# OPTIMIZATION OF VARIABLE HELIX ANGLSE PARAMETERS IN CNC MILLING OF CHATTER AND SURFACE ROUGHNES USING TAGUCHI METHOD

**Festo Andre Hardinsi**<sup>1)</sup>, **Oyong Novareza**<sup>2)</sup>, **Achmad As'ad Sonief**<sup>3)</sup> Manufacturing of Industrial Engineering, University of Brawijaya, Indonesia<sup>1)</sup> Department of Industrial Engineering, University of Brawijaya, Indonesia<sup>2)</sup> Department of mechanical Engineering, University of Brawijaya, Indonesia<sup>3)</sup>

Abstract In the manufacturing industries, the main problem in process of operating CNC milling machine was chatter effect (self-excited vibration) which increases the quality of the surface roughness. In this study is to determine optimal value of parameters for chatter and surface roughness. The chatter measured using accelerometer MPU-6050 with Arduino by software LabVIEW-2019 based on peaks-FFT value and the surface roughness measured by SJ-301 tester. The research parameters like variable helix angle, spindle speed, feed rate, and depth of cut using stainless steel 304 by Taguchi method. The optimum parameters value obtained are variable helix 35/38 degrees, spindle speed 3000 RPM, feed rate 150 mm/min and depth of cut 0.4 mm. Based on ANOVA value, the variable helix angle and depth of cut are found to be significant for chatter and surface roughness. The depth of cut was high contribution by ANOVA chatter by 93.84% and surface roughness by 91.93%.

Keywords: chatter, surface roughness, Taguchi method, ANOVA

#### **1. Introduction**

The use of alloy steel in the production process has increased, especially stainless steel in various industrial sectors such as the manufacturing industry of metal industry, transportation industry and aerospace industry. The use of austenitic stainless steel is the most popular grade and is widely used compared to other stainless steel grades [1]. AISI austenitic stainless steel 304 has excellent high ductility, high durability and corrosion resistance and has excellent machinability [2]. The design part of aerospace fixtures is one of the applications for using stainless steel 304 in the aerospace industry sector. Meanwhile, product precision is required in producing aerospace fixtures part. CNC milling machines have accurate precision with complex surface shapes on the workpiece to produce the quality of products. CNC milling machines are often used in mass manufacturing of products, because they can produce the designs product with minimum costs [3].

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However, there are problems that often occur in the operation of CNC milling machines due to vibrations in the machining process, namely the regenerative effect.

Chatter (Self-excited vibration) is also called Regenerative effect, where the regenerative effect cycle is a cycle that is formed when a cutting tool undergoes dynamic displacements between the cutting tool and the work piece. There by, the increase cutting force in the machining process and the cycle will take place continuously. The regenerative effect or chatter occurs when the tooth of cutting tools undergoes dynamic displacements in the process of cutting between the tools and the workpiece. The result of , tool wear, excessive noise, inaccuracies, and poor will give effect to the surface quality [4]. The low surface roughness can reduce the frictional impact between the surface of the material and the cutting tools [5]. Selection method of the tool geometry as a parameter in the end milling process can improve the surface quality of the workpiece by

<sup>\*</sup> Corresponding author. Email : <u>festoandrehardinsi@yahoo.com</u> Published online at <u>http://Jemis.ub.ac.id</u>

reducing surface roughness, material removal and vibration of machine parts [6].

The number of teeth and variations helix angle of the tools geometry in the cutting process will cause variations in the thickness of the chips, so this will result a bad workpiece surface and the surface roughness value increasing. One of the factors causing chatter that can increase surface roughness is cutting conditions such as feed rate, depth of cut and spindle speed [7]. The use of high spindle speed, low feed rate and low depth of cut is recommended to obtain good results on the surface finish [8]. In addition, the feature of the tool geometry angle has a direct influence on the operation process and should not be neglected in parameter selection [9]. The cutter variable of helix angle has given different variations of the helix angle and pitch angle. The geometry tools of angle feature of the variable helix angle and varying pitch of angle can reduce the occurrence of the regenerative effect (chatter) in the end milling [10]. Tools geometry variable helix angle and pitch angle can cause variations in tooth passing frequency, therefore they will reduce the delay of feeding process, so that can be reduce the occurrence of excessive chatter continuously [11].

M. Balaji et.al.[12] In the research on optimization of cutting parameters is using the Taguchi method. The results show that the optimal level of cutting parameters for surface roughness is obtained at a helix angle of 25 degrees, a feed rate of 12mm / min and a spindle speed of 800 rpm. The optimal level of cutting parameters for accelerated vibration is obtained as a helix angle of 25 degrees, a feed rate of 10 mm / min and a spindle speed of 600 RPM. J. Ren et.al [13] conducted research on the optimization of cutter parameters using the Taguchi and gray analysis method in the milling machining process. The results show optimum level of parameters for surface roughness (Ra) is a rake angle of 6 degrees, a gash angle of 35 degrees, a helix angle of 30 degrees, a gash rake angle of 2 degrees, and a pitch angle of 7 degrees, and the optimum level results for

amplitude acceleration. The vibrations are for a rake angle by 10 degrees, a gash angle by 30 degrees, a helix angle by 45 degrees, a gash rake angle by 4 degrees, and a pitch angle by 5 degrees. Conducted research on the optimization of CNC milling machine parameters is using the Taguchi method. The analysis was carried out on the spindle vibration and vibration of the vise. The parameters used are the helix angle, feed rate, spindle speed, axial depth of cut, and radial depth of cut. The measurement results are carried out on the vibration using the accelerometer. P. S. Sivasakthivel et.al [14]. The optimal level of parameters for spindle vibration is a helix angle of 45 degrees, a feed rate of 0.04 mm / rev and a spindle speed of 2 m / min, an axial depth of cut of 3.5 mm and a radial depth of cut of 3 mm. While the optimum level for vise vibrations is a helix angle of 45 degrees, a spindle speed of 1.75 m / min, a feed rate of 0.04 mm / rev, an axial depth of cut of 2.5 mm and a radial depth of cut of 2.5 mm.

However, research that analyzes the level and factors for variable helix angle with experimental and statistical approaches has not been found in literature studies. Therefore, the aim of this study is to determine the optimal level and factors that have the most significant effect on the value of chatter vibrations and surface roughness using the Taguchi methods and ANOVA

# 2. Materials and Methods 2.1 Material

The work material selected for the study of stainless steel 304 with high strength, high ductility and low thermal conductivity. The selection of the stainless steel 304 was taking into account and its almost use in all industrial applications for approximately 50% of the world's stainless steels production and consumption. The chemical composition of the workpiece material is given in Table 1. The dimension of the work piece used in the experiment was 100 mm x 100 mm x 50 mm.

Table 1: Chemical Composition of. Stainless Steel 304

Tuble IT chemical composition of Stanless Steel 501													
Element	С	Cr	Ni	Mn	Si	Co	Р	S	Fe				
wt %	0.04	18.07	8.11	1.37	0.46	0.40	0.02	0.00	Balance				

#### 2.2 Experimental Setup

This research experiment uses CNC milling machine VMC (vertical milling center) HAAS VF-2 with 7.5 kW power and maximum spindle speed 8100 RPM. The cutting tool is made of tungsten carbide end mill with 4 flutes of 6 mm diameter. This study used an experimental design using the Taguchi method to improve the quality of the machining process using slot milling. The cutter (geometry tools) used in this study uses three variable of helix angle with helix angle of 35/38, 36/38 and 40/42 degrees. In Fig 1 shows the installation of the measuring device used in the Taguchi experimental design using the  $L_9$  and the selection of factor and level in Table 2. Before taking measurements, first calibration of the tool must be carried out to provide accurate results.

# 2.2.1 Selection of Parameters Variable Helix Angle

Ling Huang [15], conducted a study to find the location of the vibration displacement on cutting tools using a dynamometer. The research was conducted using 2 types of chisels, namely the variable helix 35/38 and the uniform 38 degrees helix. Based on the results of the experimental analysis, it shows that the helix 35/38 variable has a smaller vibration value than the tool non-uniform.

Andreas Otto [16], compared the results of stability lobe on variable helix 36/38 degrees and conventional (non-uniform) tools with 30 degrees helix. Based on the results obtained, it is explained that for tools variable helix have a variation of time delay so that it prevents vibration, while on conventional tools there is no variation time delay.

NIU [17], conducted research to identify the occurrence of vibration phase regenerative chatter between teeth adjacent using a chisel variable helix 40/42 degrees. Based on the conclusion, it explains that the chatter emphasis on variable pitch and variable helix (VPVH) tools on unstable stability lobes tends to occur at low spindle speeds. In addition, to increase the effectiveness of emphasis chatter on variable helix tools, it is advisable to adopt variant pitch / helix relatively larger.

# 2.2.2 Selection of Parameter Level Range of Spindle Speed, Feed Rate. and The Depth of Cut

Mohd-Lair [18], in his study explained that. the results obtained when the feed rate is increased from 75 mm / min to 100 mm / min, the surface roughness will increase. When the feed rate is increased from 100 mm / min to 150 mm / min, the surface roughness will decrease. A. Saravanakumar, [19], in his study explained that. the results obtained When the spindle speed is increased from 2000 to 3000 RPM the surface

roughness will decrease. Nikalje [20], before conducting the research, chose a variation of the depth of cut with a range of 0.2 to 1.0 mm and a feed rate with a range of 50 to 150 mm / min The results obtained explain that there is a significant change in surface roughness values at depth of cut of 0.4-1.0 mm and a feed rate of 100-150 mm / min using material stainless steel 430.

#### 2.2.3 Chatter Vibration Measurement.

The chatter vibration sensor was fixed to the tool holder for the vibration measurement of tool. Chatter vibration was measured using the MPU-6050 accelerometer with the Lab VIEW 2019 version student software application. Then the data is transferred using the Arduino Uno microcontroller. Measurement of the chatter vibration is based on maximum value of graph FFT (Fast Fourier Transform) [21].

#### 2.2.4 Surface Roughness Measurement.

Surface roughness measurement, which is carried out off-line after the milling process, is one of the important things to improve product quality. Because this greatly affects the performance of mechanical components and production costs. The surface roughness data collection is done by calculating the distance of the measurement point based on time and maximum amplitude (peaks). the comparison between infeed distance of 30 mm and the total time in the machining process is obtained. After

measuring the point, the surface roughness (Ra) was measured using the SJ 301 Mitutoyo.

Factors	Simbola	Tin:t	Levels				
Factors	SIIIDOIS	Umt	1	2	3		
Variabel Helix Angle	А	(degrees)	35/38	36/38	40/42		
Spindel speed	В	(RPM)	2000	2500	3000		
Feed rate	С	(mm/min)	100	125	150		
Depth of cut	D	(mm)	0.4	0.7	1		

#### Table 2: Factors and Levels



Fig.1 Experimental Set-up

# 3 Result and Discussion 3.1 Experiment Results

The research design used in this experiment is an orthogonal matrix  $L_9$  (3<sup>4</sup>) [22]. The quality characteristics is "smaller the better". This aims to minimize the value of chatter vibration and surface roughness. The orthogonal array matrix form applied in this study is shown in Table 3.

**Table 3:** Orthogonal array  $L_9(3^4)$ 

Experiment	Factor					
	Α	В	С	D		
1	1	1	1	1		
2	1	2	2	2		
3	1	3	3	3		

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Fig 2 Time Domain (Acceleration-time) for The First Experiment for The First Replication



150

125

Fig 4 Frequency Domain (FFT) for The 8 Experiment for First Replication

Experimental number	Replicated	Time domain in graph (s)	Distance of measurement points (mm)	Average Ra (µm)
1	Ι	1.43	6.13	0.283
	II	1.46	6.26	0.287
	III	1.50	6.43	0.273



Fig 5. Results of The Surface Roughness Ra for The 1st Experiment for Replication 3.



Fig 6. Results of The Surface Roughness Ra for The 8 Experiment for Replication 1

In Fig 2, shows the results of the analog signal in the form of the time domain (acceleration-time) obtained in the first experiment for the first replication, by having the highest acceleration value, which occurred at 1.43. This can happen because when the machining process occurs in the 2 until 8 second and the total time on the graph for 7 seconds. An example of calculating the distance of the measurement point in the 1st experiment for 3 replications can be seen in Table 4.

In Fig 3, shows the results the chatter vibration obtained is in the form of the FFT-RMS acceleration amplitude with a maximum peak value of 21.22 mm /s<sup>2</sup> and In Fig 4, shows the results the chatter vibration obtained is in the form of the FFT-RMS acceleration amplitude with a maximum peak value of 82.57 mm /s<sup>2</sup>. In Fig 5, show the results measurement arithmetical mean roughness (Ra) with value of 0.273  $\mu$ m and In Fig 6, show the results measurement arithmetical mean roughness (Ra) with value of 0.241  $\mu$ m.

In Fig.3 is result of the lowest value of chatter vibrations and in Fig. 5 is result of the lowest value of surface roughness for experiment 1 replication 3 with parameters namely variable helix angle is 35/38 degrees,

spindle speed is 2000 RPM, feed rate is 100 mm / min and depth of cut is 0.4 mm. In Fig 4 is results of the highest value of chatter vibration and Fig 6 is results of the highest value of surface roughness in experiment 8 with the parameter namely helix angle variable is 40/42 degrees, the spindle speed is 3000 RPM, the feed rate is 100 mm / min and the depth of cut is 1 mm.

A. Bouchareb [18] concluded in his study that the highest value of surface roughness (Ra) was due to the increase in the depth of cut value and the low cutting speed value. The results of these values are directly proportional to the value of vibration and surface roughness [24]. In addition, Xiao et.al [20] explained that the difference in the value of the variable helix angle have a different pitch angle value, which causes variations in time delay/ tooth passing period and results in different tooth passing frequencies for each adjacent chisel. the existence of tooth passing frequency varies, it can control the maximum regenerative chatter and chatter resonance [21]. The existence control regenerative chatter and chatter resonance on the variable helix angle tool will have lower vibration amplitude so that lower surface roughness value [22].

The results of the surface roughness measurement value in the first experiment, and the first replication can be seen in Fig 4. In the same way in the first experiment, data collection of surface roughness values can be carried out further for the second to 9 experiments with 3 replications. The results of the chatter vibration values and surface roughness, which were obtained from the experimental design using the Taguchi L<sub>9</sub> design ( $3^4$ ), can be seen in Table 5.

In the Taguchi analysis, the value of chatter vibration and surface roughness using the "smaller the better" characteristic found in the Minitab 18 program can be obtained. The value S/N ratio of chatter vibration was obtained at 27.12 and the value S/N ratio for the surface roughness was obtained at 11.02 as shown in Table 5.

					Chatter Acceleration RMS (mm/s <sup>2</sup> )						Surface Roughness Ra (µm)					
Exp.	Α	В	C	D					S/N					S/N		
					Ι	II	III	Mean	ratio	Ι	II	III	Mean	ratio		
1	1	1	1	1	23.90	23.06	21.22	22.73	-27.12	0.283	0.287	0.273	0.281	11.02		
2	1	1	2	2	58.67	58.85	57.97	58.50	-35.34	0.331	0.333	0.319	0.328	9.68		
3	1	1	3	3	69.35	68.93	66.54	68.27	-36.68	0.427	0.426	0.424	0.426	7.41		
4	2	2	2	3	72.54	73.37	70.47	72.13	-37.16	0.433	0.436	0.431	0.433	7.26		
5	2	2	3	1	21.55	23.94	24.41	23.30	-27.35	0.289	0.29	0.292	0.290	10.74		
6	2	2	1	2	60.76	61.72	60.19	60.89	-35.69	0.34	0.349	0.34	0.343	9.29		
7	3	3	3	2	59.50	59.48	62.30	60.43	-35.62	0.361	0.369	0.371	0.367	8.70		
8	3	3	1	3	82.57	80.80	79.94	81.10	-38.18	0.441	0.44	0.438	0.440	7.13		
9	3	3	2	1	24.76	24.95	24.99	24.90	-27.92	0.292	0.297	0.296	0.295	10.60		

Table 5. Test List and Obtained Values as A Result of The	e Test Mean and S/N Ratio
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Fig.5 Normality Test for The Analysis of Experimental Data Chatter and Surface Roughness Ra.

After calculating the S/N ratio value of chatter vibration and surface rougness, it is necessary to analyze experimental data based on the normality test. The Minitab 18 program can be used to perform normality tests. In Fig 5 shows the results of the normality test of

experimental data of P > 0.05 as a hypothesis [17]. These results mean that the P value is greater than 0.05 (P value 0.150 for Ra, and 0.054 for chatter vibration). Therefore, the hypothesis can be accepted or the data can be accepted for normal distribution.

# 3.3 Optimization for Chatter and Surface Roughness Response

The result of parameter optimization design is based on the main effect of the average value on the optimal condition of the chatter and the surface roughness with the quality characteristics smaller the better as shown in Figures 6 and 7. These results indicate the conditions of the optimum value are the same as the average value of chatter and surface roughness. The parameter design model of the level and factors that influence and produce the optimal value of chatter vibration and surface roughness is shown in Table 6. In each figure, it also explains that the optimal value for chatter vibration and surface roughness is the helix angle variable of 35/38 degrees, the spindle speed of 3000 RPM, the feed rate of 150 mm/min and the depth of cut of 1 mm.

In Taguchi method, analysis of the measured response shows the importance of the process parameters to be used. Determination of the optimal setting of each factor is measured based on the slope of the plot effect. The low slope angle indicates that this factor is more

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optimal. The optimal parameter setting values for chatter and roughness are shown in Table 6. Experiment Confirmation test is the last step or step to verify the optimal value obtained based on the Taguchi experimental design. The results the experimental of optimum confirmation test are shown in Table 7.



Fig 6. Optimal Level for Chatter Vibration



Fig 7. Optimal Level for Surface Roughness

#### Table 6. Optimal Settings for Chatter and Surface Roughness.

Optimal design										
Parameter	Setting Level optimal	Value								
А	1	Variable helix angle 35/38								
В	3	3000								
С	3	150								
D	1	0.4								

	Table 7. The Resu	ults of The C	Confirmation	Experimental	Design.
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Confirmation experimental setting optimal design													
		Chatter RMS (mm/s <sup>2</sup> ) Surface Roughness (µn							s (µm)				
Factors and levels	Value	Unit	Ι	II	III	Mean	Ι	II	III	Mean			
A1	Variable helix 35/38	(Degrees)											
B3	3000	(RPM)											
C3	150	(mm/min)	22.28	20.49	21.92	21.56	0.242	0.253	0.265	0.253			
D1	0.4	(mm)											

#### **3.4 Analysis of variance (ANOVA)**

ANOVA consists of degrees of freedom, number of parameter squares, number of squares, parameter variance, parameter F-value, and parameter contribution. In this study use control parameter significant test with confidence level of 95% and P-value < 0.05 in table ANOVA,

Table 8. ANOVA Chatter and Surface Roughness

Chatter Acceleration (RMS)

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Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value						
Regression	4	952.16	91.27%	952.16	238.04	135.06	0.000						
Variable Helix Angle	1	50.03	4.80%	50.03	50.03	28.39	0.021						
Spindle Speed	1	0.25	0.02%	0.25	0.25	0.14	0.949						
Feed Rate	1	6.97	0.67%	6.97	6.97	3.95	0.465						
Depth of Cut	1	978.89	93.84%	978.89	978.89	555.40	0.000						
Error	4	7.05	0.68%	7.05	1.7625								
Total	8	1043.19	100.00%										
Surface roughness (Ra)													
Source	DF	Seq SS	Contribution	Adj SS	Adj MS	<b>F-Value</b>	P-Value						
Regression	-	0.031951	94.29%	0.031951	0.00798775	59.83	0.001						
Variable Helix Angle		0.002085	6.15%	0.002085	0.002085	15.62	0.026						
Spindle Speed		0.000052	0.15%	0.000052	0.000052	0.39	0.597						
Feed rate		0.000062	0.18%	0.000062	0.000062	0.46	0.565						
depth of cut		0.031152	91.93%	0.031152	0.031152	233.35	0.000						
Error	ŀ	0.000534	1.58%	0.000534	0.00013350								
Total	5	0.033885	100 %										

The results statistical using ANOVA regression on the Taguchi method with an orthogonal array matrix L<sub>9</sub> using Minitab 18 program. If the ANOVA regression results are P <0.05, the ANOVA regression results can be accepted [25]. The ANOVA calculation results based on mean data on the chatter obtained the calculated F value for each factor, namely variable helix angle of 28.39, spindle speed of 0.14, feed rate of 3.95, and depth of cut of 555.40.The results of ANOVA calculations based on the average response data to surface roughness, obtained the calculated F value for each factor, namely variable helix angle of 15.62, spindle speed of 0.39, the feed rate of 0.46 and the depth of cut of 233.35 with the F table results obtained  $F_{0.05,1,4} = 7.71$ .

Factors that significantly influence the value of the chatter and surface roughness based on the F value  $\geq$  F table are Depth of Cut, and Variable helix angle. Meanwhile, factors that do not significantly influence are Spindle Speed and Feed Rate. The depth of cut factor has the largest contribution, the results of ANOVA chatter of 93.84% and surface roughness of 91.93%.

# 3. Conclusion

The results obtained in each experiment using the  $L_9$  design (3<sup>4</sup>), the Optimal value for chatter and surface roughness using the Taguchi method with "smaller the better" quality characteristics were obtained with a variable helix angle of 35/38 degrees, spindle speed of 3000 RPM, feed rate of 150 mm/min, and depth of cut of 0.4 mm. Based on the calculated F value  $\geq$  F table on ANOVA chatter and surface roughness, factor D (Depth of Cut) and factor A (Variable Helix Angle) are significant factors, while factor B (Spindle Speed) and Factor C (Feed Rate) are factors which is insignificant. The depth of cut factor has the largest contribution with ANOVA chatter of 93.84% and ANOVA of surface roughness of 91.93%

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