used even the depth of cut had been reduced to shallow depth of cut, 0.003mm. Apart from that, when tested to least depth of cut and higher feed rate, 0.03mm and until 3000 mm/min respectively, the tool wear have shown no significant different for both materials in both experiments. Other than that, this proves that, material removal rate strongly contributes to tool wear rate because when the material removal rate was kept constant for both experiments, the tool wear rate too almost kept unchanged. In nutshell, high speed milling technique can be implementing in conventional milling machine with high feed rate, shallow depth of cut since there is no significant influence to tool wear rate by making material removal rate constant.

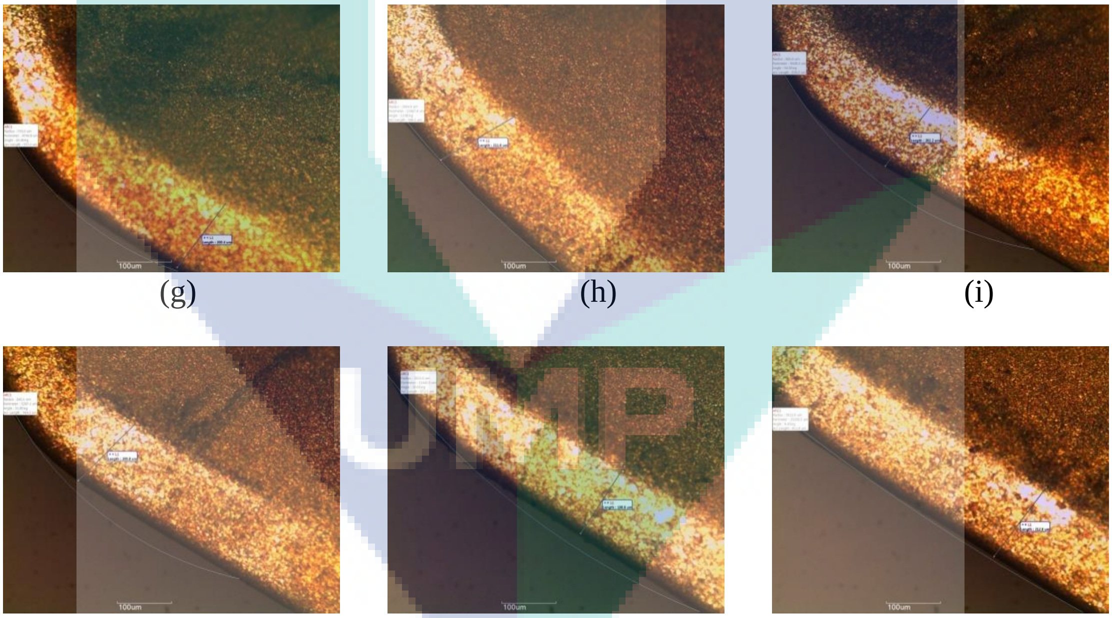
Figure 4.3 and Figure 4.4 shows that no significant different in tool wear length were observed after using the metallurgical microscope machine for each experiment. The micrograph image taken indicates that feed rate and depth of cut did not influence the tool wear length when material removal rate, spindle speed and radial depth of cut are kept constant.



(a) (b) (c)

(d) (e) (f)

Figure 4.5 (a)-(d) The metallurgical microscope image taken that displays tool wear length for feedrate 0-1500 mm/min in machining Aluminium.

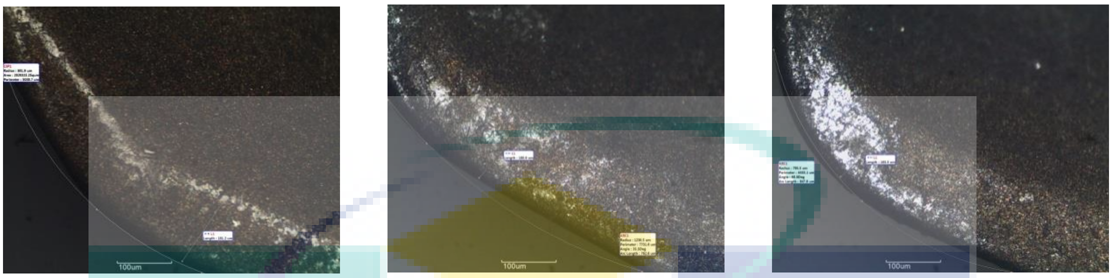


(g) (h) (i)

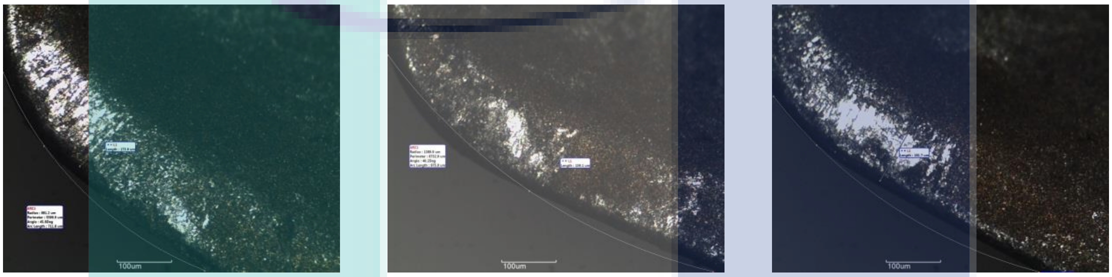
(j) (k) (l)

Figure 4.6 (g)-(l) The metallurgical microscope image taken that displays tool wear length for feedrate 0-1500 mm/min in machining P20 Steel.

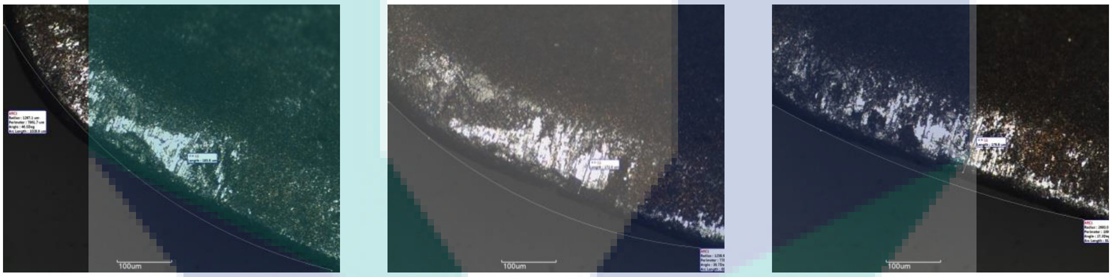
Apart from that, Figure 4.7 and Figure 4.8 show that no significant different also in tool wear length were observed after using the metallurgical microscope machine for each experiment. The micrograph image taken indicates that feed rate and depth of cut did not influence the tool wear length when material removal rate, spindle speed and radial depth of cut are kept constant.



(a) (b) (c)

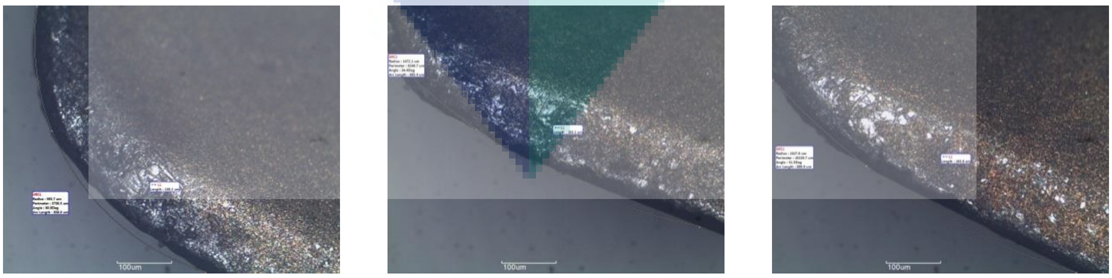


(d) (e) (f)

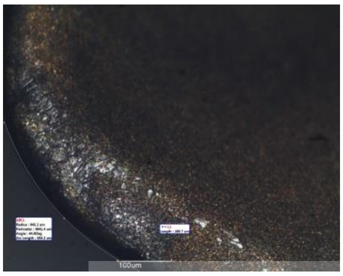


(g) (h) (i)

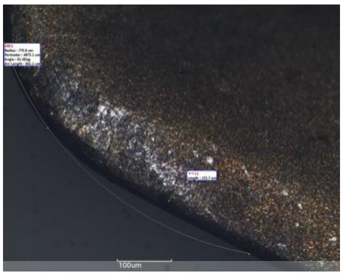
Figure 4.7. The metallurgical microscope image taken that displays tool wear length for feedrate 0-3000 mm/min in machining (a)-(i) Aluminium.



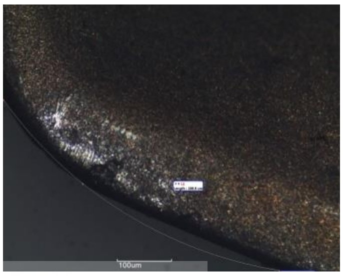
(j) (k) (l)



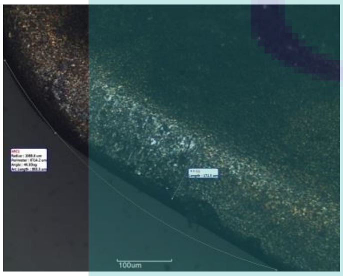
(m)



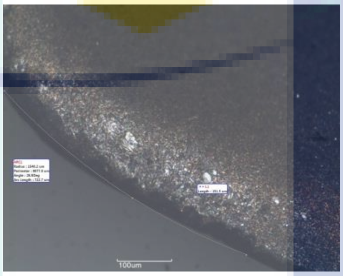
(n)



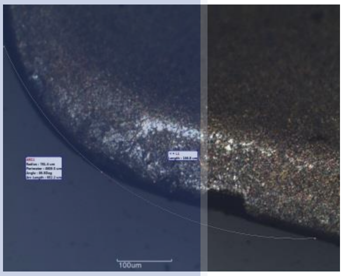
(o)



(p)



(q)



(r)

Figure 4.8. The metallurgical microscope image taken that displays tool wear length for feedrate 0-3000 mm/min in machining (j)-(r) P20 Steel.

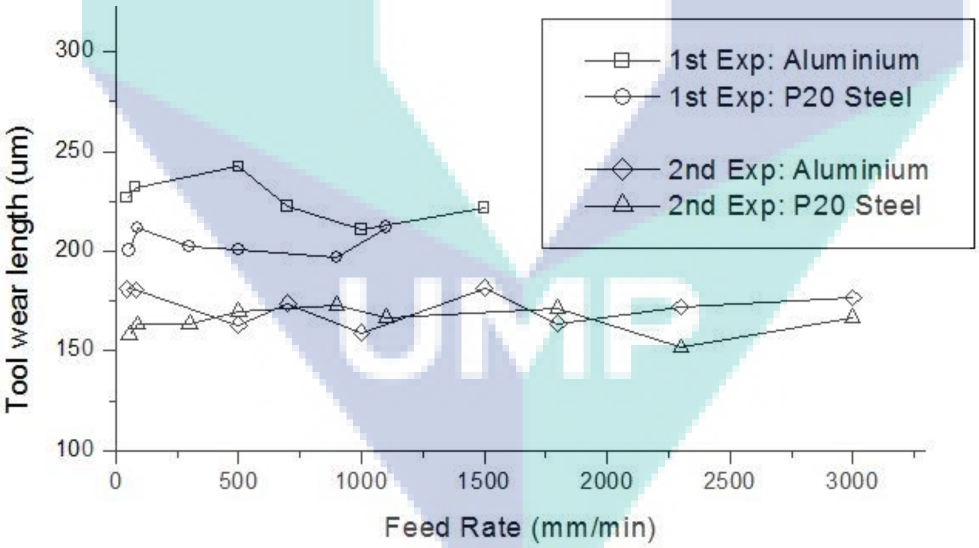


Figure 4.9. Tool wear length at different feed rate

Based on Figure 4.9, obviously mentioned that there is no significant influences in tool wear length when the material removal rate is kept constant throughout the experiment even though varies of depth of cut and feed rate was used. This is because the constant material removal rate that had been set for both experiment had balance the amount of heat generated at the tool. Moreover, the trend of tool wear length is quite similar for both materials in both experiments where no significant differences in tool wear length different were found.

4.3 PID Chatter Detection

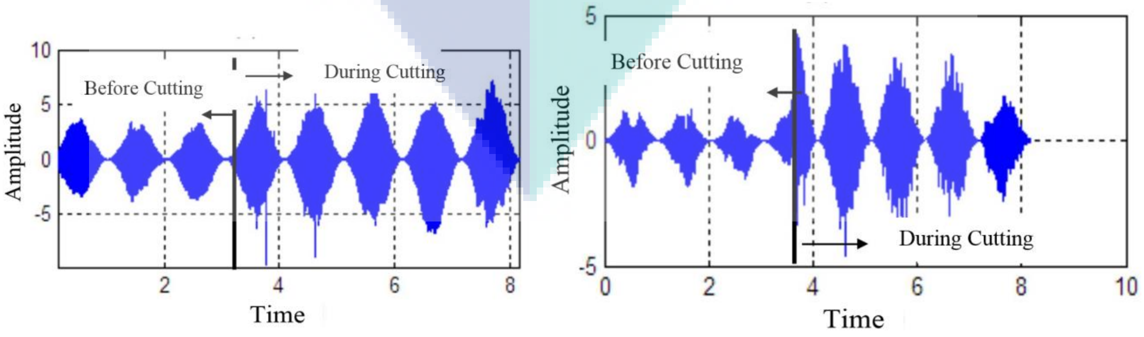
4.3.1 Time Domain Frequency Result

Time domain analysis is use to distinguish the pattern of sound pressure in different cutting condition based on its classification using a pre-set surface roughness threshold. It is the first data that can differentiate the chatter condition of those particular parameters. The pattern determines how loud the sound produces during the process.

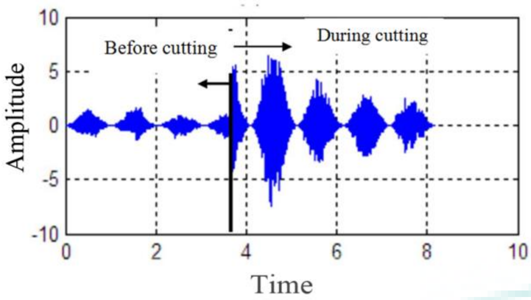
As the stability of the cutting condition increase, the amplitude ratio of sound pressure before cutting and during cutting process is increase by 1:1.5, 1:3, 1:4.5, 1:4.8 and, 1:5 for no vibration, average, poor, very poor and severe chatter respectively as shown in Figure 4.10 and Table 4.1.

Table 4.1 Amplitude ratio of sound pressure

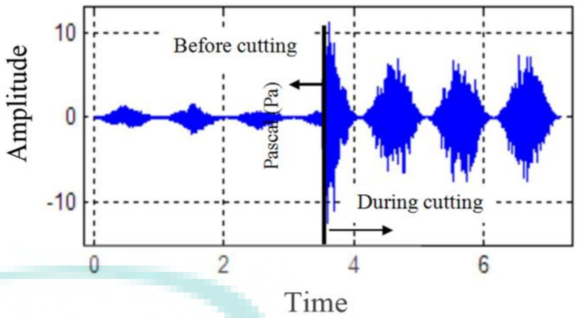
Classification	Sound Amplitude Ratio
No vibration	1: 1.5
Average	1: 3.0
Poor	1: 4.5
Very poor	1: 4.8
Severe	1: 5.0



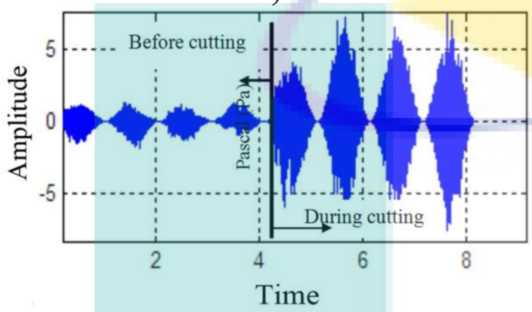
a) b)



c)



d)

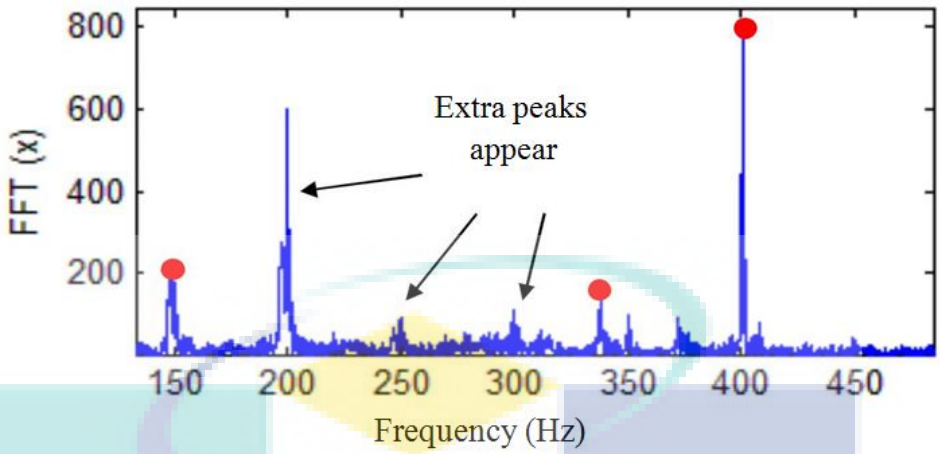


e)

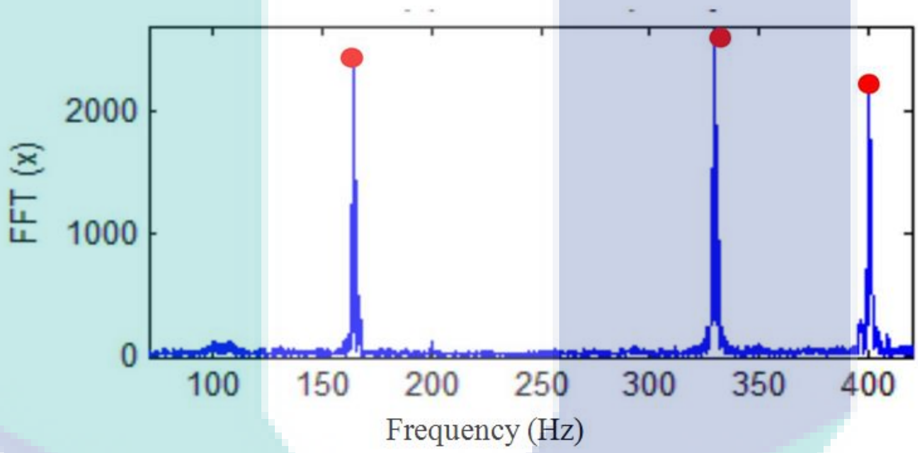
Figure 4.10. Sound pressure pattern of (a) no vibration, (b) average, (c) poor, (d) very poor, and (e) severe chatter condition

Unfortunately, time domain analysis is not enough to deduce that the particular process is stable or not. This is because time domain function consists of the summation of all the involved frequency in that sets of time. From this point, data is analysed in frequency domain using FFT technique. Figure 4.11 shows the FFT result of non-stable and stable cutting process.

Extra peaks or harmonics appear in Figure 4.11 (a), which the cutting parameter is set at 0.1 mm depth of cut, 2800 mm/min feed rate with 3000 rpm spindle speed. Thus, this parameter is set as not stable. Same parameter is repeated with 10000 rpm spindle speed in Figure 4.11(b) shows that the strange peaks disappear, leaving only the spindle speed, machine and tooth pass frequency at 160 Hz, 330 Hz and 400 Hz respectively in the spectrum labelled with ‘dot’ indicate it is in the stable condition.



(a)

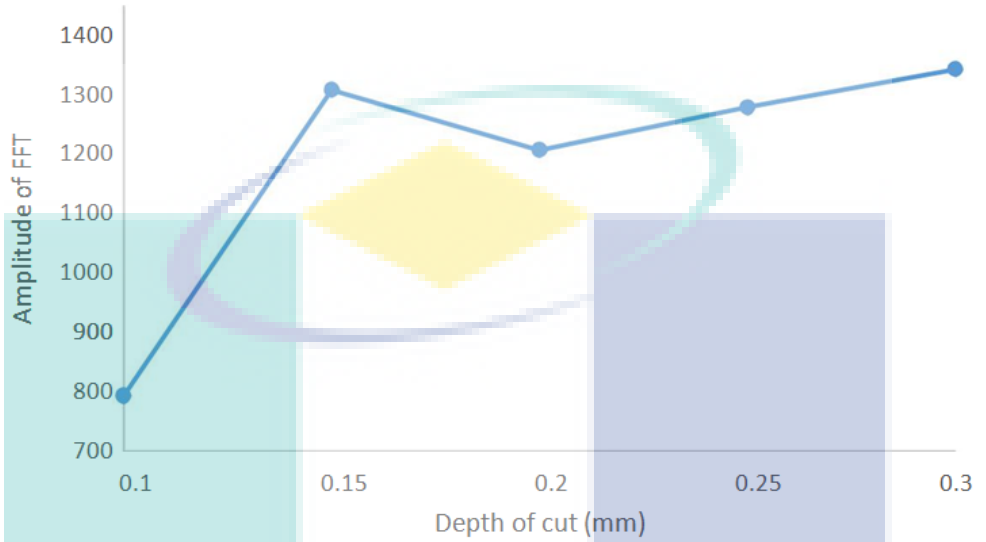


(b)

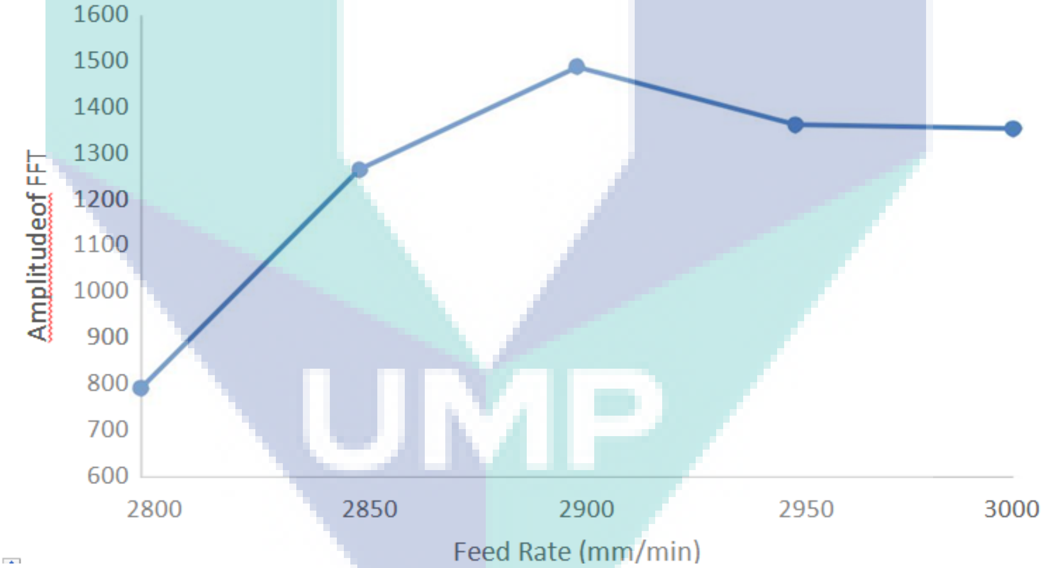
Figure 4.11. FFT result for non-stable and stable condition for (a), and (b)

The frequency domain analysis scope is adjusted to focus on determining the common dominant frequency in each cutting parameter (interest frequency). It turns out that all cutting parameters have shared the same dominant frequency at 400 Hz which varies in amplitude of density for each parameter. Figure 4.8 (a), (b), and (c), shows the relationship of amplitude of 400 Hz frequency with depth of cut, feed rate and spindle speed respectively. It is clearly shown that the trend of amplitude of interest frequency is increasing as the parameters increase. The amplitude of frequency decrease at 15000 rpm spindle speed (Figure 4.8 (c)) as the machine meets its stable condition. At the same time, by survey Figure 4.8 (a) there is slight decrease when depth of cut is 0.2 mm. This is due to during selection for optimal parameter for active experiment; at the constant feed rate used at 0.2mm give fine cutting but compared with 0.1mm depth of cut still have some vibration. By review Figure 4.8(b), the pattern keeps drop after

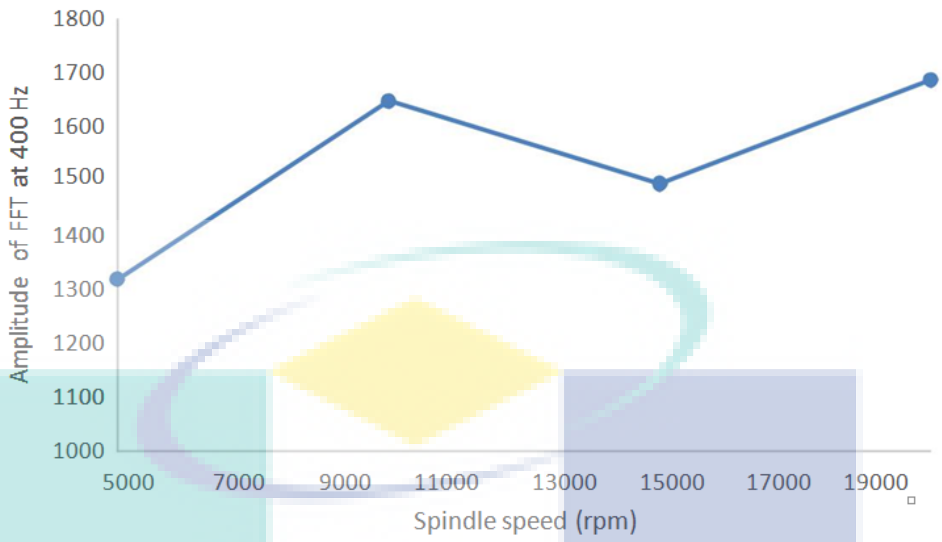
2900mm/min due to at high feed rate the tool was keep broken. It means the feed rate not suitable to proceed out.



(a)



(b)



(c)

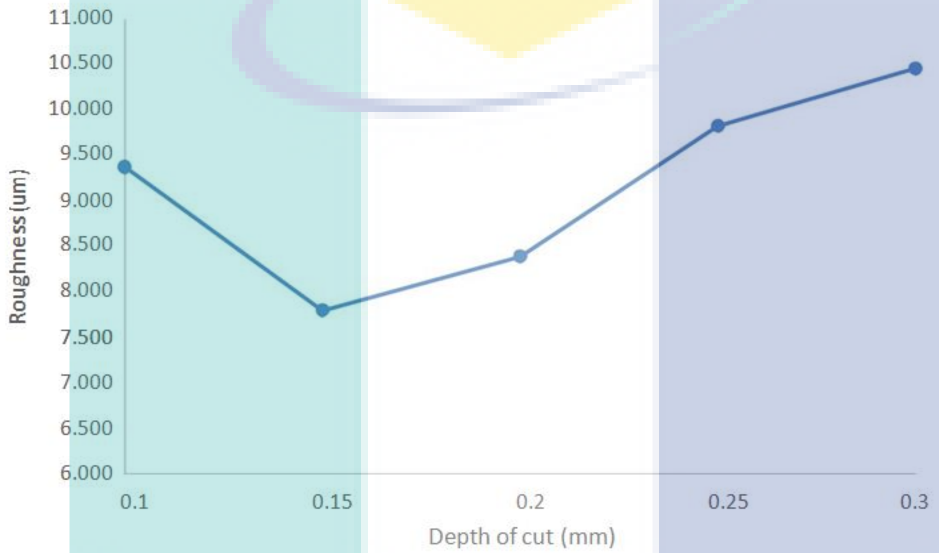
Figure 4.12. Amplitude of spectral density of microphone signals at 400 Hz. The cutting parameter variation is depth of cut (mm), feed rate (mm/min), and spindle speed (rpm) for (a), (b), and (c), respectively.

The increasing trend for depth of cut and feed rate variation indicate the reduction of stability of the cutting condition. As the stability of the cutting condition decrease, roughness value, Ra, increase. The surface roughness of the specimens for depth of cut and feed rate experiment are shown in Figure 4.9 a, and b. Unlike for the spindle speed variation experiment (see Figure 4.9 c), the surface roughness trend is decrease as the spindle speed increase. This situation complies the equation of relationship between feed rate and spindle speed, whereas increasing the spindle speed will reduce the feed per tooth for that particular parameter. Hence, the surface roughness and stability will improve. In Figure 4.9 (b), the surface roughness value trend decreases when the feed rate of the cutting achieves 2950 mm/min. This data is considered as invalid because the cutting did not happen on this parameter. Cutting tool is stuck before machining process occurs.

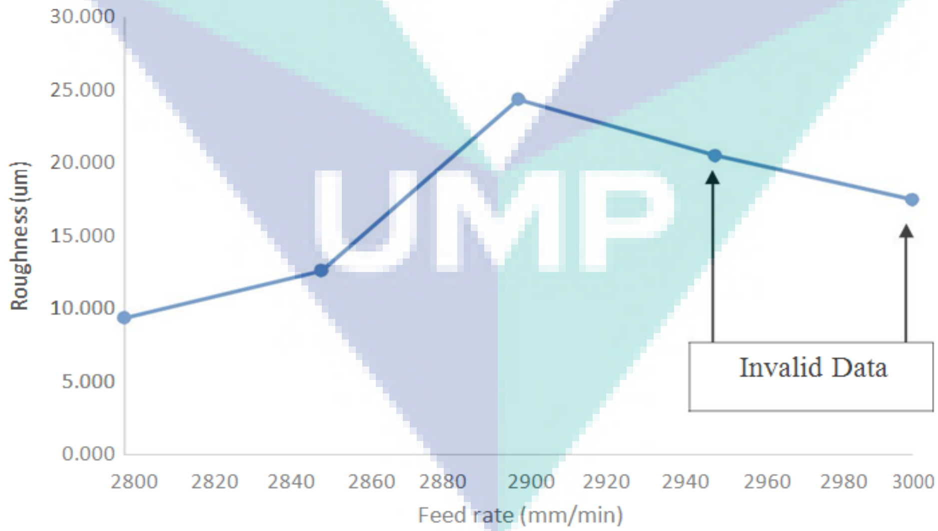
Data shows that only cutting speed of 10000 rpm to 20000 rpm will be classified as ‘no vibration’. Data collected from the experiment are rearranged. The relationship between surface roughness pre-set threshold and the amplitude of interest frequency in Fourier transform analysis is shown in Table 4.2. This relation is useful for active controller.

4.3.2 Surface Roughness Result

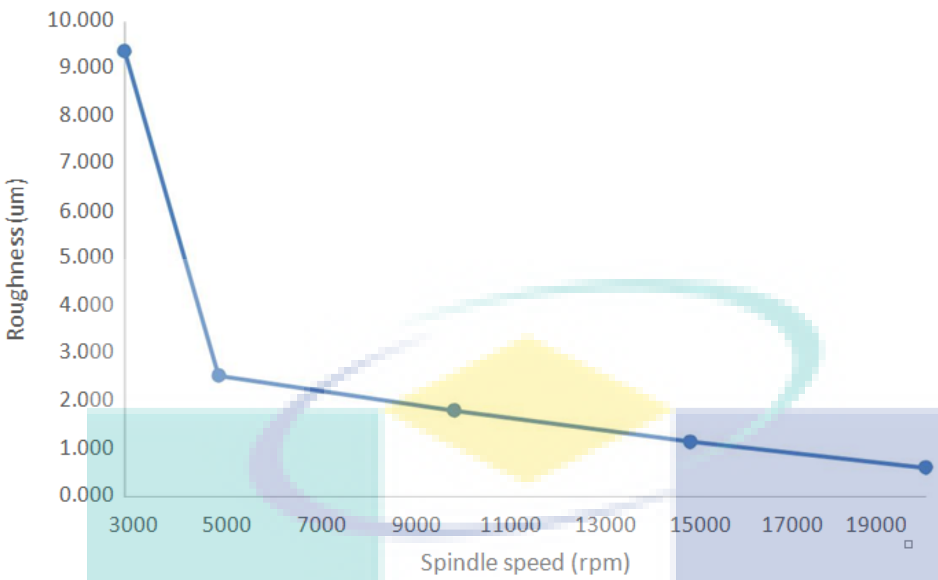
The FFT amplitude value increase as the surface roughness increase. At some points. The roughness value decreases gradually to ‘no vibration’ classification which its FFT amplitude is in range of 1500 to 1700. So, 1500 FFT amplitude value is set as the cut-off value so that any value below the cut-off will return to ‘no vibration’ range. This have been discussed in previous section as shown in Figure 4.8.



(a)



(b)



(c)

Figure 4.13. Surface roughness of the specimens. The cutting parameter variation is depth of cut (mm), feed rate (mm/min), and spindle speed (rpm) for (a), (b), and (c)

Those figures above illustrate that by increasing the depth of cut the surface roughness value also keep increasing which crystal clear shown by the pattern in figure 4.13 (a). Moreover, in Figure 4.13(b) also explains that by increasing the feed rate the surface roughness value but after 2900mm/min seems invalid data due to the broken tools. This both scenario explains that by keep increasing depth of cut and feed rate may contribute to the chatter occurrence.

Table 4.2 Classification of Surface Roughness and FFT amplitude value

Classification	Surface roughness ( )		FFT amplitude value at 400 Hz	
	min	max	min	max
Average	2.1	8	901	1300
Poor	8.1	10	1301	1359
Very poor	10.1	18	1360	1450
Severe chatter	18.1	25	1451	1499
No vibration	0	2	1500	1700

Cut-off

4.3.3

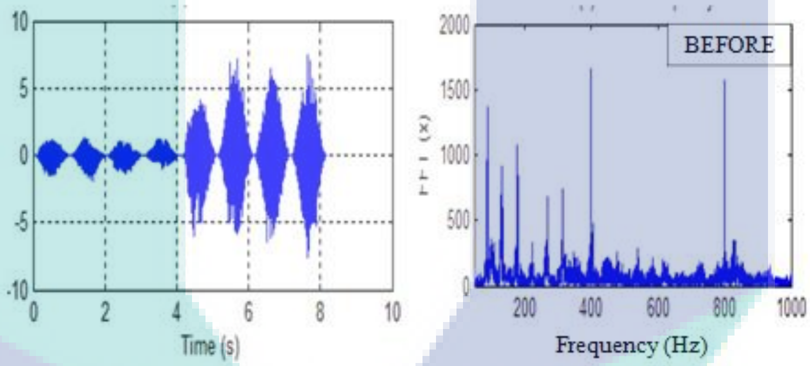
The result shows that the influences of feed rate and depth of cut with constant speed where the chatter mark on the machining surface. Apart from that, based on Table 4.4, high FFT amplitude have strong influences with surface roughness value. The FFT amplitude is directly proportional to the surface roughness value.

4.4 SSV Chatter Suppression

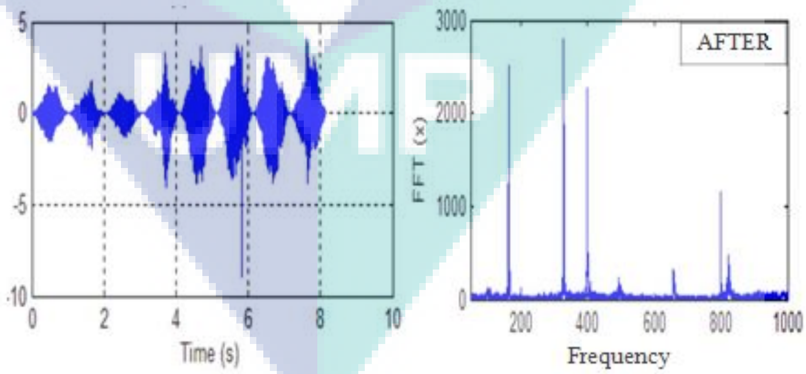
A control system is set up using an Arduino Uno equipped with RS-485 serial communicator module. This controller plays a big role to control the spindle speed of the machine through the variable frequency Drive (VFD) based on the feedback from the sensor.

4.4.1 Feed rate variation result

Figure 4.11 (a) and (b) show the time and frequency domain result of feed rate 2900 mm/min before and after the spindle speed control.



(a)

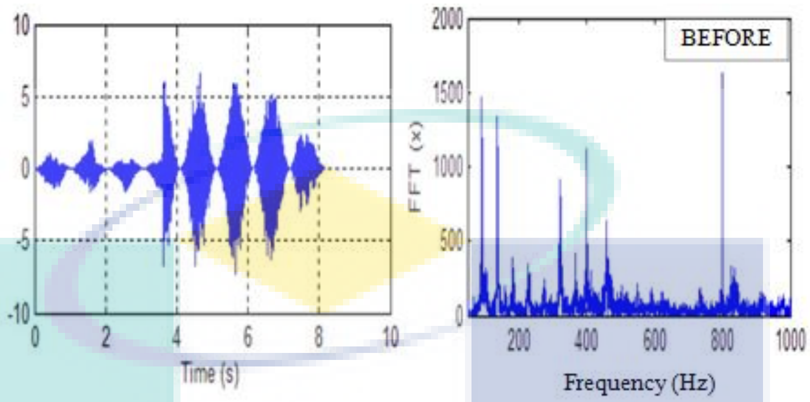


(b)

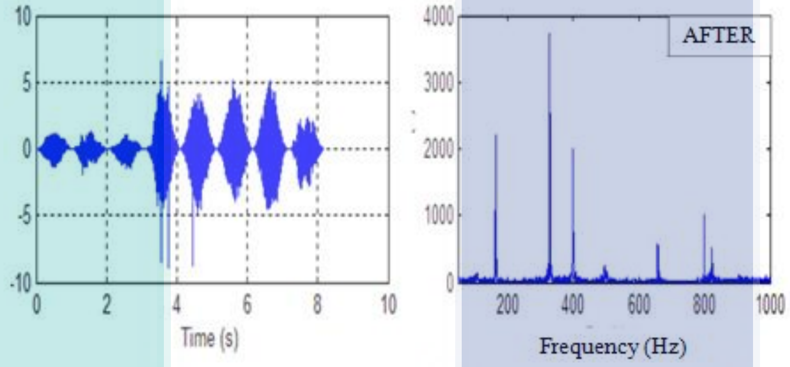
Figure 4.14. Time and frequency domain of 2900 mm/min feed rate before and after spindle speed control for (a) and (b) respectively.

4.4.2 Depth of Cut Variation Results

Figure 4.15 (a) and (b) shows the time and frequency domain result of the cutting parameter of 0.2mm depth of cut before and after spindle speed control.



(a)

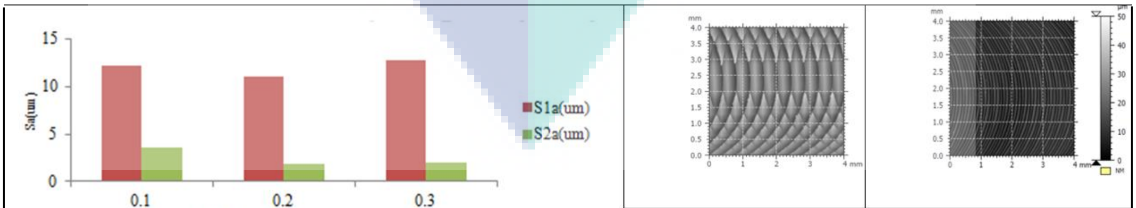


(b)

Figure 4.15. Time and frequency domain of 0.2mm depth of cut before and after spindle speed control for (a) and (b)

4.4.3 Surface Topography Results

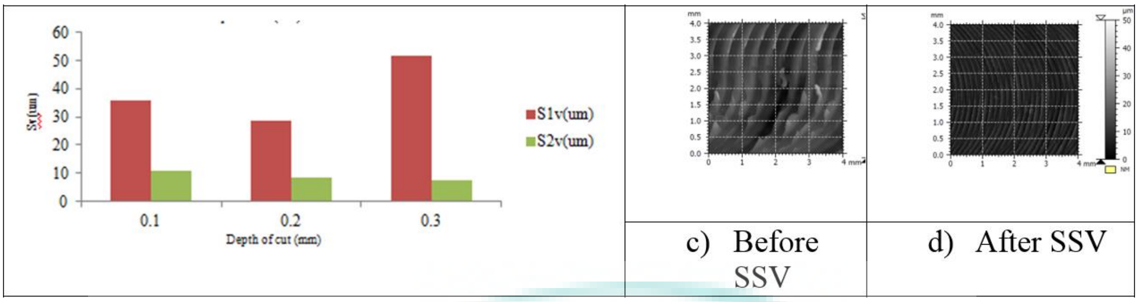
Experiment of surface topography was conducted at two different stages. There is constant depth of cut and feedrate. The result help to view the different structure before spindle speed variation technique and after spindle speed variation experiment.



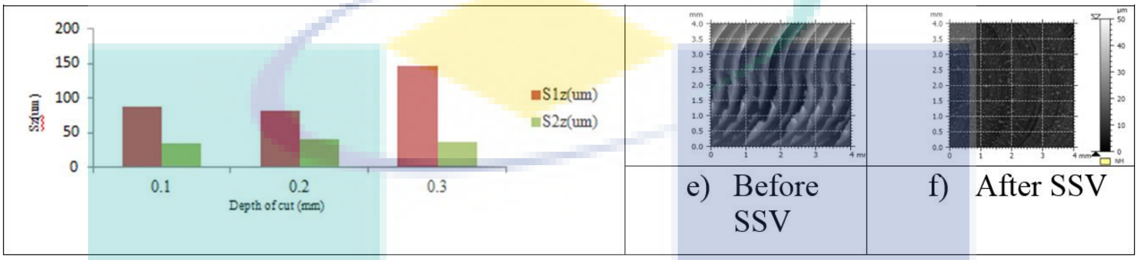
a) Before SSV

b) After SSV

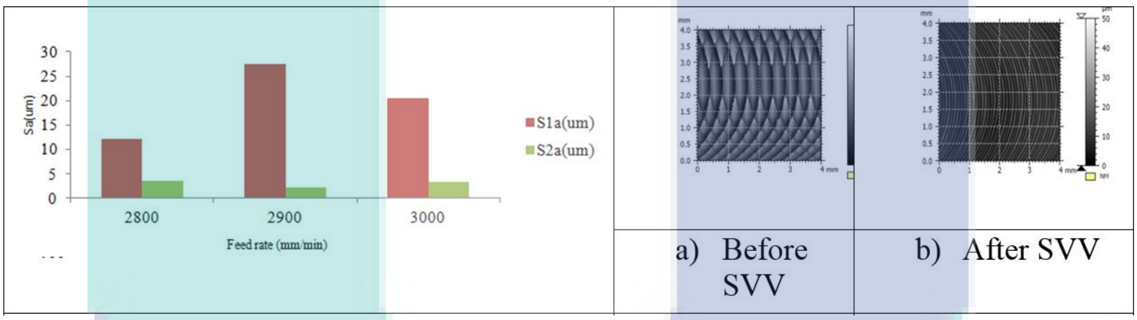
(a)



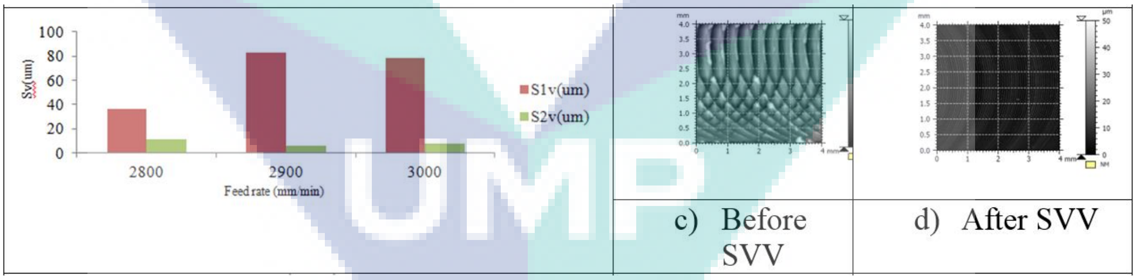
(b)



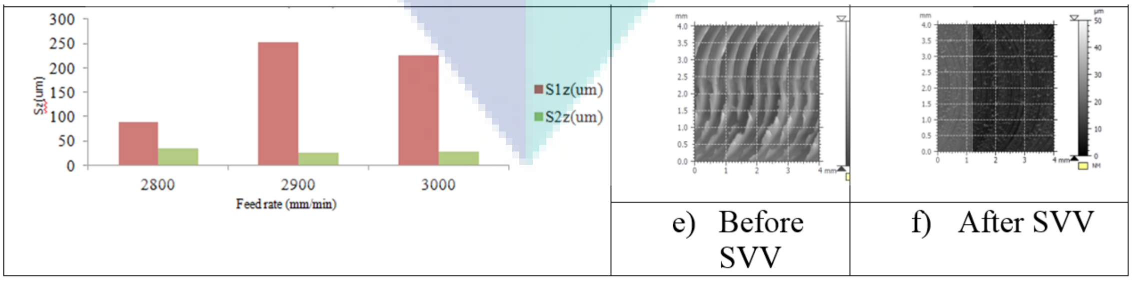
(c)



(d)



(e)



(f)

Figure 4.16: Surface topography result of material during constant (a) Feedrate and (b) depth of cut respectively.

4.4.4 Discussion

In Figure 4.16 and 4.17, it clearly shows that the strange peaks appear in the frequency domain during constant speed cutting is no longer appear for spindle speed control experiment. For constant speed experiment, 0.2 mm depth of cut is classified as not stable since the surface roughness is higher that the threshold value but same parameter is completely stable with spindle speed control. As for time domain result, the sound wave before the spindle speed control oscillated at higher amplitude of pressure compared to the one with spindle speed control. This data also represents the sound produce is not too loud after spindle speed control.

Figure 4.16 shows the product surface finish of 0.2 mm depth of cut before and after spindle speed control and Figure 4.17 shows the product surface finish of 2900 mm/min feed rate before and after spindle speed control. The surface finish of product has improved gradually with spindle speed modulation. The results agree with Equation 1.1, where cutting condition is become more stable as the feed per tooth of the process is reduced by increasing the spindle speed (Dijk, 2010).

To validate the results, surface roughness test also done and shows a great improvement after spindle speed control in term of numerical value. Figure 4.14 shows the surface roughness results of the cutting parameters for active control experiment. Following the increasing trend as in the chatter detection experiment, surface roughnesses for active control are in lower range.

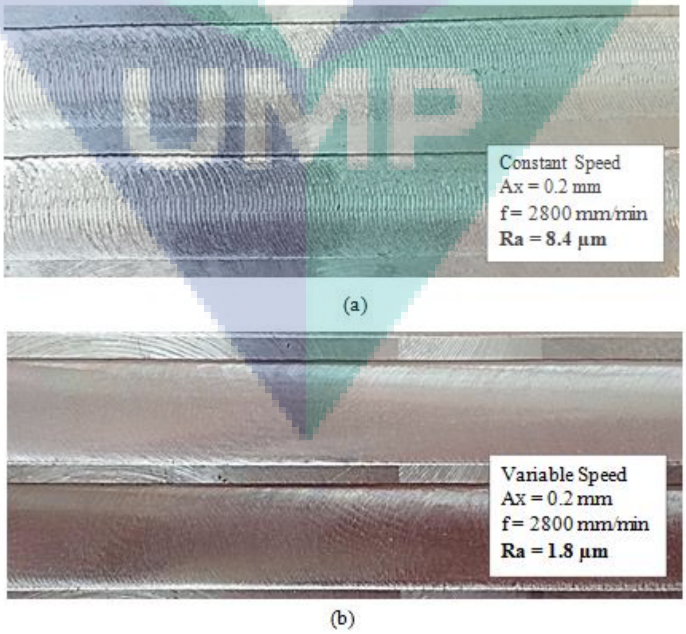


Figure 4.17. Surface finish of 0.2 mm depth of cut before and after spindle speed control for (a) and (b) respectively.

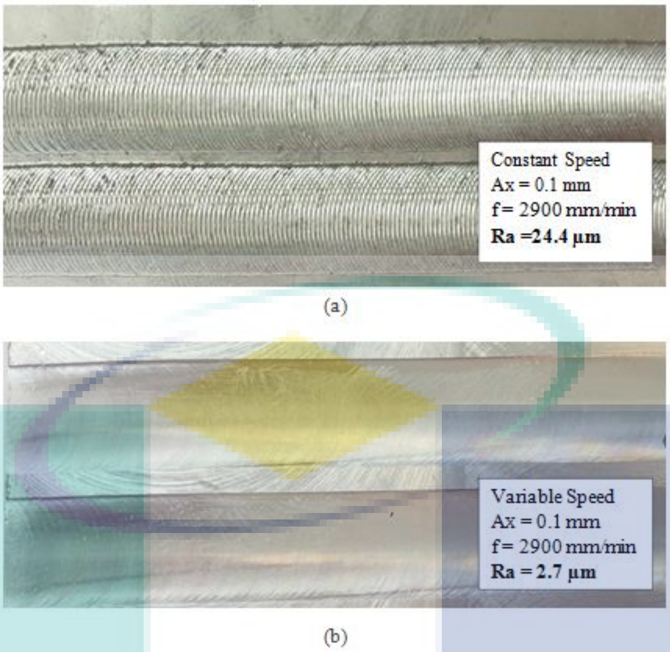
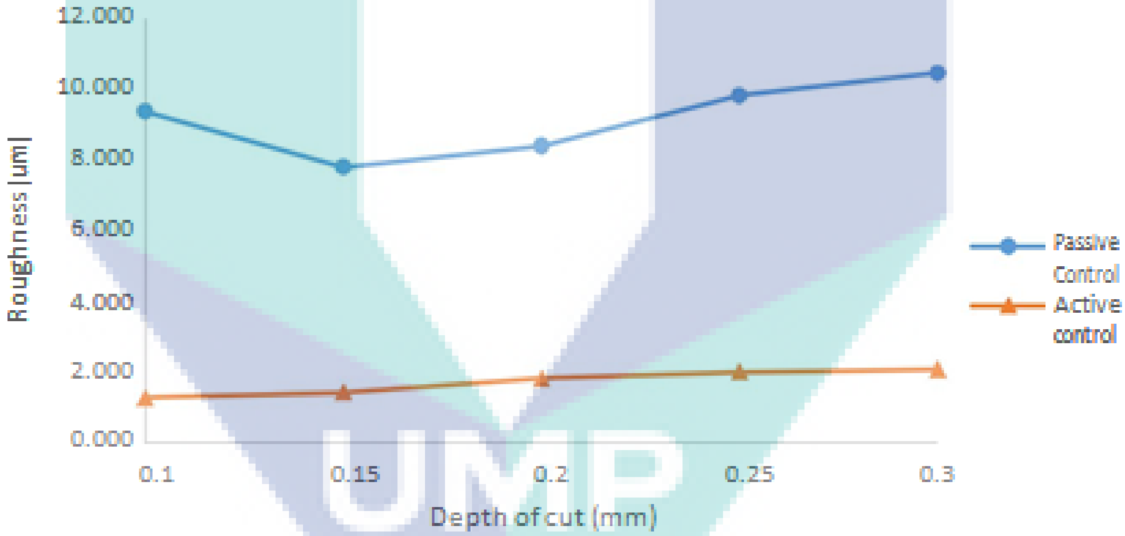
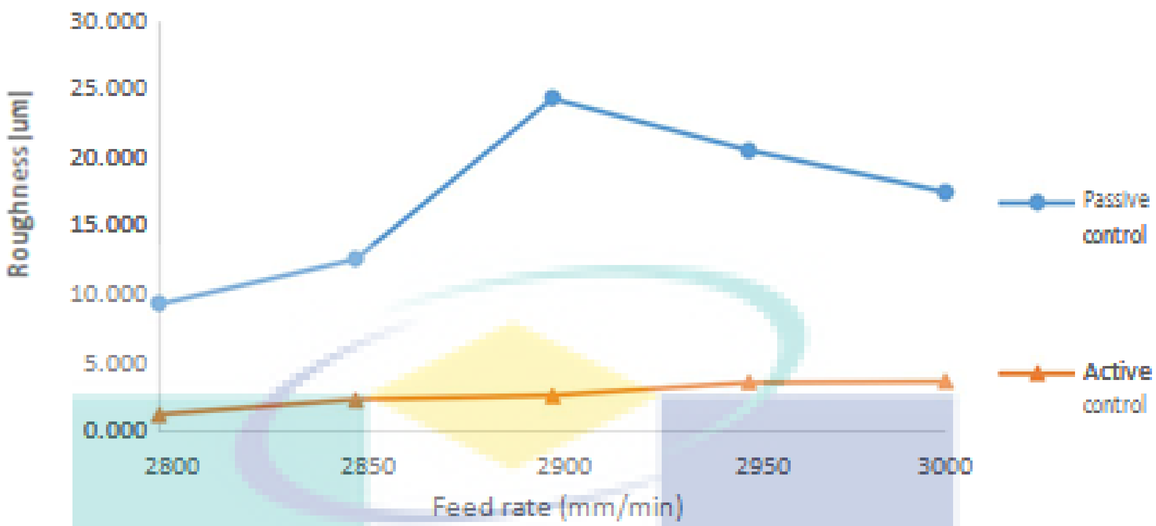


Figure 4.17. Surface finish of 2900 mm/min feed rate before and after spindle speed control for (a) and (b) respectively.



(a)



(b)

Figure 4.17. Surface roughness value of the specimen in active control for depth of cut and feed rate variable for (a) and (b) respectively

4.6 Summary for Chapter 4

Both experiment for chatter detection and active controller yield significant result for evaluation purpose. Active suppression of chatter is expected to give lower value of surface roughness, as well as improvement on FFT result and sound patterns. Results show the improvement of stability during machining through surface roughness. This shows spindle speed variation is a noble technique to suppress chatter in machining process.

Microphone sensor is capable for on-line chatter detection but a lot of variable has to be taken into considerations such as the surrounding noise. Type of microphone sensor play a big role in detecting a specific sound and it has to be very sensitive. Since the signal of microphone sensor is oscillating and has a very small range, an optimum amplification is needed. It is better to make a full use of frequency domain data by Fourier Transform technique to provide stable input for microprocessor.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Spindle speed modulation for machining process and its performance testing has been successfully carried out. Comparison of the cutting condition and results during normal process and spindle speed control process is shown clearly. The testing on the performance of the spindle speed modulation controller achieves the objectives of this project. Therefore, overall project is considered successful. On top of that, a lot of improvement surely can be done for better performance and results. This research is a good study as it helps manufacturer to increase productivity rate through higher material removal rate with excellent product surface finish.

In this thesis, through the experiments, with constant material removal rate, radial depth of cut and spindle speed, surface roughness value has been influenced by feed rate while depth of cut does not contribute at all. From the both experiment results given, the surface roughness value keeps incrementing when higher feed rate was used even the depth of cut had been reduced to shallow depth of cut, 0.03 mm. Apart from that, when tested to least depth of cut and higher feed rate, 0.03 mm and until 3000 mm/min respectively, the tool wear have shown no significant different for both materials in both experiments. This proves that, material removal rate strongly contributes to tool wear rate because when the material removal rate was kept constant for both experiments, the tool wear rate too almost kept unchanged.

At the same time, in next experiment, initial experiment began with constant material removal rate in which varying depth of cut, feed rate, and spindle speed were analysed using time and frequency domain. Based on the result, microcontroller-based proportional-integral-derivative (PID) algorithm was retested in active mode. Microphone may be used as sensor to predict the instability due to the microphone pressure emitted by a structure during machining is proportional to the displacement of the tool. Otherwise, it must be noted that ambient condition such as environmental noise, reflection and near field which can distort the signal because the direct analogy exists between the microphone feedback in public address systems and chatter occurrence during machining where both are time-delay feedback systems with stability that depends on the system gain. After the process of machining, both machined materials surface roughness was measured using portable surface roughness for both initial and active experiments.

Result shows significant differences in frequency, confirming that chatter occurrence during machining can be suppressed using spindle speed variation method with microphone feedback PID controller. At the same time, the surface roughness value for both materials in first and second experiments shows in clear cut that keep decreasing as the spindle speed variation method was implemented. Moreover, in the aspect of sound pattern where obviously found that the sound produced during cutting process slowly decrease from louder to normal sound during active moment.

In nutshell, high speed milling technique can be implementing in conventional milling machine with high feed rate, shallow depth of cut since there is no significant influence to tool wear rate by making material removal rate constant. On the other hand, HSM technique provides numerous benefits such as eliminate semi-finishing process and needs of coolant; reduce tool-load for finishing operation, better surface finish with good dimensional accuracy, cut off machining time and cost, production of smaller chip for easy cleaning purposes. Most importantly, this can boost the production of high quality and efficient materials and also contribute for higher productivity owing.

Fast processing process is the most widely recognized and flexible innovation contrasted and customary processing process for machining profitability of metal cutting industry. In any case, the efficiency of machining is frequently constrained at high marked in processing process. Chatter is a wavy check on an item surface complete that happens when self-energized vibration creates the procedure, which brings about poor surface complete, increase the rate of tool wear and reduce the spindle lifetime. The aims of this study are to suppress chatter by spindle speed variation method at high speed machinery and a better surface finish is also achieved. This examination PID controller was produced to give on-line input to the machine in view of information sustained by the receiver sensor. The information got from mouthpiece sensor is broke down in time and recurrence area. Moreover, in the wake of machining, result likewise was contrasted and the surface roughness of all cutting conditions. Feed rate actually significantly influences the surface roughness value while depth of cut does not as the surface roughness value keep increasing with the increase of feed rate and decreasing depth of cut. This concludes that high speed milling techniques contributes more in suppressing chatter.

From the conducted experiment, it contributes to the current to industries using high-speed milling by offering additional benefits such as high productivity, reduced time, and low cost. This method provides numbers of advantages such as high efficiency, accuracy, quality of final workpieces, eliminate the secondary or semi-finishing process, increase of productivity, cut off of costs and machining time, better surface finish, eliminates the needs of coolant, reduce tool load for finishing operation and last but not least small chips are produced for easily cleaning purposes. These are the proving result by successfully eliminates chatter occurrence by on-line.

5.2 Recommendations

There are some constrains when carrying the experimental testing for the controller. Microphone sensor needs very high sampling frequency for it to function at optimum level. More advance type of microprocessor with higher sampling time capability is recommended tor more accurate result (Delio, 1992). Furthermore, using a microphone sensor in very practical as it is a non-contact sensor but the process must be done in highly isolated room that capable of reducing external noise. Furthermore, may use other type of sensor where can detect the occurrence of chatter or combinational of microphone and other sensors too to gather more data which can improve more the process of machining.

Apart from that, for the future experiment recommend to use any other type or material or similar material with different characteristics. By doing this, can study more on the influences of material properties on occurrence of chatter also. Not only material, even the cutting tool also suggested using different type of material and more than single flute to study more influences of itself in contributing chatter suppression. Other than that, if possible, can also try on industrial high-speed milling machine to see the result of spindle speed variation technique on milling process. Furthermore, by having development in the aspect of controller also can be suggested for future experiment. In my thesis, I have been developed the chatter suppression using PID controller and in future may use Fuzzy controller or combination of both, Fuzzy-PID controller. By implementing advanced controlling system, the chatter suppression during machining process will be more effective where in the result of high quality and accuracy fined products. At the same time, contributes   deeply in boost the production of high quality and efficient materials and also contribute for higher productivity owing.

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Suppression of Chatter in High Speed Milling Machine Using Spindle Speed Variation Method with Acoustic Feedback PID Controller

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Keywords: Chatter detection, high speed milling, spindle speed variation, material removal rate, microphone, PID control, surface roughness

Abstract. High speed milling (HSM) process limited by tool failure and dynamic instabilities due to the influence of relative vibration between tool and workpiece, so called chatter. Chatter vibration literally responsible for lower productivity and poor surface quality. In this project, chatter occurrence during machining was suppressed using spindle speed variation (SSV) method via microphone online detection techniques. The initial experiment begins with constant material removal rate (MRR) where varies depth of cut, feedrate and spindle speed were analyzed using time and frequency domain. Then, based on the result, microcontroller based PID algorithm was tested again in active mode. The material roughness was measured using portable surface roughness for both initial and active experiments. The results showed that material's surface roughness in active experiments better than initial experiments. This proves that chatter occurrence during machining can be suppressed using spindle speed variation method with microphone feedback PID controller. This also offers high speed milling usage industries with extra benefits of high productivity and can conserve time and money. Moreover, this method could enable providing high efficiency, accuracy, quality of final workpieces and eliminates semi-finishing process.

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Investigation of surface roughness and tool wear length with varying combination of depth of cut and feed rate of Aluminium alloy and P20 steel machining

Madan Varmma a/l Suparmaniam and Ahmad Razlan Yusoff

Abstract

High-speed milling technique is often used in many industries to boost productivity of the manufacturing of high-technology components. The occurrence of wear highly limits the efficiency and accuracy of high- speed milling operations. In this paper, analysis of high-speed milling process parameters such as material removal rate, cutting speed, feed rate and depth of cut carried out by implemented to conventional milling. This experiment investigate the effects of varying combination of depth of cut and feed rate to tool wear rate length using metallurgical microscope and surface roughness using portable surface roughness tester after end milling of Aluminium and P20 steel. Results showed that feed rate significantly influences the surface roughness value while depth of cut does not as the surface roughness value keep increasing with the increase of feed rate and decreasing depth of cut. Whereas, tool wear rate almost remain unchanged indicates that material removal rate strongly contribute the wear rate. It believe that with no significant tool wear rate the results of this experiment are useful by showing that HSM technique is possible to be applied in conventional machine with extra benefits of high productivity, eliminating semi-finishing operation and reducing tool load for finishing.

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ABSTRACT – High speed milling (HSM) process limited by tool failure and dynamic instabilities due to the influence of relative vibration between tool and workpiece, so called chatter. Chatter vibration literally responsible for lower productivity and poor surface quality. In this paper, chatter occurrence during machining was suppressed using spindle speed variation (SSV) method via microphone online detection techniques. The initial experiment begins with constant material removal rate (MRR) where varies depth of cut, feedrate and spindle speed were analyzed using time and frequency domain. Later, microcontroller based PID algorithm was tested again in active mode. The result shows great differences in frequency.This proves that chatter occurrence during machining can be suppressed using spindle speed variation method with output feedback from PID controller. This also offers high speed milling usage industries with extra benefits of high productivity and can conserve time and money. Moreover, this method could enable providing high efficiency, accuracy, quality of final workpieces and eliminates semi-finishing process.