THE EFFECT OF SURFACE FINISH BY VARYING MACHINING STRATEGIES OF FIVE-AXIS FLANK MILLING FOR CURVY ANGLED CONVEX PROFILE

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ABSTRACT: The main aim of this research is to identify the best machining strategy on the five-axis flank machining curvy angled shapes using various machining approaches or strategies offered by CATIA V5 software. In machining of curvy angled shapes, the most important factor is to obtain the exact shape or machined part in certain acceptable tolerance with good surface finish. Hence, applying the right and the best machining strategy in Computer Aided Manufacturing (CAM) process is the most vital phase. The machining strategies that have been applied were Tanto Fan, Combin Tanto and Combin Parelm. In this study, only convex shape is analyzed throughout the study. Each of every machining part has been gone through a thorough analysis of surface finish by using Mitotuyo Surf-tester to determine the effect of the surface finish. Meanwhile, the parts chosen to be machined was modified aero-structural component part using the same aerospace standard material, Aluminum A6063. Based on the analysis carried out, the best machining strategy for the sample chosen part was Combin Parelm according to the mean Ra values. Factors contributed to the results obtained are further discussed in this paper.

KEYWORDS: *Five-Axis Flank Milling; Machining Strategies; Surface Finish; Convex Angle Shapes*
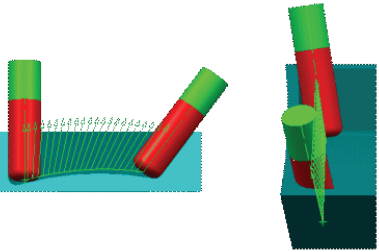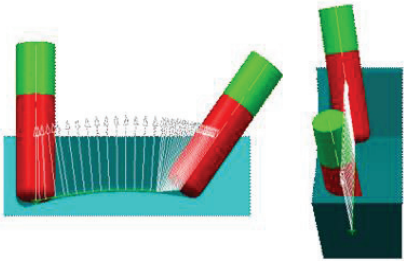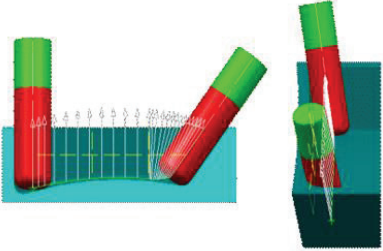
1.0   INTRODUCTION

Five-axis CNC machining has been commonly used in manufacturing of complex geometries in automobile, aerospace, energy, and mold industries. This advanced machining operation provides better shaping capability and higher productivity compared to traditional three-axis machining. The 5-axis machining operation contains two different milling methods: end milling and flank milling. The cutting edges near the end of a cutter perform the actual material removal in end milling while the circumferential part of a cutter mainly does the cutting in flank milling.

There were numbers of researches focusing on machining strategies but very seldom to see researchers focusing on flank milling strategies. Yet, very few studies found focusing on the end results of machined parts. Thus, this research initiated to investigate the effect of machining strategies that are offered by CATIA V5 by focusing on the end results of convex flank shape utilizing five-axis flank milling strategies. Milling process has been one of the most widely used for metal removal processes [1]. Realizing the gap in the extant literature, more researches are needed for 5-axis machining of flank milling. In the previous study, mathematical understanding of flank milling is proposed which was used to develop a method for milling [2]. Furthermore, another study carried out on flank milling but applying different approach called dynamic model as simulation for flank milling. In the final result, a formula for obtaining the ruled surface was successfully derived [3]. On the other hand, advanced PSO algorithm was then utilized to optimize the tool path planning in 5-axis flank milling [4]. Most of mentioned studies were focusing more on fundamental or theoretical of flank milling without really emphasize on the final result of machined parts.

To address these gaps, a study on 5-axis flank milling has been conducted by comparing the tool path movement in CATIA V5 namely Tanto Fan, Combin Tanto, and Combin Parelm. The definitions given by CATIA V5 were too general especially for common users to determine which strategy is the best to be selected in machining certain angled shapes. Table 1 shows the definition provided by CATIA V5. From the Table 1, it is hardly to understand and differentiate those given three strategies. Moreover, the diagram

illustrates almost the same motion of the tool path. To the author best knowledge, although CATIA V5 is able to perform simulation for CAM, deciding which the best machining strategy to be used is still a big question. Sometimes, the simulation seems to be perfect but the real end result of the machined part indicated the opposite way.

Table 1: Definitions of chosen machining strategies described by CATIA V5 [14]

Flank Strategy	Definitions	Diagrams
Tanto Fan	The tool is tangent to the drive surface at a given contact height, and the tool axis is interpolated between the start and end positions.	
Combin Tanto	This strategy combines three phases: • Tool fans over a given Leave distance • Tool is tangent to the drive surface at a given Contact height and is contained in a plane normal to forward direction • Tool fans over a given Approach distance.	
Combin Parelm	This strategy combines three phases: • Tool fans over a given Leave distance • Tool is tangent to the drive surface at a given Contact height and follows the surface isoparametrics. • Tool fans over a given Approach distance.	

2.0 EXPERIMENTAL

To demonstrate the potential of this approach and its suitability for the application, an actual three-dimensional (3D) Computer Aided Design (CAD) model aerospace part is selected as shown in Figure 1. A few modifications on the CAD model are made to fit with the scope of

study by utilizing CAD software. The modified CAD model was then gone through Computer Aided manufacturing (CAM) to obtain machining programming code. At this stage, the three machining strategies namely Tanto Fan, Combin Tanto, and Combin Parelm are applied. The completed machining was post processed and transferred to Computer Numerical Control (CNC) machine center for actual machining. In the physical machining process, facing process was done by using Face mill diameter 75mm. Meanwhile, end mill diameter 20 mm is used for Roughing process. On the other hand, for multi-axis flank contouring process, ball mill radius 5 mm is utilized. In order to obtain better surface finish, machining tolerance was changed from 0.1mm to 0.01mm instead. The parameters such as depth of cut, spindle speed and feed rate are the constant variables in this study. The spindle speed applied was 6500 rpm and the feed rate was 1100 mm/min with maximum depth of cut was set to be 1.5 mm for every machining cycle. The total duration taken to completely machine one sample was approximately 54 minutes. The final phase was the surface roughness analysis done by utilizing Mitutoyo Surface Roughness tester (MJ-410) to obtain the arithmetic average (Ra) value. All the data obtained are shown in the results and discussed in the following sections.
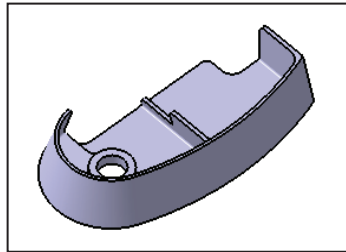

Figure 1: The chosen CAD model (courtesy of Unigraphics-NX)

3.0   RESULTS AND DISCUSSION

Generally, the reference indicates the quality of surface roughness in this research is measured by the Ra value. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging it over the entire cut-off length. There were three points taken in every side of the sample parts which been using for further analysis of the surface roughness and labelled as A, B, and C.

Figure 2 illustrates the location of the points taken as mentioned earlier and how it was measured.

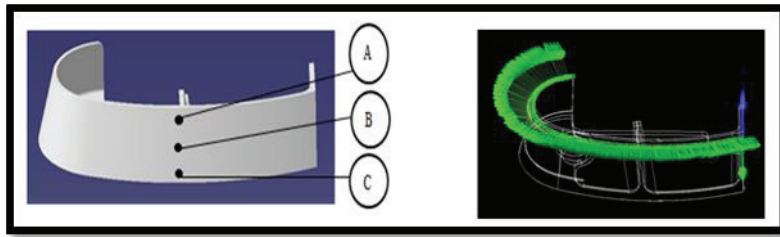(a)   (b)

Figure 2: (a) Measuring location and (b) how it measured

The measurement was taken five times for each of every point. Each reading was taking based on the Ra (µm) value given by the surf-test equipment.   Then, the Ra (µm) values are then recorded and compared with others machining strategy. On other hand, the Table 2 exhibits the ranking of the best machining strategies according to the mean of Ra value. Meanwhile, Figure 3 indicates the final machined sample parts of flank milling with different strategies.

Table 2: Ranking of the best machining strategy according to the mean value of surface roughness

Rank	Type of machining strategies	Mean (µm)
1st	Combin Parelm	0.349
2nd	Tanto Fan	0.413
3rd	Combin Tanto	0.503

Figure 3: Machined parts of flank milling strategies

The mean of the Ra value at all points for all machining strategies

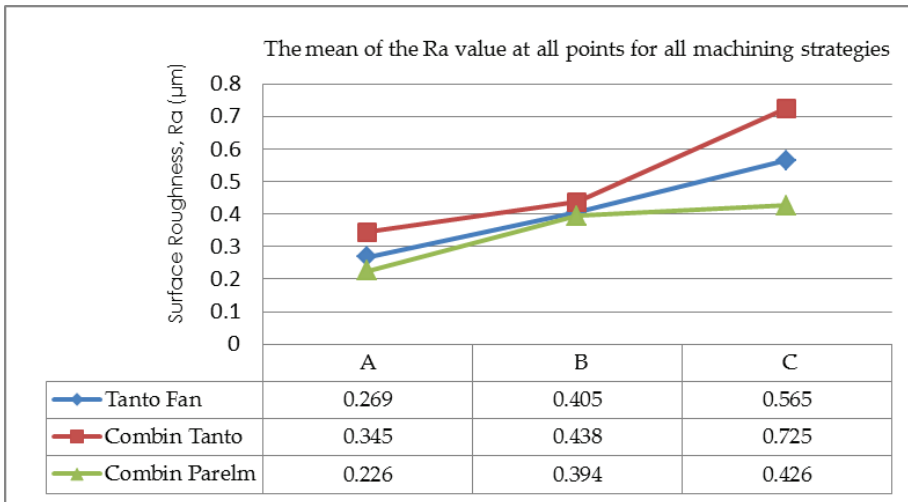|	A	B	C
Tanto Fan	0.269	0.405	0.565
Combin Tanto	0.345	0.438	0.725
Combin Parelm	0.226	0.394	0.426

Figure 4: Mean Ra values of point A, B and C for all chosen machining strategies

Figure 4 illustrates the mean surface roughness values represented by Ra value at all points for the chosen machining strategies. Referring to the numbers shown by the point A, B and C, it is obviously seen the best surface finish among the three machining strategies is in the A section, followed by B and finally C section. The trend of the Ra mean value exhibits gradual increases from the point A to point C. The main reason contributed to this result is strongly believed due to the machining tool paths which are travelled repeatedly on the same location since the strategy used in machining was waterline steps strategy. This strategy applying constant depth of cut which was set at 1.5 mm in per level this case is begin from the top to the bottom area. On the other hand, point C is located at the lowest area which possibly increases cutting forces during machining due to more than one machining contact points occurred at the same time namely the wall and bottom area. Higher cutting forces increase the possibility of getting higher chatter and vibration which is depends on the total length of the tool as well [3].

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 [16]. Roughness measurement data was subjected to statistical treatment in order to more thoroughly characterise the

effectiveness of the machining strategies. The rank was calculated by the value of the Ra in statistical surface roughness controller. The finding provides that the machining strategy of Combin Parelm as exhibited in Figure 5 showed the finest surface finish followed by Tanto Fan and Combin Tanto.

Combin Parelm is one of the strategies which the tool axis is moving tangent to the drive surface at the specified contact height and follows the isoparametric of the surface. Isoparametric curves are lines running along the surface in the U and V directions. When the cutter follows the isoparametric curve, the surface will be well formed and produced better surface finish. It is obviously different from Tanto Fan and Combin Tanto strategies where the tool only tangent to the drive surface and cutting with forward direction.

Figure 5: Combin Parelm strategy gives the best surface finish

4.0   CONCLUSION

The findings of this study highlight that Combin Parelm offered the best surface roughness in machining curve angled convex profile as chosen in this study. The main reason affecting this result is believed due to the difference of cutting tool trajectory while performing the flank milling which also closely related to the machining chatter caused by variation of cutting forces whilst machining. Furthermore, Combin Parelm is one of the strategies that the tool axis is tangent to the drive surface at the specified contact height and follows the curve line isoparametric of the surface smoothly.

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