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# Evaluation of Aluminum Surface Roughness in the Slot End-Mill Process with Variable Helix Angle

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**Abstract.** Chatter control in machinery significantly affects the product surface quality. The variable helix angle tool is a technique that gives the tool an angle with a different pitch angle to the tool axial axis. The variable helix angle tool provides a solution for solving time delay as a cause of the emergence of chatter. In this research, an evaluation of the two tool conditions with normal helix angle ( $40^\circ$ ) and variable helix angle ( $40^\circ/42^\circ$ ) was performed on the cutting parameters (depth of cut; spindle speed, feed rate). The results obtained by performance evaluation were tools with variable helix angles capable of producing significantly better surface roughness quality compared to normal helix angle tools.

**Keywords:** Chatter control, slot end mill, variable helix angle, surface roughness.

## 1. Introduction

The optimal machinery process plays an important role in the advanced manufacturing industry. The quality of the product components is determined by the cutting parameters and tools. Tool problems will be related to the vibration tool that is called chatter. The self excited vibration is the most difficult problem to solve from all the problems faced in machinery. The appearance of chatter is very damaging and detrimental, because it decreases the quality, shortens the life of the engine, and other components. In the chatter there can be two types of vibrations that greatly damage the machinery work piece surface, namely regenerative chatter and resonance chatter, Munoa et.al. [1].

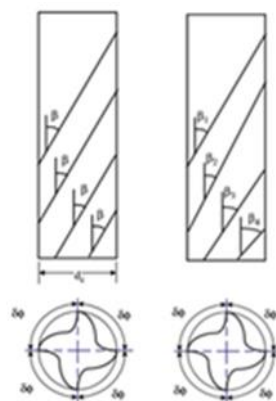
According to Wang et al. [2] in his study, the unstable milling process due to the intermittent cut will result in a phase difference in chip load, this is a Regenerative chatter phenomenon. If this will continue with the same time delay, it can become a maximum with high amplitude, leaving a file on the product so that the value of surface roughness increases. According to Song, et.al [3], the other most destructive chatter model is chatter resonance. This happens when the natural frequency and tooth passing frequency have an integer comparison value. In this phenomenon the tool vibration amplitude increases, resulting in poor product quality. Chatter control is done by controlling the phenomenon of resonance by making the variable helical angle on the end mill. In the process with the helix angle that the variable will produce a different pitch angle to the axial axis of the mill. Lacerda and Lima [4], in their research, when resonance occurs the mill displacement amplitude increases significantly, which affects the poor machinery product. One of the efforts to control resonance is by



varying the time delay in the adjacent mill. Variations in time delay will prevent regenerative and resonance effects. In the milling process, varying the time delay is performed by making a different pitch angle to the axial axis of the mill, forming a variable helix angle. In Kiswanto et.al. [5], states the axial depth of cut machining parameters, feed rate and simultaneous cutting speed will affect the product yield. Therefore it is necessary to optimize the cutting parameters for the milling process. In this study we will evaluate the surface roughness of slot end mill products with variable helix angle toward simultaneous cutting parameters.

## 2. Experimental setup

In this study, the work piece used was aluminum AL-2011 which was processed with slot milling at CNC. End mill tools used as a test variable was formed with the same helix angle of  $40^\circ$  (normal) and the helix variable was  $40^\circ/42^\circ$  (variable) as in Figure 1. The angular shape of this variable will give a different pitch angle between two adjacent end mill tools conducted by Yusoff et.al. [6]. Prepared specimens were installed in a CNC machine with an end-mill slot process. In the tool holder vibration meter was connected to the computer through the Labview 2013 myRIO program. In experiments such as in Figure 2, each machining process of different cutting parameters was measured by amplitude data and vibration frequency spectrum and at the end of the process test specimens surface roughness measurements were performed (Ra) with surface roughness tester (Mitutoyo-SJ-301) at each of the same locations in the sample.

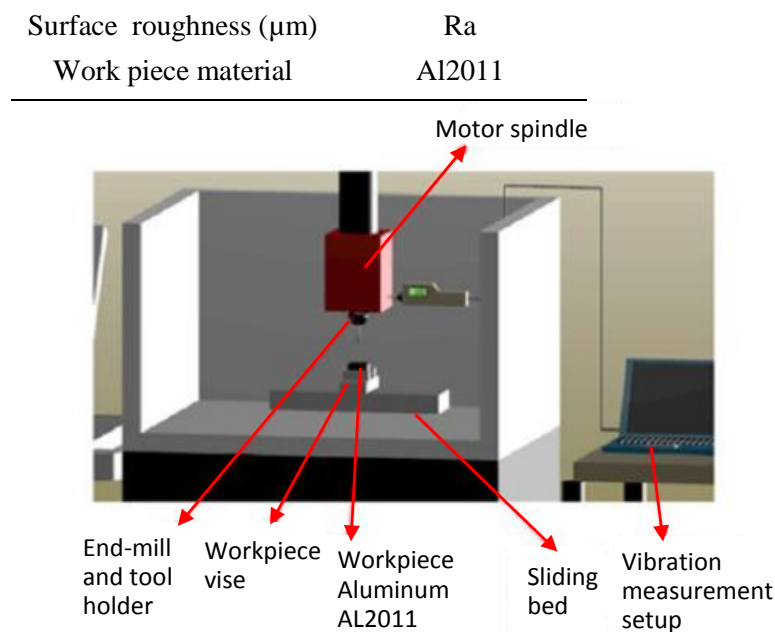


**Figure 1.** Normal helix angle (left) and variable helix angle (right)

The experimental design was carried out with parameters such as in Table 1.

**Table 1.** Slot Milling Parameter

Parameters	Value(s)
Spindle speed (rpm)	600 ; 900 ; 1200
Feed rate (mm/min)	50 ; 75 ; 100
Axial depth of cut (mm)	0,6 ; 1,2 ; 1,8
Helix Angle ( $^\circ$ )	
Normal	40
Variable	40/42
Diameter end mill (mm)	6
Number of flutes	4
Overhang length (mm)	25

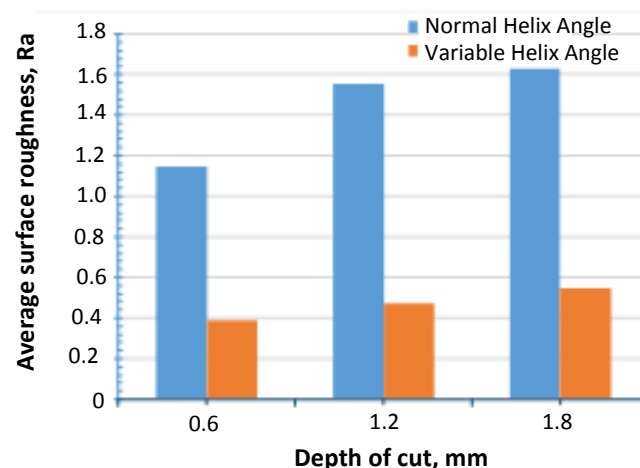


**Figure 2.** Experimental setup slot end-mill process

### 3. Results and discussions

#### 3.1 Surface Roughness

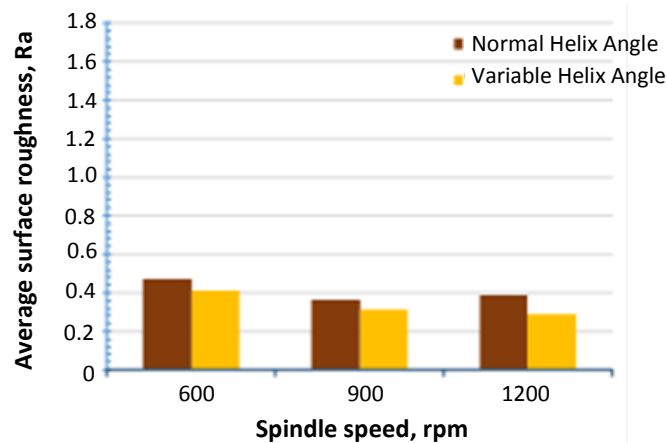
Surface roughness experimental results in the end-mill slot process in both normal helix angle and variable helix angle conditions toward the cutting parameters as shown in the following graphics. Figure 3 shows the results of the average surface roughness of the variations of Depth of Cut (DOC) with Normal Helix Angle (NHA) end-mill tools and Variable Helix Angle (VHA). In this condition there was a decrease in Ra (VHA) value of 67.56% from the RA value (NHA). The use of NHA shows a greater gradient than the use of VHA.



**Figure 3.** Surface roughness under various depth of cut

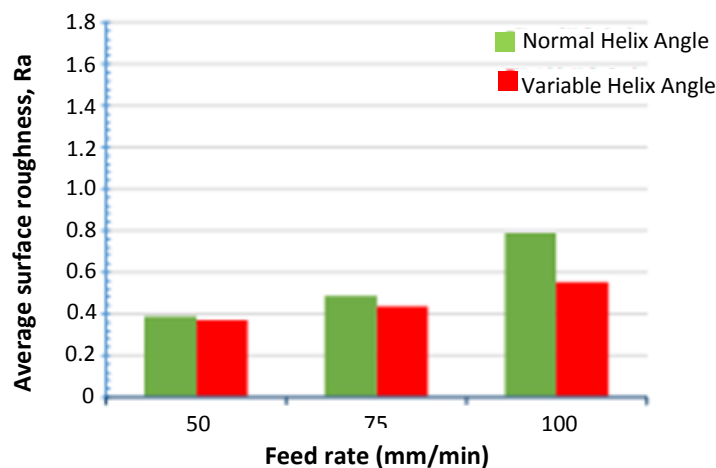
In Figure 4., shows the results of the average surface roughness of variations of Spindle Speed (SS) with Normal Helix Angle (NHA) end-mill tools and Variable Helix Angle (VHA). In this condition

there was a decrease in the value of Ra (VHA) of 17.17% from the value of RA (NHA). The use of NHA is more fluctuation than the use of VHA which is more sloping towards SS variations.



**Figure 4.** Surface roughness under various spindle speed

In Figure 5., shows the results of the average surface roughness of variations of Feed Rate (FR) with Normal Helix Angle (NHA) end-mill tools and Variable Helix Angle (VHA). In this condition, there was a decrease in Ra (VHA) value of 14.50% from the RA value (NHA). The use of NHA is more fluctuation than the use of VHA which is more sloping towards FR variation.



**Figure 5.** Surface roughness under various feed rate

### 3.2 Regression Analysis

The evaluation results through regression analysis of NHA sample and end-mill processes of VHA on the sample surface roughness are seen in the following tables 2 and 3. In the regression analysis with NHA obtained Multi R: 0.574, which means NHA and cutting parameters affect surface roughness (Ra) of 57.4%, while 42.6% is influenced by other variables. The regression equation and ANOVA analysis is in table 2. ANOVA results are obtained  $F_{(value)}$  which is greater than  $F_{(table)}$ . It states that the regression equation plays a role in the diversity of surface roughness (Ra) data. The compatibility of the regression equation model with the cutting parameters of surface roughness (Ra) in NHA tool is 33%.

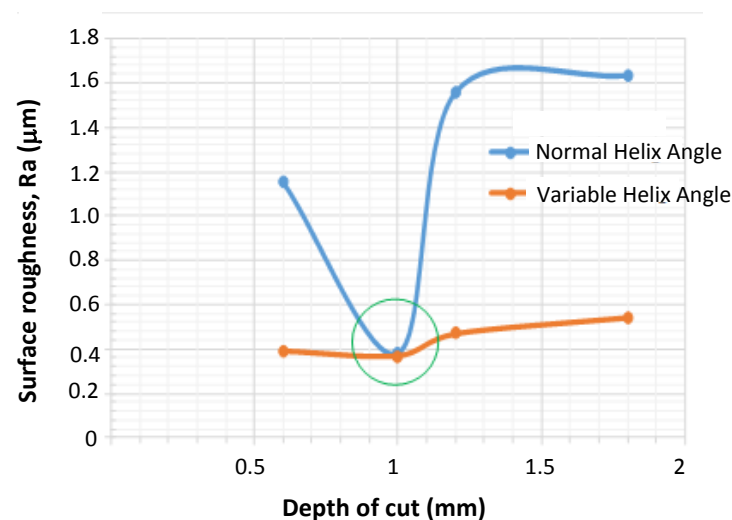
In the regression analysis with VHA, the Multi R: 0.889 value was obtained, which means that the VHA tool and the cutting parameters affect surface roughness (Ra) by 88.9%, while 11.1% is influenced by other variables. The regression equation and ANOVA analysis is in table 3. ANOVA results were obtained  $F_{(value)}$  which is greater than  $F_{(table)}$ . It states that the regression equation plays a role in the diversity of surface roughness (Ra) data. The compatibility of the regression equation model with the cutting parameters of surface roughness (Ra) on the VHA tool is 79%.

**Table 2.** Normal Helix Angle Regression Analysis Results

Normal helix angle (400)						
Ra= 15,583.72 . $a_p^{0.546}$ . $n^{-1.304}$ . $v_f^{-0.391}$						
Anova Table						
Source	Sum of squares	df	Mean square	F Value	F Table	R <sup>2</sup>
Regression	0.997	3	0.332	6.71	2.83	0.33
Error	2.03	41	0.0495			
Total	3.02	44	0.0686			

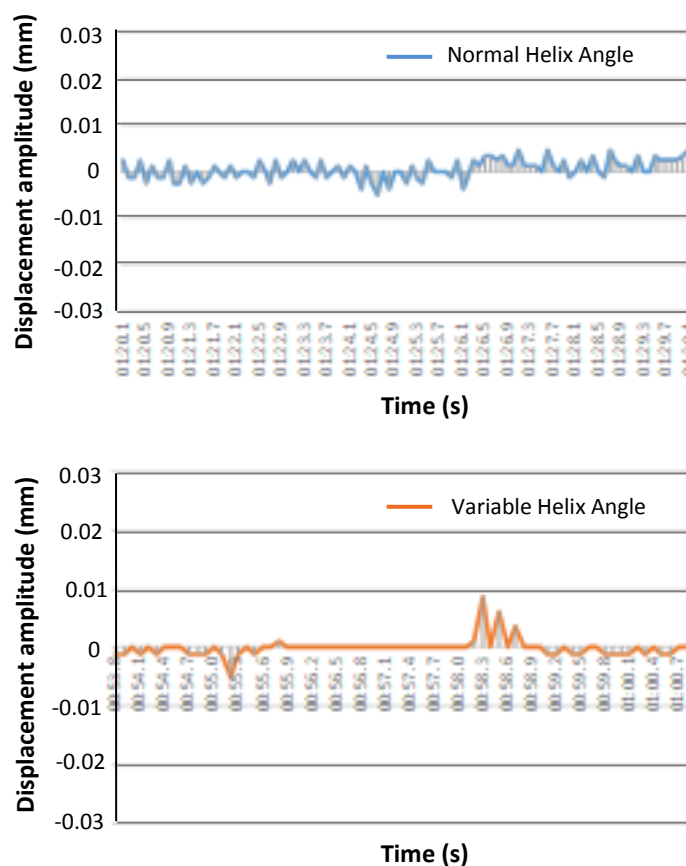
**Table 3.** Variable Helix Angle Regression Analysis Results

Variable helix angle (400/420)						
Ra = 4.83 . $a_p^{0.331}$ . $n^{-0.586}$ . $v_f^{0.332}$						
Anova Table						
Source	Sum of squares	df	Mean square	F Value	F Table	R <sup>2</sup>
Regression	0.338	3	0.113	52.1	2.83	0.79
Error	0.089	41	0.00217			
Total	0.427	44	0.00970			



**Figure 6.** Comparison Ra versus DOC on normal and variable helix angle end-mill

In Figure 6, shows the evaluation results on Ra for DOC variations between the NHA tool and the VHA tool on the cutting parameters condition of the SS (600rpm), FR (50mm / men). In this condition, the DOC variation causes fluctuating (unstable) Ra on the NHA tool compared to the VHA tool. However, there is an interesting phenomenon in the condition of the DOC parameters (1 mm). The NHA tool and the VHA tool are close to the same value. This is because neither regenerative chatter or chatter resonance is justified by the small value of Ra NHA ( $0.385\ \mu\text{m}$ ) and RA VHA ( $0.368\ \mu\text{m}$ ) which are not significantly different and NHA amplitude displacement ( $0.005805\ \text{mm}$ ) and VHA amplitude displacement ( $0.005006\ \text{mm}$ ) which relatively small as in Figure 7.



**Figure 7.** Displacement amplitude of NHA and VHA.

The surface roughness investigation results of the slot end mill process with a variable helix angle are better than the normal helix angle. This is due to the helix angle variable having a different pitch angle which causes variations in the time delay / tooth passing period and results in a different tooth passing frequency for each adjacent chisel, Xiao et al. [7]. The existence of a tooth passing frequency varies so that it can control the maximum regenerative chatter and chatter resonance as Niu et.al. [8]. With this resonance control the VHA tool will have a small vibration amplitude so that the lower surface roughness value is obtained from the NHA tool.

#### 4. CONCLUSIONS

This study evaluates the surface roughness of the end-mill slot by comparing the NHA tool and the VHA tool to the cutting parameters. The main conclusions can be summarized as follows:

- The Ra performance on the VHA tool is 67.56% lower than Ra on NHA to DOC variations.
- The Ra performance on the VHA tool is 17.17% lower than Ra on NHA to SS variations.
- The Ra performance on the VHA tool is 14.50% lower than Ra on NHA to FR variation.
- The cutting parameters simultaneously affect Ra by 57.4% on the NHA tool.
- The cutting parameters simultaneously affect Ra by 88.9% on the NHA tool.
- The VHA tool can control regenerative and resonance chatter.

#### Acknowledgement

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