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Comparison of the Effect of Variable Helix Angle Geometry Tools on CNC Vertical Milling Machines on Chatter using a microcontroller Based on SLD

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Abstract- Taking into account the vibrations that often occur during the production process using CNC milling machines is very important. These vibrations can cause dimensional changes and affect the quality of the produced parts. Therefore, the impact of chatter vibrations on production becomes a major problem in the milling process. The vibration values are determined experimentally, analytically, and semi-analytically using SLD graphs. In this study, the materials used were SS 304 and MPU 6050, which were connected to an Arduino Uno using LabVIEW 2019 student edition software to generate FFT charts. The data collection involved experimental methods and the following tool geometry parameters: VHA 35/38 degrees and VHA 36/38 degrees, spindle speeds of 2000, 2500, and 3000 RPM, depth of cut of 0.4, 0.7, and 1 mm, and feed rates of 100, 125, and 150 mm/s. The results of the SLD study showed that using a variable helix angle of 35/38 degrees, chatter occurred at feed rates of 100 mm/min and cut depths of 1 mm, 0.7 mm, and 0.7 mm. At a feed rate of 125 mm/min, chatter occurred at cut depths of 0.7 mm, 1 mm, and 0.7 mm. At a feed rate of 150 mm/min, chatter occurred at cut depths of 1 mm, 1 mm, and 0.7 mm. The spindle speeds used were 2000, 2500, and 3000 RPM. Similarly, with a VHA of 36/38 degrees, chatter occurred at a feed rate of 100 mm/min and cut depths of 0.7 mm, 1 mm, and 1 mm. At a feed rate of 125 mm/min, chatter occurred at cut depths of 1 mm, 1.1 mm, and 0.7 mm. At a feed rate of 150 mm/min, chatter occurred at cut depths of 1.1 mm and 0.7 mm. The spindle speeds remained the same at 2000, 2500, and 3000 RPM.

Keywords : Chatter, VHA, SLD, microcontrolle, FFT

I. Introduction

Today, advances in engineering, science, and technology influence developments in the industrial and manufacturing world. Production processes in the automotive, *aerospace*, mold industry, *to the military require a high level of production efficiency, productivity* and product precision so that it can meet market needs and existing demands. In an effort to meet these problems, the quality of the machine tools used, the selection of parameters in the machining process, to the selection of appropriate methods. Technological developments have increased significantly applied to equipment and machines - production machines in various industrial fields, especially in the metal industry. One of the main challenges in the metal industry is the increasing number of consumer demands with products that have anti-corrosion resistance properties.

A material that has anti-corrosion resistance properties is *austenitic stainless steel.* Type *Stainless steel 304* is a type of *austenitic steel* that has elements of chromium, nickel, and carbon. Therefore, stainless *steel* 304 is generally used in the manufacture of bolt nuts, springs, screws, tableware and etc. AISI 304 *Austenitic stainless steel* can be found in aircraft applications, Aerospace components such as bushings, shafts, valves, screws. However, to improve work efficiency and production process time, machines are needed in manufacturing product design. One of the right production machines to solve this problem is the *vertical milling center* machine. Dynamic vibrational

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characteristics acting in the *vertical* direction can cause various deviations [1].

A vertical milling center machine is a type of CNC machine with the main spindle rotation in the vertical position. The effect of chatter vibration or self-excited vibration on the production process is a major problem in the milling machining process. This vibrational effect can cause dimensional changes that affect the level of product design [2]. Chatter is a self-excited vibration that can occur during machining operations and is a general limitation for productivity in terms of quality [3]. Chatter can occur in machining processes, including turning machining [4], milling [5] drilling [6] and grinding, [7]. Chatters are classified in two different categories, namely primary and secondary. The main category is chatters produced in such cutting processes, i.e. friction between tools and workpieces [8]. In the secondary category, chatter is caused by the regeneration effect of corrugated surfaces on the workpiece [9].

The effects of chatter vibration in the machining process can result in tool damage, excessive noise, inaccuracies, and poor surfaces [10]. To reduce the occurrence of excessive chatter vibration on the machine, a way is needed to minimize chatter in the operating process. In addition, tool geometry has an influence on the machining operation process and should not be neglected in the selection of parameters. Various kinds of angular shape tool geometry are ultimately the milling process, such as variable helical angle and ordinary helical angle tool geometry. The variable geometry of helical angles has different variations of helical angles and pitch angles. Tool geometry features variable helical angles and varying pitch angles can optimize regenerative effects in the final grinding process.

One way to tell if excessive chatter is to use a stability lobe diagram. A stability lobe diagram is a diagram that shows the boundary between the stable and unstable zones of the cutting process using the cutting speed and spindle depth parameters as comparison parameters. The main function of the above parameters is to show the boundary between stable cut and unstable cut which aims to find out which area is recommended in the cutting process. The recommended areas are those that have little chance of displacement on the cutting tool that can produce a regenerative chatter effect. Regenerative chatter is caused by inhomogeneous chip cutting or growling or overlapping processes that minimize vibration and leave a bumpy surface on the workpiece. When the previous incision leaves a wave on the workpiece, the incision further creates a new wave, each of these phenomena will cause a large vibration in the system. When a wave occurs on the workpiece it will cause a difference in the phase of the chipload. This makes the force on each incision different depending on the previous incision eye displacement, resulting in a regenerative effect. As the name implies, regenerative chatter goes on continuously. Self-excited vibrations can be stopped by varying the passing frequency of the teeth so that the chip load phase does not go out of phase and the regenerative effects of the system do not occur.

Yusoff (2011) conducted research on geometry optimization of variable helical tools to reduce chat incidents. From this study, it was concluded that regenerative chatters can be minimized by using variable helical angle chisels compared to ordinary chisels. Geometric shapes or helical angle variations on the tool provide good stability in the workpiece feeding process which reduces the appearance of chatters so that the resulting workpiece has good surface roughness [11] .

Zhou (2015) conducted research on Chatter Stability Prediction using a 4-axis milling machine on aluminum alloy material for aero-engine casing, experiment using bull-nosed-endmill chisel. This study used a stability lobe diagram to obtain the spindle velocity and radial depth of the cut that was ideal for identifying chatter in the machining process [12].

Zatarain (2015) conducted research on chatter reduction techniques in metal cutting. Parameters such as cutting force, dynamic force in the system, process parameters, and tool geometry, are determined using a stability lobe diagram. The effect caused by fluctuating vertical vibrations can affect the quality of work in a system [13]. Previous research has also shown that the higher the spindle rotation speed and the smaller the depth of the piece used will reduce the appearance of chatters. Based on the description above, the purpose of this study

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was to determine the influence of spindle speed parameters, cutting depth, and helical angle variables on chatter vibration using SLD diagrams (stability lobe diagrams).

II. Research Methodology

This study using experimental methods aimed to determine the effect of *helical angle variables and pitch tools* on the transformation of *stability lobe diagrams* using VMC (*Vertical Machining Center*) machines. Chat control in the machining process used *stainless steel* 304 material.

A. Research Variables

The independent variables used were variations in *spindle velocity* used in each of the *following tools*, and with *variations in axial cutting depth.*

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Table 1. Research Variable Parameters

Parameter	Unit			
Variabel Helix Angle	(derajat)	36/38	35/38	
Spindel Speed	(RPM)	2000	2500	3000
Feed Rate	(mm/s)	100	125	150
Depth Of Cut	(mm)	0.4	0.7	1

B. Materials and Tools

The 304 stainless steel workpieces with dimensions of 200 x 50 x 5 mm3 were used in the machining process as shown in Figure 1 below.

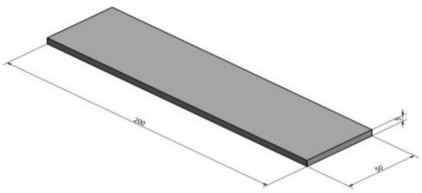

Figure 1 Workpiece Dimensions

Figure 2 shows the feeding process of a 304 (1) Stainless Steel workpiece mounted just below the endmill tool (2) used as a cutting tool in the slot milling process. The first feeding process used a variable helical angle chisel by adjusting the spindle rotation (rpm) and feed so that the machine's pneumatic motor rotated to drive the spindle and table. During the feeding process, the shifting data was taken using the MPU6050 accelerometer (3), then the data was processed by the Arduino Uno microcontroller (4). The Arduino Uno microcontroller was connected to a laptop (5) that has LabVIEW software version 2019 student edition installed and a program has been created that can translate vibrations that occur into data in the form of a time domain, after that the time domain data was inputted into the DIAdem software to get graphic data in the form of FFT (Fast Fourier Transform). Making vibration programs in the LabVIEW 2019 student edition version of the software can be seen in Figure 2

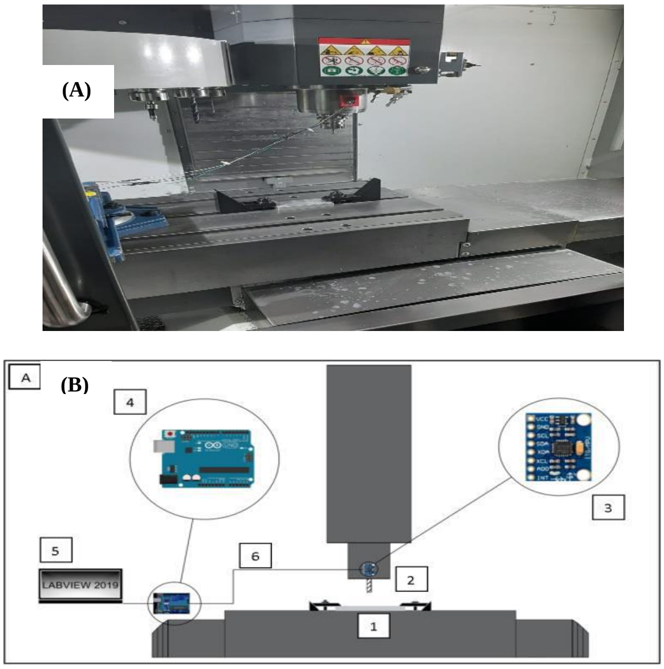

Figure 2 (A) Research Schematic and (B) Experimental setup

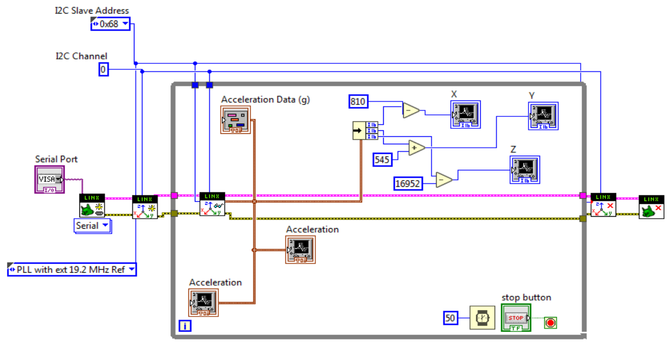

Figure 3. Vibration program uses LabVIEW 2019 version of student edition software [14].

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Figure 4 shows the boundary between the stable and unstable zones of the cutting process depending on the cutting depth and spindle speed. As a function of these two cutting parameters, the boundary between stable cut and unstable cut can be shown on the stability lobe diagram. The preparation of stability lobe diagrams can be done by analytical methods, semi-analytical methods, and experimental methods [16].

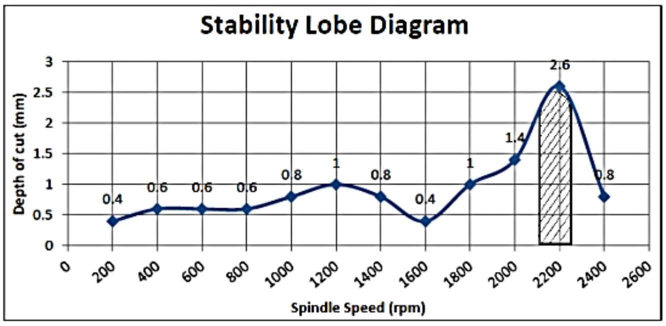

Figure 4 *Diagram Lobus Stabilitas*

III Results and Discussion

A. Research Results

Data collection of the Stability Lobe diagram from the results of CNC milling machining was carried out by determining the vibration value of the chatter used based on the Fast Fourier Transform (FFT) value by comparing the spindle speed value and variations in the depth of cut parameter in each feed rate variation using 2 types of tools, namely variable helix and pitc angle tool 35/38, 36/38 can be seen in Table 1 and Table 2.

Table 2 Data Stability Variable Lobe Diagram Helical Angle 35/38 degrees

Feed Rate (mm/mnt)	Spindel Speed (RPM)	Depth of Cut (mm)		
		0.4	0.7	1
100	2000	▲	▲	X
	2500	▲	X	
	3000	▲	X	
125	2000	▲	X	
	2500	▲	▲	X
	3000	▲	X	
150	2000	▲	▲	X
	2500	▲	▲	X
	3000	▲	X	

Table 3. Helical Angle Variable Data Stability Lobe Diagram 36/38 degrees

Feed Rate (mm/mnt)	Spindel Speed (RPM)	Depth of Cut (mm)		
		0.4	0.7	1
100	2000	▲	▲	X
	2500	▲	▲	X
	3000	▲	X	
125	2000	▲	▲	X
	2500	▲	X	
	3000	▲	X	
150	2000	▲	▲	X
	2500	▲	▲	X
	3000	▲	▲	X

Note:
X = Chatter Occured
▲ = Free Chatter

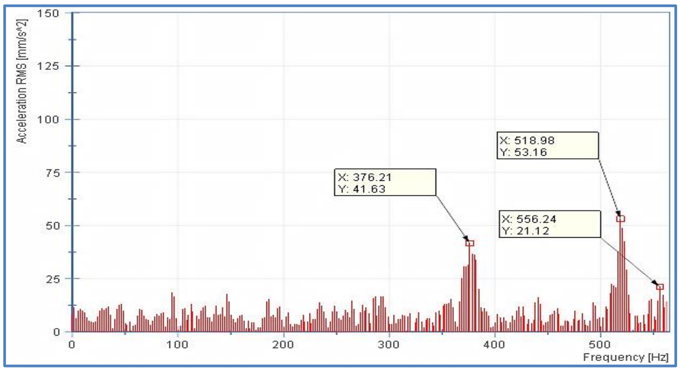

Figure 5. Fast fourier transform graph (bottom) at a feed rate of 100 mm/min with a spindle velocity of 2000 RPM and a Cut Depth of 1 mm using a variable Helical Angle of 35/38 degrees

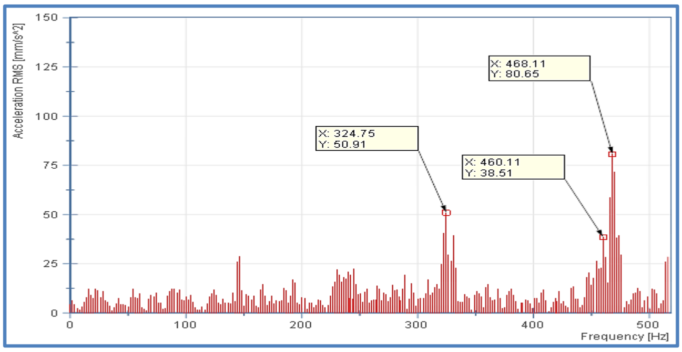

Figure 6. Fast fourier transform graph (bottom) at a feed rate of 100 mm/min with a spindle velocity of 2000 RPM and a Cut Depth of 1 mm using a variable Helical Angle of 36/38 degrees.

Figure 5 is the result of *signal processing* in the form of FFT (*Fast Fourier Transform*) graphs from the *milling slot* machining process at a feed rate of 100 mm / minute with a spindle rotation variation of 2000 RPM using variable helix and pitch tools with a *helical* angle of 35/38◦ *and* a pitch angle of 82/93◦ expressed *chatter* at *a cut depth of* 1 mm with *RMS* values of peak acceleration in FFT spectra 41.63, 21.12 and 53.16 mm/s^2

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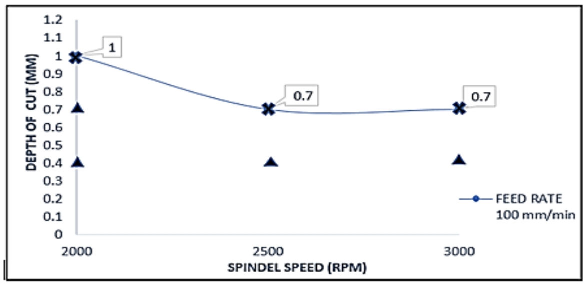
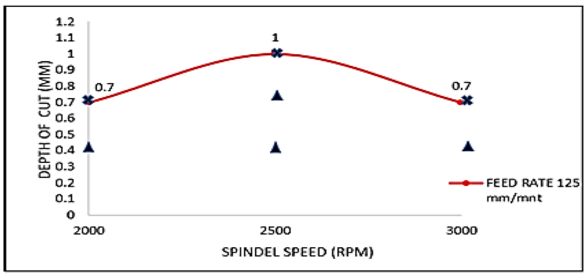
Figure 6 is the result of signal processing in the form of FFT (Fast Fourier Transform) at a spindle rotation variation of 2000 RPM, using variable helix and pitch tools with a helical angle of 36/38 and a pitch angle of 83/93◦expressed chatter at a cut depth of 1 mm with peak acceleration RMS values in the FFT spectrum of 50.91, 38.51 and 80.65 mm / s^2.

The method in identifying chatters used the same method and had been compared with variable axial depth cut at values of 0.4, 0.7 and 1 mm with the same feed rate and spindle rotation. In the variable helix 35/38◦ and pitch 82/93◦ the highest RMS acceleration amplitude value is 53.16 mm/s^2 at a frequency of 518.98 Hz. In the variable helix 36/38◦ and pitch 83/93◦, the highest RMS peak acceleration amplitude value was 80.65 mm/s^2 with a frequency of 468.11 Hz. The difference in cutting depth and RMS acceleration amplitude value at each helical angle and pitch angle can occur because there are differences in pitch angles in each geometry tool. The difference in pitch angle at the incision eye resulted in variations in the tooth graduation frequency value during the machining process. This variation in the frequency of tooth delay was what caused the geometry tool to prevent the possibility of a chatter so that it can maintain its stability until the chatter occurs at a certain cutting depth.

(A)



(B)



(C)

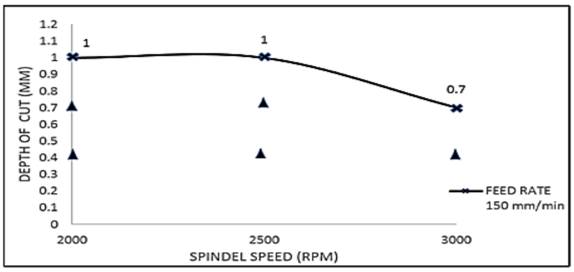
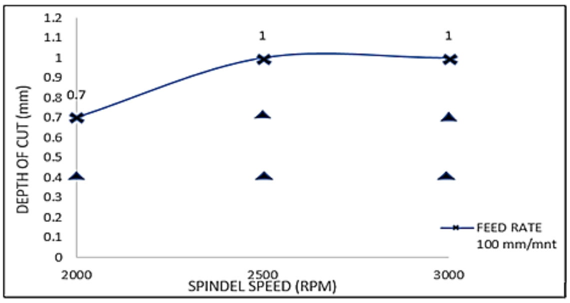
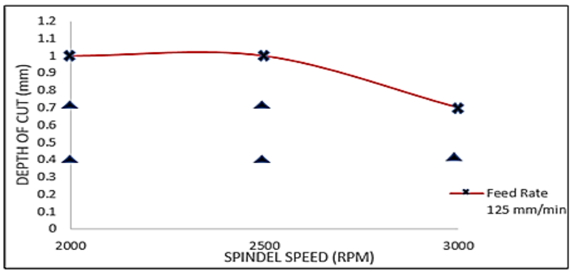


Figure 7. Helical Angle Variable Stability Lobe Diagram 35/38 and picth 82/93 degrees (A) Feed Rate 100 mm/min, (B) Feed Rate 125 mm/min, (C) Feed Rate 150 mm/min

(A)



(B)



(C)

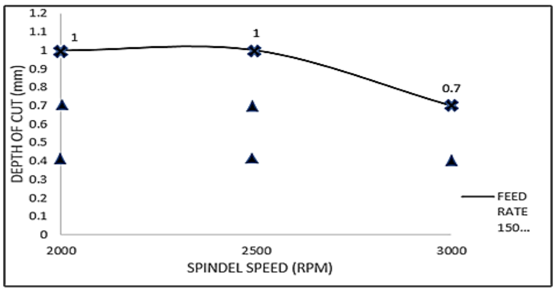


Figure 8. Variable Helical Angle Stability Lobe Diagram 36/38 and picth 83/93 degrees (A) Feed Rate 100 mm/min, (B) Feed Rate 125 mm/min, (C) Feed Rate 150 mm/min

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In Figure 7 of the chatter phenomenon using the *helical angle variable geometry tool* 35/38, at a feed rate variation of 100 mm/min the chatter is experienced at cut depths of 1, 0.7 and 0.7 mm, with spindle speeds of 2000, 2500 and 3000 RPM. At a feed rate variation of 125 mm/min there was a chatter at cut depths of 0.7, 1 and 0.7 mm with spindles of 2000, 2500 and 3000 RPM. At feed rates of 150 mm/min chat at cut depths of 1, 1, and 0.7 mm with spindle speeds of 2000.2500 and 3000 RPM

In figure 8 can be seen the chatter phenomenon using the helical angle variable geometry tool 36/38 at a feed rate of 100 mm/min chatter at cut depths of 0.7, 1 and 1 mm, with spindle speeds of 2000, 2500 and 3000 RPM. At a feed rate of 125 mm / min of chat cut depths of 1, 1 and 0.7 with spindles of 2000, 2500 and 3000 RPM. At a feed rate variation of 150 mm/min chatter experienced at cut depths of 1, 1, and 0.7 mm with spindle speeds of 2000.2500 and 3000 RPM.

Figures 7 and 8 illustrate distinct instances of chatter phenomena, which can be attributed to variations in the helical angle and pitch angle of the tool's geometry. The dissimilarity in helical angle and pitch within the cutting edge leads to differences in tooth graduation frequency, thereby enabling the use of tools with variable helix and pitch angles to mitigate vibrations and minimize the occurrence of chatter, as discussed in reference [16]. Chatter during the machining process arises from abrupt spikes or peaks in acceleration displacement. By utilizing tools with variable helix and pitch angles, a more stable acceleration displacement can be achieved.

IV Conclusion

Based on the research that has been done, it can be concluded that the stability lobe diagram graph resulting from this experimental study, it can be known that:

1. When employing a variable helix angle of 35/38 degrees, chatter was observed during the milling slot machining process. At a feed rate variation of 100 mm/min, chatter occurred at cut depths of 1 mm, 0.7 mm, and 0.7 mm, using spindle speeds of 2000, 2500, and 3000 RPM. Similarly, at a feed rate variation of 125 mm/min, chatter was observed at cut depths of 0.7 mm, 1 mm, and 0.7 mm, with the same spindle speeds of 2000, 2500, and 3000 RPM. Furthermore, at feed rates of 150 mm/min, chatter occurred at cut depths of 1 mm, 1 mm, and 0.7 mm, utilizing spindle speeds of 2000, 2500, and 3000 RPM.
2. When utilizing a variable helix angle of 36/38 degrees, chatter occurred during the milling slot machining process. At a feed rate of 100 mm/min, chatter was observed at cut depths of 0.7 mm, 1 mm, and 1 mm, using spindle speeds of 2000, 2500, and 3000 RPM. Similarly, at a feed rate of 125 mm/min, chatter occurred at cut depths of 1 mm, 1 mm, and 0.7 mm, with the same spindle speeds of 2000, 2500, and 3000 RPM. Additionally, at a feed rate variation of 150 mm/min, chatter was experienced at cut depths of 1 mm, 1 mm, and 0.7 mm, utilizing spindle speeds of 2000, 2500, and 3000 RPM.

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