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# High Speed Machining of High Strength Aluminium Alloy for Satellite Application

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**ABSTRACT:**

*In this research tool path is generated for high speed machining of aluminium alloy.High Speed Machining (HSM) is a powerful machining method that combines high feed rates with high spindle speeds, specific tools and specific tool motion. This practice can be effective for machining intricate core and cavity geometries in mold machining, and for quickly machining large, complex aircraft structural components out of solid blocks of aluminium. The milling operation employed in the research is pocket milling. Pocket milling is a major machining process carried out in aerospace industry. They are mainly employed in isogrid panels of heat shields used in launching vehicles. The conventional sharp cornered tool path limits the feed rate of high speed machine. So a new smooth tool path is generated using mathematical method along with the help of Matlab software. For comparison of conventional strategy with the generated smooth tool path, two different pockets are machined namely each using both strategy. The machine used for experiment is Jyothi Huron machine and the tool used is Kennametal solid carbide end mill tool.*

***Keywords**: Aluminium alloy, Tool path, Pocket milling, High speed machining*

## INTRODUCTION

Pocket machining is one of the most widely used operations in machining. It is extensively used in aerospace and shipyard industries. In pocket milling the material inside an arbitrarily closed boundary on a flat surface of a work piece is removed to a fixed depth. Firstly roughing operation is done to remove the bulk of material and then the pocket is finished by a finish end mill. Most of the industrial milling operations can be taken care of by 2.5 axis CNC milling. Since pocket milling is very frequently used effective pocketing approaches can result into reduction in machining time and cost. In pocket machining, material is removed from stock, layer by layer, until pockets are formed and a manufactured part emerges. The tool path for a layer of a pocket is the centreline path along which a tool end mill is fed as its rotating teeth cut the material. In this research aluminium alloy 2014 AA is used for milling. We know aluminium has high strength to weight ratio which is an important property needed for aerospace applications. Its superior mechanical and chemical properties compared to other materials make it one of the important aerospace material. In this work it mainly focus on tool path generation for pocket milling operation of aluminium alloy.

## PROPERTIES OF ALUMINIUM 2014 AA

*Table1: Chemical Composition*

| Component | Percentage |
|---|---|
| Cr | 0.1 |
| Cu | 3.9-5 |
| Fe | 0.7 |
| Mg | 0.2-0.8 |
| Ma | 0.4-1.2 |
| Si | 0.5-1.2 |
| Ti | 0.15 |
| Zn | 0.25 |
| Al | Balance |

*Table 2: Mechanical Properties*

| | |
|---|---|
| Hardness (Brinell) | 135 |
| Yield Strength | 414Mpa |
| Tensile Strength | 483Mpa |
| Shear Strength | 290 Mpa |
| Poisson's Ratio | 0.33 |
| Modulus of Elasticity | 73.1Gpa |
| Density | 2.80 g/cm$^3$ |
| Thermal Conductivity | 154W/m-K |

## CUTTING CONDITIONS

Cutting condition is created by appropriate selection of cutting parameter values corresponding to cutting speed, feed, axial and radial depth of cut. The ranges of cutting parameters are determined using Kennametal solid carbide tool catalogue. In this study pocket milling operation is carried out. In pocket milling operation material is removed between selected boundaries. The milling operation is carried out in a wet condition. A 6% soluble oil through coolant system at 1 bar pressure and 12 litre/minute flow rate.

## MACHINE TOOL

The machine tool used in the cutting test was Jyothi Huron K2X10 which is a three axis CNC machine. The machine is installed with Siemens 840D-SL controller with updated machining cycles. This machine has a maximum rapid traverse of 60m/min and maximum work feed of 30m/min. The spindle type is electro spindle and has a maximum spindle speed of 30,000rpm.The maximum spindle torque is 86N-m. The tool measuring system is Renishaw NC-4 Laser. This machine complies with VDI DGQ 3441 standards.

**Figure 1: Three Axis Machining Centre**

## WORK PIECE

The work piece material used in the machining test was Aluminium 2014AAin T651 heat treated conditions.

- **Work piece Dimension:**
  A rectangular block of 300×215×20mm is used for machining

***Figure 2: MachinedWork Piece***

## EXPERIMENTAL DESIGN

**Table 3: Cutting Condition used for Initial Experiment**

| | |
|---|---|
| Spindle Speed (rpm) | 12000 |
| Feed Rate(mm/min) | 8000 |
| Depth of Cut(mm) | 1 |

## TOOL USED FOR EXPERIMENTAL ANALYSIS

***Table 4: Tool used for Experimental Analysis***

| Tool | Tool Diameter(mm) |
|---|---|
| Kennametal solid carbide end mill | 10 |

*Figure3:Tool used for Experimental Analysis.*

## CONVENTIONAL TOOL PATH

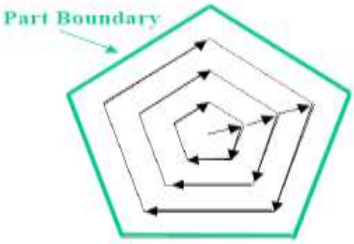


*Figure 4: Conventional Tool Path*

High Speed Machining (HSM) involves very high cutting speeds. Figure 4 shows a conventional parallel-offset tool path used to machine a rounded-cornered pentagonal pocket. In conventional path, the pocket boundary is offset inward a fixed distance, and the process is then repeated. Starting at the pocket centre, the tool moves sequentially from one orbit to next orbit. The tool has to decelerate and when comes out of a corner it accelerates again. The main problem of this is that the feed rate of high speed machine is limited by this. The solution to this problem is known by the machinists and programmers who practically have experience in machining. They know that if we can introduce curves over much of the path the feed rate can be kept almost constant and hence the machining time can be reduced. So our aim is to develop a method by which we can convert sharp corners into smooth curves so that the feed rate of high speed machine is not limited.

## TOOL PATH GENERATION

The first step is to draw the geometry of the required pocket in matlab graphical user interface. Next selecting the boundary of the geometry, the Dirichlet boundary condition is applied. Then the elliptic pde that have to be solved is defined. The equation used here is$\partial^2u/\partial x^2 + \partial^2u/\partial y^2=-1$. The reason for selecting this equation is that from literature survey I understood that the solution contours of this elliptic partial differential equation is smooth for the pocket geometry for which we solve this equation.

The next step is to generate the mesh and initialize the solution. By selecting the solve option the equation is solved and the contour plot obtained is checked for smoothness. If not smooth

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then refine the mesh and solve again. When smooth contours are obtained the x, y and u values are exported.Using the smooth contour and the algorithm developed for spiraling the path, obtain spiral path coordinate. Then using 2D contour module of CAM software, generate tool path. Then for validating the generated tool path machining can be performed at high feed and high rpm.

The matlab solution contour and path generated for the different pocket geometries are shown in figure 5 and figure 6 respectively.

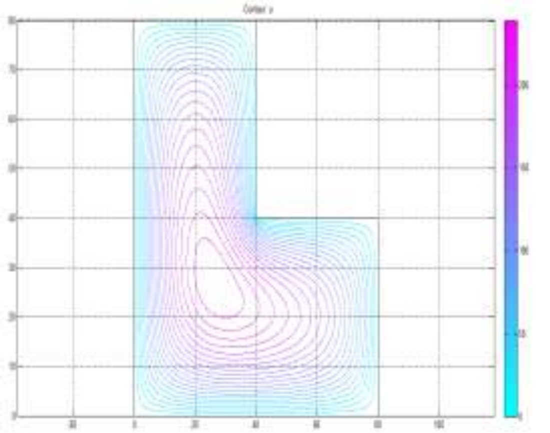

***Figure 5.1: contours of L shaped pocket***

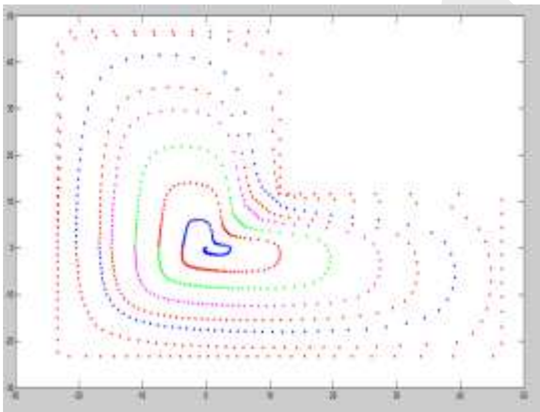

***Figure 6.1: Tool path of L shaped pocket***

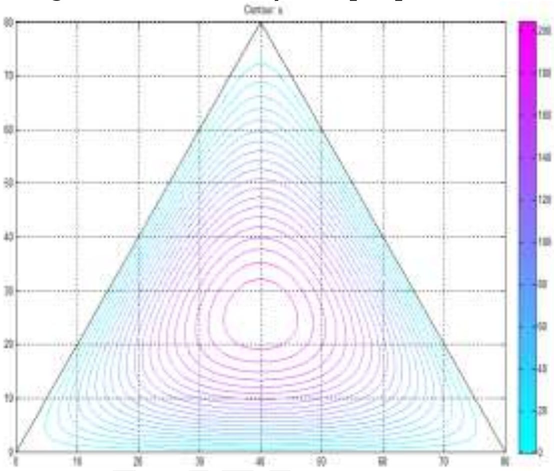

***Figure 5.2: Contours of triangular pocket***

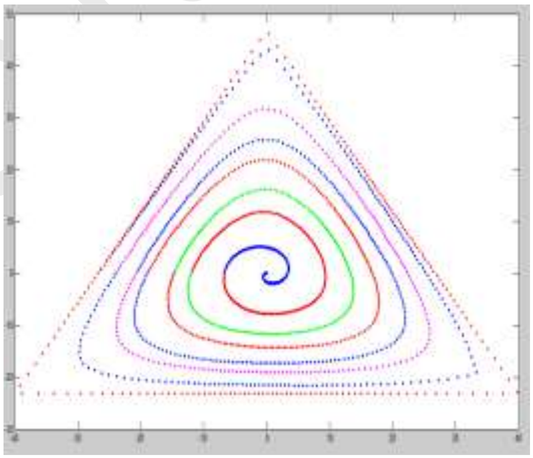

***Figure 6.2: Tool path of triangular pocket***

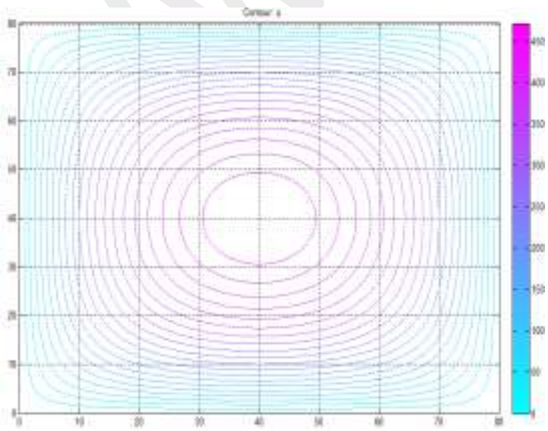

***Figure 5.3: Contours of square pocket***

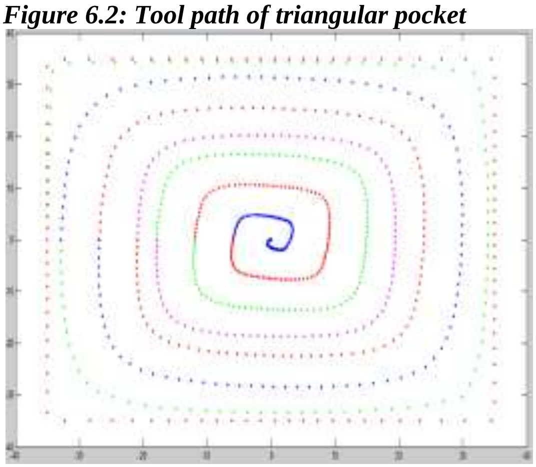

***Figure 6.3: Tool path of square pocket***

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*Figure 7: Pockets Machined Using Generated Tool Path*

Four pockets were machined for validating the tool path generated. The L shaped pocket was machined using both single contour based tool path and multicontour based tool path. In single contour method we are taking parameterized value of single contour and multiplying it to obtain the spiral path. In multi contour we are taking the parameterized value of more than two contours and using them to obtain the spiral path. From experiment it is seen that multi contour path is having more smoothness. A triangle and a square shaped pocket was also machined using the generated tool path. From this experiment it was validated that the generated tool path can be applied for machining purpose

## EXPERIMENTAL ANALYSIS

For comparing the surface finish and machining time of the generated tool path with the strategy available in hyper Mill software four pockets were machined. In the four pockets two pockets tool path was modelled using hyper Mill and other two pockets path was the generated tool path. The experiment was performed for two different shape of pockets that is L shape and Triangular pocket. First the strategy available in hyper mill software was used to generate the geometry and its tool path. Next the smooth generated tool path was used to machine the same sized pockets.

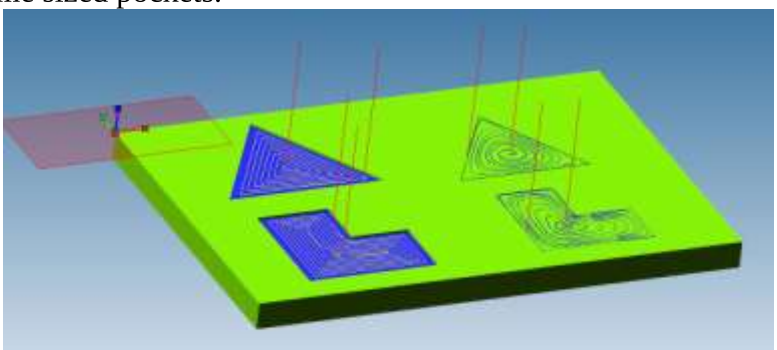

*Figure 8: Tool Path Comparison*

In figure 8 the path shown in left are the hypermill path and that shown in the right is the smooth path generated. It can be seen that the generated tool path is having smooth rounded corners.

## EXPERIMENT PARAMETERS

*Table 5 Experiment Parameters For Comparison*

| | |
|---|---|
| Spindle speed | 12096 rpm |
| Feed rate | 8056 mm/min |
| Depth of cut | 0.5mm |

*Figure 9:Machined Pockets*

The pockets shown in left side of figure 9 is machined using hyper mill generated tool path and to the right is machined using the generated smooth tool path.

## RESULTS AND DISCUSSION

The experimental conditions were kept same for the two types of tool path. Two pockets were machined namely triangle and L shaped pocket. The experiment was conducted to assess the machining time and surface finish of the generated smooth tool path. The machining time and surface finish obtained after the experiment are shown below:

### Machining time

**Table 6: Machining Time of Conventional Tool Path**

| Pocket shape | Tool path | Machining time (seconds) |
|---|---|---|
| Triangle | conventional | 16 |
| L shape | conventional | 25 |

*Table 7: Machining Time of Smooth Tool Path*

| Pocket shape | Tool path | Machining time (seconds) |
|---|---|---|
| Triangle | Smooth tool path | 15 |
| L shape | Smooth tool path | 24 |

From the experimental result it is seen that the smooth tool path requires less machining time. This reduction in machining time is due to the introduction of smooth corners instead of the sharp corner at the conventional tool path. Due to this the acceleration and deceleration of the tool is limited and the feed remains almost constant. So the feed of high speed machine is not limited as compared to the conventional tool path.

**Surface roughness measurement**

*Table 8: Surface Finish of Conventional Tool Path*

| Pocket shape | Tool path | Surface Roughness Ra (microns) | | | Average Ra |
|---|---|---|---|---|---|
| Triangle | conventional | 0.951 | 0.789 | 0.943 | 0.894 |
| L shape | conventional | 0.582 | 0.969 | 0.626 | 0.725 |

*Table 9: Surface Finish of Smooth Tool Path*

| Pocket shape | Tool path | Surface Roughness Ra (microns) | | | Average Ra |
|---|---|---|---|---|---|
| Triangle | smooth | 0.419 | 0.645 | 0.261 | 0.441 |
| L shape | smooth | 0.361 | 0.400 | 0.357 | 0.372 |

From the experimental result it is seen that the surface finish of the generated smooth tool path is much better than the conventional tool path. The reason for this is that the tool deflection is less due to the introduction of smooth corners in place of sharp corners present in the conventional tool path. So with this tool path walls with very low thickness can be machined.

**CONCLUSION**

In this work a new tool path generation strategy is developed. Here an elliptic partial differential equation is solved using Matlab. The smooth solution contours of the required pocket geometry are used to develop a smooth tool path for pocket machining. With the strategy developed tool paths are generated for different pockets and experiment is done for validating the practical applicability of the generated tool path. After validating two pocket shapes are machined using conventional and the generated smooth tool path strategy. After conducting experiment it is found that the generated smooth tool path requires less machining than the conventional sharp cornered tool path. The generated tool path can be used for machining of pockets with complex shapes. In this research it also find that the surface finish of pockets milled using generated tool path is better. The tool path can be used for other materials also.

In future work the machining time could be decreased by increasing the smoothness of the path. Optimisation of process parameters like feed rate can be performed by using the generated tool path.The whole process can be combined into a single algorithm by which the smooth tool path can be generated by simply giving the geometry of pocket.

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