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3 AXIS CNC MILLING TOOL PATH STRATEGY FOR MACHINING SPHERICAL SURFACE

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Abstract

CNC milling machines are widely used in the die and mould industry especially 3-axis CNC machines. Die and mould usually involves complex shapes on its surfaces and in its cavities. Spherical surfaces are among the hardest surface to be machined using 3-axis CNC milling. Despite the fact that die and mould making industry equipments is ever evolving, it still requires manual labour for finishing process. This is due to the burrs created during machining process, particularly milling operation. Burrs occur when the cutting tool does not manage to completely machined the required area because of problems like step over, sharp corners, complex shape, etc. Several studies on different approaches have been done to counter this problem. This particular study concentrates on tool path strategy planning and aims to select the best tool path strategy for machining the part designed. Tool path or cutter path is the series of movements made by the tip of a cutting tool. A good tool path strategy should impart specified surface finishes and achieve acceptable metal-removal rates and tool life. The method used in tackling this problem is by applying different cutter path strategies to machine the same part designed and selecting the strategy with the best surface finishing. In this study, parallel lace, an EdgeCAM tool path is used. This tool path is then conducted using three strategy conventional, climb and optimized. The machined parts were later analyzed by measuring machining parameter; surface roughness, tool wear and machining time. Using the result from this study, ANOVA was done to analyze the best tool path strategy. Based on the analyses, the optimum cutter path strategy selected was optimized parallel lace.

Key word: tool path strategy, spherical surface, CNC milling, die and mould making, 3-axis CNC

1. Introduction

Precision machining is all about metal cutting process that produces high quality product with low tolerances. End milling process is one of the most commonly used in precision machining [1] which is often utilized in die and mould making industry. Nowadays, mould and die makers are faced with challenges to reduce costs, optimizing machining time and ultimately boosting productivity [2].

Based from figure 1.1, die manufacturing involves a lot of complex shapes that takes up a lot of time, and will lead to higher cost. Jasywal and Taufik [3] suggested in their study, optimizing cutter path strategy might resolve the challenges faced by die and mould maker mentioned above. As die and mould production involves many complex shapes, it requires proper selection of cutter path strategies to ensure a more optimized machining process.

Figure 1.1: Current die manufacturing process sequence

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Aside from optimizing cutter path strategies, another costly aspect related to milling complex shape is the need to polish or grind a part manually after machining process has been completed. Referring to the following figure 1.2, Fallböhmer *et. al.* [4] study shows that polishing time constitutes 20-30% of total manufacturing time in die production.

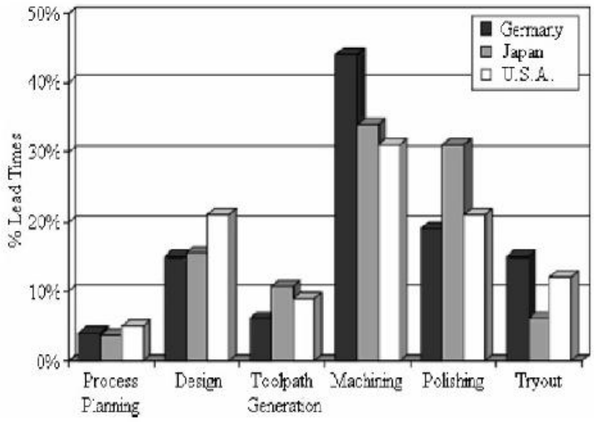


Figure 1.2: Lead Time in Die Manufacturing [4]

Many researchers have conducted studies in improving die and mould making in machining complex shape. Most of the research work and published information related on machining mould and die material only concentrated on conventional milling condition (low cutting speeds, low feed rates, low depths of cut, etc.). However, another aspect in milling complex shapes that could be taken into consideration is its cutter path strategies. Besides that, finishing process such as grinding or polishing manually not only increase cost, it affects the parts accuracy as well.

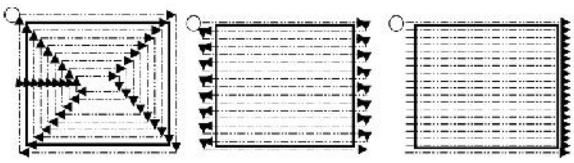
In order to optimize the machining process and to obtain a finished part without additional processes, proper selection of cutter path strategies must be taken into account and should not be neglected. Current CNC milling processes have defined several operation strategies or the algorithm for milling. The names for these strategies differ for every CAM software, but the path is very much similar. Among the algorithm names used are lace, inward helical, outward helical, back and forth, part one way and offset of zig-zag.

Based on the current technique to manufacture a die, the ultimate improvement should be done is on cutter path strategy planning. The purpose of this research is to study the output of machinability parameters; surface roughness, tool wear and machining time under different cutter path strategies/ algorithms applied in milling process for complex shape parts.

2. Literature Review

An efficient method of tool path generation will contributes to the current manufacturing industry. Better and shorter tool traversing paths used in machining the same workpiece with the same equipment and cutting parameters can reduce not only machining time, but also tool wear and the risk of tool breakage. Most machining processes often require secondary operations such as edge finishing to improve the part's form and function. The cost of the edge finishing operation can be significant, but is often neglected by part designers and process planners. In many cases, it is possible to avoid edge finishing process if the part's edge quality is taken into consideration during part design and process planning stages. In milling, it has been known that when the tool leaves the part while removing work material, burrs are likely to form.

Cutter path strategies in milling have evolved over the years. In general, they can be classified into three main strategies namely offset, single direction raster and raster strategies [5] which are shown in figure 2.1.



(a) (b) (c)

Figure 2.1: (a) Offset, (b) raster and (c) single direction raster cutter path strategies.

A lot of studies have been done regarding the many aspects involved in CNC milling process. Tsui and Chan [2] researched for an efficient NC tool path planning approach, which is by reducing and stabilizing the cutting load in NC milling operation. This in turn will reduce the adverse effects caused by excessive undulation of milling tool path. Dotcheva and Millward [6], generates CNC tool paths which is more efficient using simulation modeling. This study concentrated on planning the finishing process when end-milling a pocket-type feature part. This is done by optimizing mechanisms that affects dimensional tolerance such as

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cutting force and cutting tool deflections. Daneshmand *et. al.* [7], investigates the optimal tool path for its sample part based on its machining time. Soepardi *et. al.* [8], studied the most optimized way to machine triangular pocket. In this study, the steps in the inner portion and corner portion stage are reduced, which shorten the length of the cutter path. Song [9] research was on finishing surface quality when machining was done by applying contour – parallel path interval when using cutter path strategies such as contour-parallel method, parallel cutting method, shape cutting method, contour - shape cutting method and profile transition method. Flavius *et. al.* [10] studies the time improvement of machining a complex cavity shape by using CAM softwares compared to traditional method.

This study used one of the cutter path strategy in Edgecam Advanced Machining software, which is parallel lace. EdgeCAM is an industry leading CAM solution for production machining. Parallel lace is perhaps the most selected finishing for surface operation in Edgecam. It is versatile as several factors such as step over, cusp height, cut increment, and maximum and minimum angle of cut can be controlled. Parallel lace control the cut direction relative to the angle of the surface. This cycle takes parallel cuts along the part, and allows for optimum, climb or conventional approaches.

3. Methodology

The method used for this research is end milling process for a complex design using different mill type, namely climb, conventional and optimized for finishing cutter path strategy, parallel lace.

Computer numerical controlled (CNC) machining requires a part program being developed before machining process can proceed. This program will define the cutting tool path needed for a certain design. In order to produce this program, first, the part need to be design using computer aided design (CAD) drawings. Next, this drawings are converted into a computer aided manufacturing (CAM) machine input format. Commands that will instruct a specific machine to follow the tool paths that were created during the CAD/CAM phase of design are defined in this program.

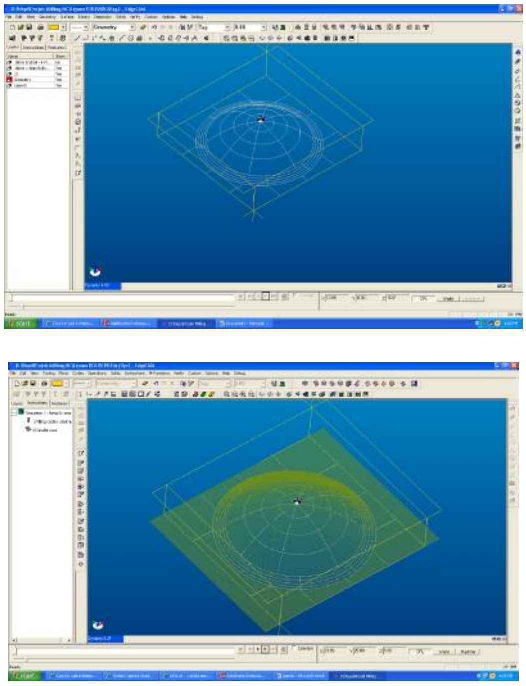
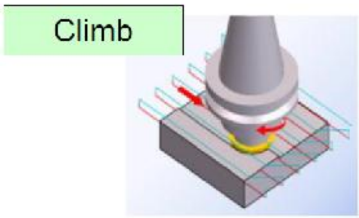
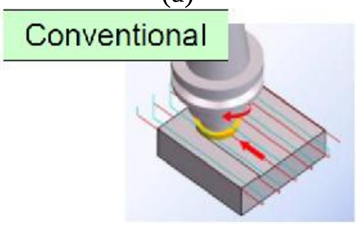


Figure 3.1: The initial drawing of the part in EdgeCAM

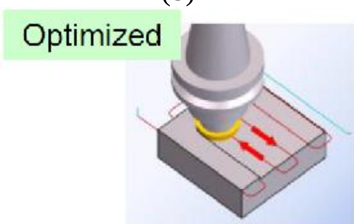
Based on the part drawn, software limit and machine capabilities, the cutter path chosen is parallel lace. After selecting the strategy, the drawing for all three mill type; climb, conventional and optimized is generated individually. The following figures show the different mill type available for parallel lace strategy in EdgeCAM:



(a)



(b)



(c)

Figure 3.2: Milling types for cutter path strategy: (a) climb; (b) conventional; and (c) optimized

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The following flow chart summarizes the procedure used for this study:

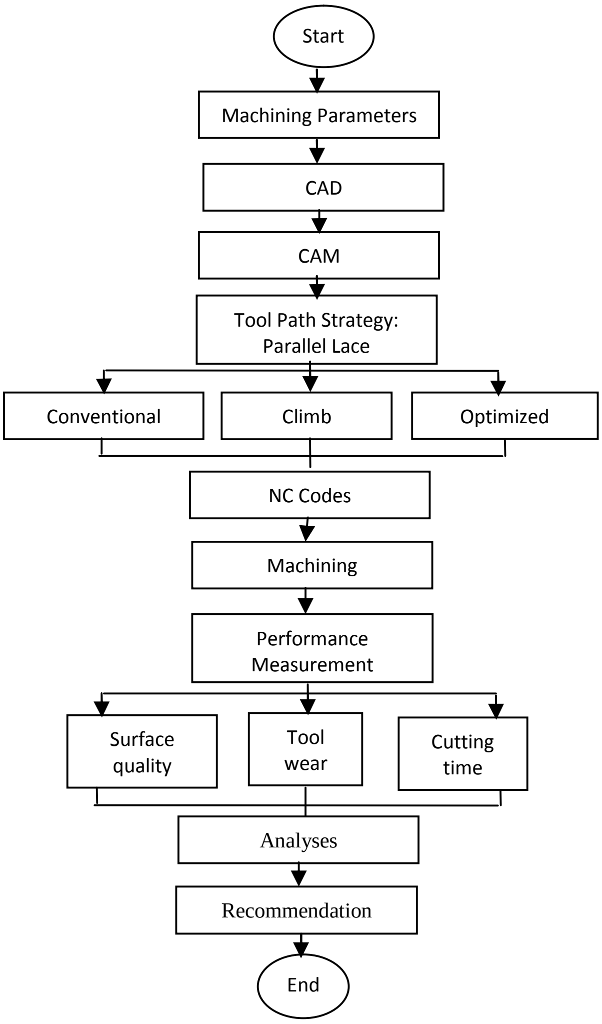

Figure 3.3: Research Flow Chart

4. ANALYSIS

ANOVA analyses were generated using Design-Expert V6 software. One factor plot graph is generated to display a plot containing all the response data and the average value at each level of the treatment (factor). This plot gives an excellent overview of the data and the effect of the factor levels on the mean and spread of the response. The squares in this effects plot represent predicted responses for each factor level (cutter path strategy).

Based from figure 4.1, the best cutter path strategy that produces minimal surface roughness is climb milling. Figure 4.2 shows that the best cutter path strategy that produces minimal tool wear is climb milling and figure 4.3 shows that the best time is obtained when using optimized milling.

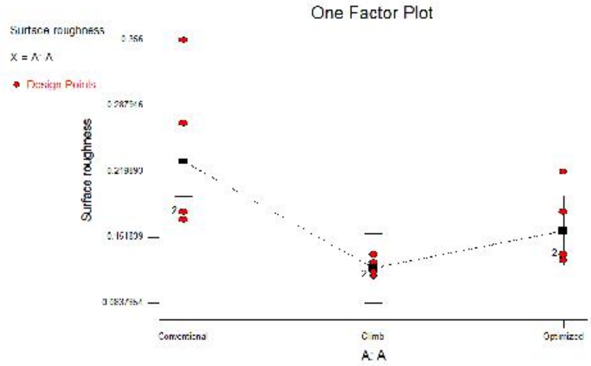

Figure 4.1: The main effect of cutter path strategy on surface roughness.

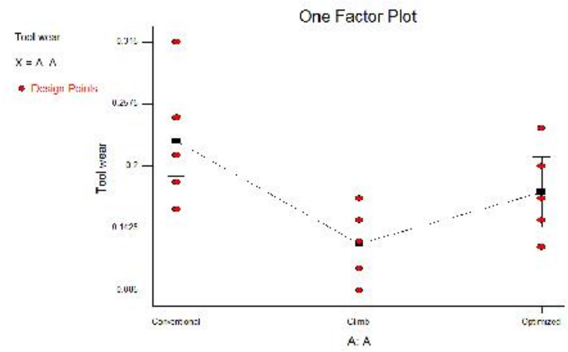

Figure 4.2: The main effect of cutter path strategy on tool wear

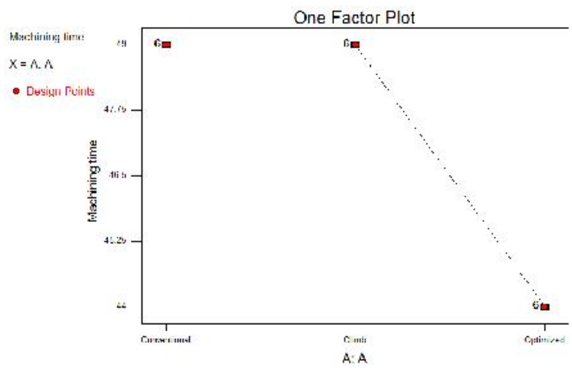

Figure 4.3: The main effect of cutter path strategy on machining time

Ultimately, after analysing the statistical data and graphical diagnostic, it comes down to the crucial phase of numerical optimization. Before ANOVA can propose anything, the optimization parameters must be assigned. For this experiment, all three response are set according to priority:

(i) surface roughness,
(ii) tool wear, and
(iii) machining time.

Desirabilities range from zero to one for any given response. The program combines the individual desirabilities into a single number and

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then searches for the greatest overall desirability. A value of one represents the ideal case. A zero indicates that one or more responses fall outside desirable limits. Design-Expert uses an optimization method developed by Derringer and Suich. The following table shows the constraint for optimization by the software:

Table 4.1: Constraint for optimization

Constraints Name	Goal	Lower Limit	Upper Limit
A	is in range	Conventional	Optimized
Surface roughness	minimize	0.112	0.356
Tool wear	minimize	0.085	0.315
Machining time	minimize	44	49

The following table 4.2 is the suggestion made by software, which shows optimized cutter path strategy has the highest desirability;

Table 4.2: Selection

Tool path strategy	Surface roughness	Tool wear	Machining time	Desirability
Optimized	0.1588	0.176	44	0.774

5. CONCLUSION

Based from the data collected and result of analysis, it can be concluded that cutter path strategy does have significant effect on machining a 3D complex shape. All three machining parameter studied, also, exhibits significant relationship with the cutter tool path strategy. The three parameter importance in this study, are in the following sequence, surface roughness, tool wear and machining time. The lowest surface roughness was produced by climb milling, followed by optimized and conventional milling. Tool wear effects on the three cutter path strategies, also, shares the same result, which is, climb milling followed by optimized and conventional milling. The third parameter, machining time, shows that the shortest machining time belongs to optimized milling, while both climb and conventional milling share same machining time. This is because climb and conventional milling share the same algorithm that differs only at the entry point and feed direction. Overall, the cutter path strategy that fulfils all the machining parameter is optimized milling. Selecting the best cutter path strategy will depend on the requirement priority.

As this study concentrates on one cutter path strategy, there are still more discovery could be made on the effects of cutter path strategy in surface operation for complex 3D shapes. Several improvements on area of study can be pursued:

- Latest CNC machine
  Nowadays, there are many CNC machine is being produced, that has superior technology which could be use in machining complex shape. A more advance machine will provide more solution for machining complex shape, and perhaps with better and improved result.
- Latest software
  Different CAD and CAM software offers different cutter path strategies. Latest software might offer even more option, not only for the cutter path, but also taking into consideration the complex shape that will be machined.
- Coated tool
  Even though, the tool used is solid carbide, but it still experience wear and chipping after only a couple of runs. Coated tool might offer higher durability ensuring wear defects happen much later, and in turn ensure a better surface finish for the part.
- Lubrication
  This study used wet machining condition. There are other types of lubrication that can be taken into consideration, such as dry machining, minimum quantity lubrication, solid machining, etc. Using other than synthetic coolant is also an option, such as oil.
- Vibration
  Some studies have also shown that vibration, done rapidly can increase the surface properties. Perhaps combining vibration with cutter path strategy might produce an even better surface finish.

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