SURFACE ROUGHNESS ANALYSIS ON FIVE-AXIS FLANK MILLING FOR CURVED SHAPE PART – FULL FLUTE AND GROUND SHANK END MILL

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ABSTRACT: *Five-axis machining is gaining popularity as it provides additional flexibility, which can be used to improve production efficiency and quality of surface finish. Rather than milling with the tip of the tool, flank milling cuts with the shaft or body of the tool, removing greater amounts of material in a single pass. The main analysis focused in this research was surface roughness analysis which was initiated to investigate the differences between full flute or also known as extra long tool and ground shank tool. The type of cutting tool used was end mill 10 mm diameter with High Speed Steel (HSS) material. Machining tests were carried out by using Mazak-VRX630 multi-axis CNC machine on aluminum alloy 7075-T6 series. One factor at a time was used to analyze the overall data. Feed rate and spindle speed were the two main factors that been analyzed specifically on the front and the back surface of the curved shape part. However, based on the equal comparison results, ground shank end mill showed better result on the back surface area whilst full flutes end mill indicated the opposite result (better result on the front surface). Overall reachable tool length differences and the number of contact point occurred during machining were the two possible factors that contributed to the mentioned result which is related closely to the chatter vibration development*.

KEYWORDS: Surface Roughness, Five-Axis Flank Milling, Full Flute and Ground Shank End Mill.

1.0 INTRODUCTION

Five-axis machining has received much attention in both industry and the research community since 1980s. With additional two rotational degrees of freedom, it offers numerous advantages compared to the three-axis machining, such as higher production rate, increase the flexibility of machining, shorten the machining setup and time. In point milling, the cutting edges near the end of a tool perform the material removal. In contrast, the side face of a cutter does the machining in flank milling.

Sencer et al. [1] had conducted a study on feed optimization for five-axis machine tools with drive constraints. Feed rate and spindle speed were the two main factors involved in this research. Nevertheless, the research was only looking on an optimal feed scheduling along five-axis tool-path without violating the limits of the drives, which leads to more accurate CNC performance and reduced machining time. The result obtained shows that the machining time can be significantly reduced by optimizing the feed along the tool-path while respecting velocity, acceleration and jerk limits of all five drives. Meanwhile, Chu et al. [2] investigated on improving the machining accuracy in five-axis flank milling of ruled surfaces. The obvious different that can be seen from the designed shape was the convex shape cutting movement. In their design, mainly was concave cutting movement without any convex cutting movement taking place. Furthermore, the most recent research found related to the flank milling machining was done by Ramy F. Harik, Hu Gong and Alain Bernard [3]. They agreed that the flank milling is very important in machining of aircraft structural parts, turbines, blades and several other mechanical parts. Besides, they also stated that the flank milling developable ruled surfaces do not contain geometrical errors.

Surface roughness also affects several functional attributes of parts, such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating, or resisting fatigue. Therefore, the desired finish surface is usually specified and the appropriate processes are selected to reach the required quality. Boothroyd and Knight [4] reported that several factors will be influence the final surface roughness in a CNC milling operation are (i) the ideal surface roughness is a result of the geometry of tool and feed rate and (ii) the natural surface roughness is a result of the irregularities in the cutting operation. On the other hand, Mike S. L. et al. [5] have developed techniques to predict the surface roughness of a product before milling in order to evaluate the fitness of machining parameters such as feed rate or spindle speed for keeping a desired surface roughness and increasing product quality. Feed rate was the most significant machining parameter used to predict the surface roughness in the multiple regression models. Furthermore, John L. Y. and Joseph C. C. [7] proposed a systematic approach for identifying optimum surface roughness performance in end milling operations. Taguchi parameter design was used as the main approach of the design. This approach also used in identifying the significant processing parameters and optimizing the surface roughness of end-milling operations.

Most of the works or researches so far have focused on point milling or face milling. Considering the existing researches done in flank milling, most of researchers spent more attention on the tool path generation, positioning and optimization of machining accuracy. It is really seldom to get research in flank milling that concentrating on the end result of the machining as what is going to be presented in this paper.

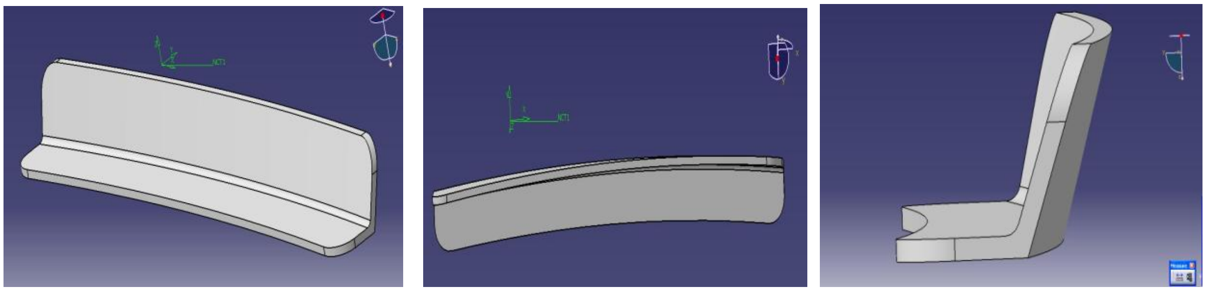


Figure 1: Part or CAD model selected in isometric, top and side views

2.0 RESEARCH METHODOLOGY

In general, the overall research activities started with preparation of the part modeling which was assisted by Computer Aided Design (CAD) software. The edited and modified part modeling was then gone through a process called machining programming which was assisted by Computer Aided Manufacturing (CAM) software. The completed program was post processed and transferred to the Computer Numerical Control (CNC) machine center to perform the actual machining. Actually, the model chosen was an actual aerospace part. Figure 1 illustrates the CAD model that was modified from three different views namely isometric, top and side view.

Before preparing the CAM program for the CAD model shown, some preparations need to be done. The preparation processes mentioned were a stock creation, machining axis positioning, plane system, and jig or fixture assembly. “Advanced Machining” workbench in CATIA V5 was the main interface or also known as workbench that had been utilized to create and generate the five-axis machining programs (CAM). In preparing the CAM program, the front and the back wall surface were finished by using the “*multi-flank contouring*” process with spindle speed and feed rate specified accordingly. The following step which was the most important part called post processing phase. The initial data required was called “APT. source” format. The output of the NC format which is posted by the post processor must be a readable format understood by the controller such as “ISO”, “EIA” or “.H” format.

On the other hand, the cutting tool used for this research were two types of end mill diameter 10 mm namely extra long (long series) tool and standard end mill with ground shank. Basically, extra long (long series) tool is very useful in machining deeper contour or profile where is not accessible by normal or standard series of tool. Despite the advantage of this tool, there are number of disadvantages that can be stated. Firstly, the cost of the tool is definitely more expensive than typical or standard tool because of the extra flute and overall length of the tool. Secondly, in actual industrial practices this tool always used as the final finishing process which means there are normally two or more machining processes involved where the normal tool is used in initial stage before the long series tool does the finishing. The ground shank tool is then initiated to overcome the disadvantages of the long series tool mentioned before. In general, ground shank tool is a normal or typical series cutting tool with standard flute length offered by the tool’s manufacturers in their catalogues. There is minor adjustment made to the shank diameter by grinding out a few millimeters to ensure that the shank will not be rubbing up the work piece during machining. Obviously if the ground shank is able to perform as good as the long series tool does, there will be a great savings for the industry. Hence, this research is initiated to investigate the performance of both tools. In grinding the shank of the tool, there are number of methods available. Figure 2 shows the cutting tools used in this research as mentioned above.

Figure 2: The physical comparison of the long series/full flute and ground shank end mill

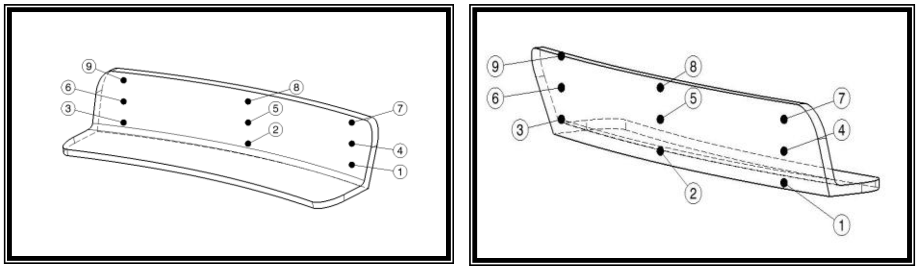
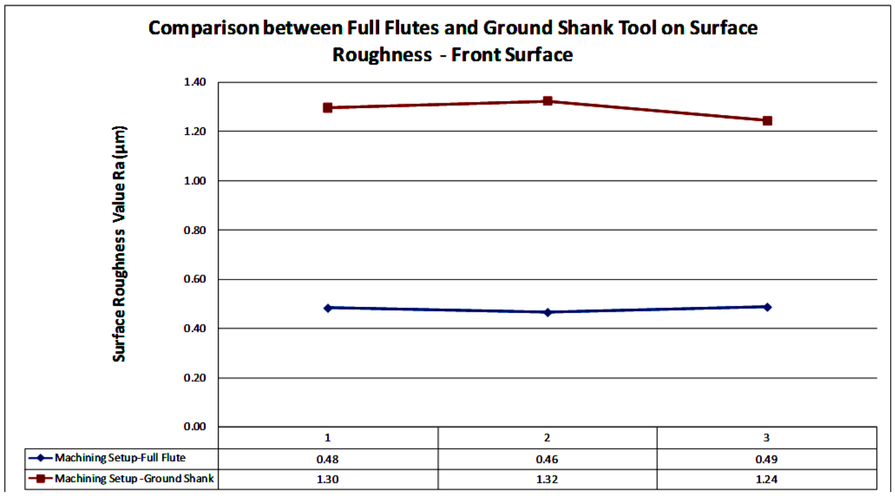
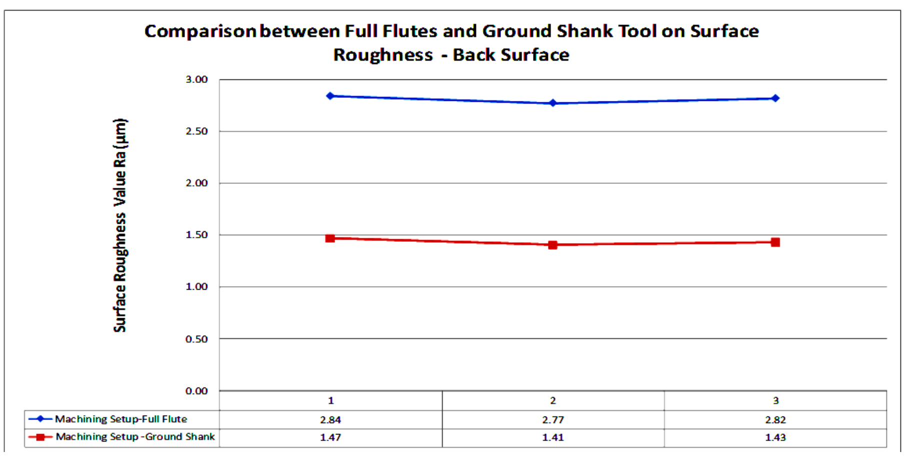


Figure 3: Points taken for the analysis on the *back and front side* of the machined part



(i)



(ii)

Figure 4: Comparison of surface roughness data for the (i) front surface (ii) back surface

3.0 RESULTS AND DISCUSSION

There were nine points taken in every side of the sample parts which were categorized into front and back side for further analysis of the surface roughness. The first three points were taken at the beginning of the part where the cutting tool started to approach the work piece. Meanwhile, another three points were located in the middle of the part. In this section, the tool was assumed to be in steady state whilst cutting the material. The last three points evaluated were at the end of the part where the last position of the tool before leaving the work piece. All the points taken as previously described were illustrated by Figure 3 below.

3.1 Comparison on Surface Roughness Data Analysis

The comparison results of the surface roughness analysis for the front and the back surface of the machined part are shown in the following figures.

Figure 4 above indicates the result obtained from an equal comparison between full flute and ground shank end mills on the front and back side of the sample parts. The Y axis represents the surface roughness value (Ra) in µm. Meanwhile, the X axis represents the average values for all nine (9) points taken for the front and the back side. The blue line indicates the result for full flutes tool whereas the red line for the ground shank tool. There are three time replications taken for each of sides respectively. The spindle speed applied was 4500 rpm and the feed rate was 1000 mm/min. According the graph above, it is clearly shows that the full flute end mill shows better result than the ground shank end mill on the front side but not for the back side of the curved shape profile. The opposite result happened on the back side where the ground shank end mill indicates better result than the full flute. One of the factors that may contribute to the mentioned results was the length of the reachable flute which related to number of paths involved in the finishing process. Obviously the full flute end mill has longer reachable flute. Thus, the cutting or finishing process to the respective surface can be done from the first path of the first level to the last path of the final level continuously. On the other hand, the ground shank end mill was not able to perform the same process since the reachable flute length was shorter and the shank diameter was smaller than the flute diameter. Therefore, there were areas which not able to be reached in the last level especially the top area as illustrated in Figure 5 below.

Meanwhile, the opposite result happened on the back surface where the ground shank end mill indicates better result than the full flute is probably caused by the overall tool reach needed in order to machine the back surface was longer than required to machine the front surface. The longer the tool reach leads to higher chatter and vibration in machining. Chatter and vibration in machining is partly depending on the overall length or the flute reachable length of the tool. The longer the flute or overall length of the tool will encourage higher vibration or chatter occurrence in machining [8]. In addition, the final depth or the final level in machining the back surface has two contact points of cutting which were bottom or face and wall or side area. Whereas, for the front surface it was only one contact cutting point which was the wall or side of the end mill. More contact point of cutting definitely increases the cutting forces needed in removing the material. An increase in cutting forces would degrade or reduce the surface finish [9]. Higher cutting forces increase the possibility of getting higher chatter and vibration which is depends on the total length of the tool as well. Chatter is one of the major limitations on productivity and part quality even for high speed and high precision milling machines. Chatter vibrations develop due to dynamic interactions between the cutting tool and work piece, and result in poor surface finish and reduced tool life [10]. Figures below indicate the difference of required length to machine the front and the back surface as well as the contact points occurred during machining the curved shape profile for both sides.

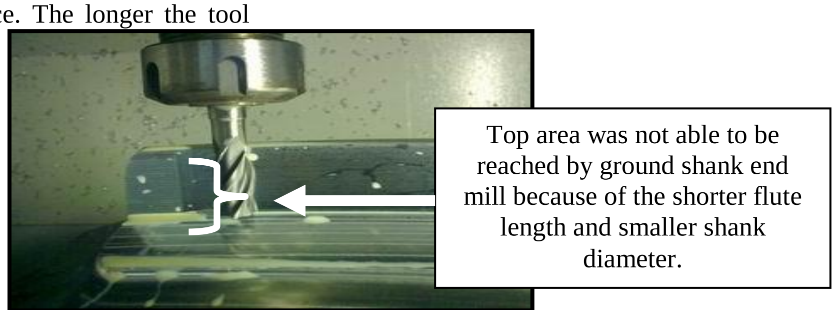


Figure 5: Ground shank end mill at the final path of the last level on the front surface area

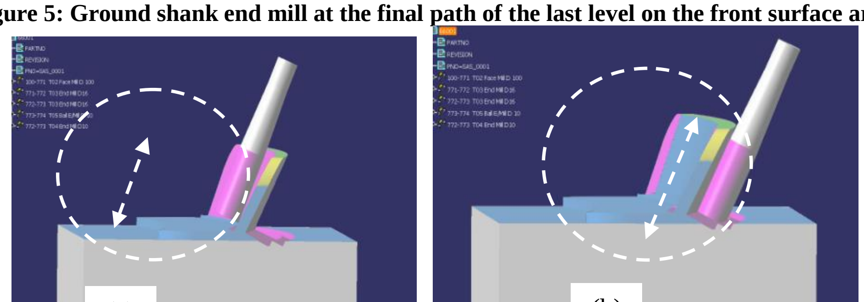


Figure 6: Arrows show the total length required in final level finishing (a) front surface and (b) back surface

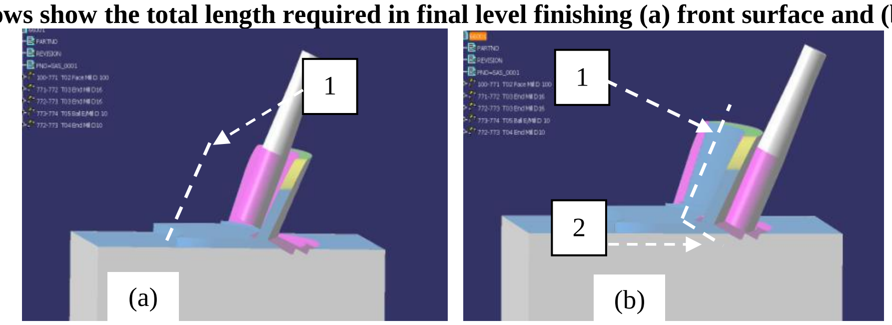


Figure 7: Arrows show the contact point(s) of cutting (a) front surface and (b) back surface

4.0 CONCLUSION

In this study, the impact of cutting tools' geometry variation namely extra long or full flute end mill and ground shank end mill to the surface finishes are observed and evaluate. According to the equal comparison made between both types of cutting at the same machining parameters applied, the results indicate that the full flute end mill shows better result than the ground shank end mill on the front surface but not for the back surface of the curved shape profile. The opposite result obtained for the back side of the curved machined part where the ground shank end mill indicates better result than the full flute tool. Among possibilities which contributed to the mentioned results were the overall reachable tool length differences and the number of contact point occurred during machining. Longer reachable tool length was required on the back surface than the front surface. The longer the tool reach leads to higher chatter vibration in machining which will caused poorer surface finish. There were two contact points of cutting involved on the back surface which were bottom area as well as wall area while there was only one contact cutting point for the front surface which was the wall or side of the tool. More contact point of cutting increases the cutting forces required in removing the material. An increase in cutting forces would degrade or reduce the surface finish.

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