Surface matrix based Machining Planes Determination for Milling Process (Roughing Stage)

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Abstract

This paper deals with machining plane determination process for CNC milling machining. Three methods, Matrix, 3D contour matrix and flow line are presented. All methods depend on the data set point of the surface matrix of the workpiece to be machined. All methods can be used to automate the CAD/CAM operation for roughing process in milling machining. Two surface examples are included to illustrate all methods. By a comparison among the three presented methods, a conclusion has been reached that the presented 3D contour matrix method requires maximum number of blocks to build G-codes program for CNC tool path programming. It means that, this method requires longer time to accomplish tool paths. On the other hand the other two methods require minimum number of blocks of G-codes and shorter time for roughing.

Keywords: CAD/CAM, CNC Milling, Sculptured surfaces

ايجاد مستويات التشغيل بالأعتماد على مصفوفة السطح لعملية التفريز [مرحلة التشغيل الأولي]

الخلاصة

تتناول هذه المقالة عملية ايجاد مستويات التشغيل لعملية التفريز باستخدام مكائن القطع المبرمجة تم تقديم ثلاث اساليب لهذا الغرض وهي اسلوب المصفوفة واسلوب مصفوفة الحدود ثلاثية الأبعاد واسلوب المسار الأسيابي جميع هذه الأساليب تعتمد على التعريف البياني لنقاط سطح الجزء المطلوب تشغيله يمكن استخدام هذه الأساليب لأتمتة عملية التشغيل بالتفريز (في مرحلة التشغيل الأولي) تم تطبيق هذه الأساليب على نموذجين من السطوح الهندسية من خلال المقارنة بين الطرق التي تم تناولها، تم التوصل الى استنتاج ان اسلوب مصفوفة الحدود ثلاثية الأبعاد تتطلب أكبر عدد من الصفوف البرمجية لأعداد برنامج الحركة لمكائن القطع المبرمجة أي ان هذا الأسلوب يحتاج زمن أطول لتحقيق مسارات القطع بينما الأسلوبين الأخرين فانهما يتطلبان عدد أقل من الصفوف البرمجية ووقت أقصر لأجراء عملية التشغيل الأولى

Introduction

In the manufacturing industry, the production cost of a part depends largely on the part's machining time. Machining parameters, such as cutters and machining planes, are typically selected to reduce the machining time and to prolong tool life. Due to the combinational nature, it has been proven to be very difficult for manufacturing engineers to select

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cutters and determine machining planes (1-4).

reduction Because any in the machining time can be directly translated into savings in production cost, it is of interest to manufacturing engineers to study such a problem (5). Most commercial CAD/CAM systems today are feature-based, and their use involves considerable operator effort and experience (6). This paper, shows useful approaches to prepare tool path machining planes for roughing milling process. Instead machining of decomposing the shape into manufacturing features (7), it is possible to generate tool paths directly from the shape of workpiece using surface matrix definition of workpiece.

The machining of sculptured surface consists of the roughing and finishing processes. Roughing is to remove excess material from a raw stock, while finishing is to remove residual material along the surface after roughing is applied. In general, the removal volume in roughing is more than the removal volume in finishing. Thus, the reduction in roughing time can considerably increase productivity, which, in turn, leads to a manufacturing lower cost (8). Therefore, this paper concentrates on the roughing stage of machining. To increase the efficiency of the roughing process, one could select the largest cutter to work on a machining plane with the cutter's maximal depth, however. due to the nature of different sculptured surfaces. machining planes have different boundary contours that limit the choice of cutters. This paper utilizes the surface's matrix to generate machining planes with different resolutions that, in turn, helps for

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applying different cutter size and shapes.

Assuming that the part is already oriented in a given setup direction, all methods to global roughing are based on slicing the component into a number of layers directly from the boundary representation, slices are generated as sequences of closed contours. Then generate 2-axis tool paths is generated using the coordinates of points, which construct each layer.

The tool paths go along the intersection curves between the surfaces and a series of parallel planes. Fig.(1) shows the main algorithm of applied methods.

In this paper, there are three methods prepared to accomplish the roughing milling process. These are, matrix, *3D* contour matrix and flow line oriented roughing methods.

Matrix Oriented Roughing:

Tool path generation for roughing could be established using either lines of rows or columns of the matrices XYZ for the workpiece surface, through the representation of heights of Z matrix as X, and rows of Z matrix as Y. Rouging is mostly done on parallel layers until a certain depth and uses high metal removal rates, therefore this approach helps to rough the workpiece surface and facilitate using flat end mill cutter and shorting the G-codes program.

The mathematical form, equation (1), of this method, (9), is based on construction of bilinear curves using interpolation of line segment:

$$\mathbf{Q}\frac{t_1 - t}{t_1 - t_2} = \frac{p(t_1) - p(t)}{p(t_1) - p(t_2)}$$

$$p(t_1)(t_1 - t) - (t_1 - t)(p(t_1) - p(t_2)) = p(t)(t_1 - t_2)$$

$$(t - t_2)p(t_1) + (t_1 - t)p(t_2) = p(t)(t_1 - t_2)$$

$$\therefore p(t) = \frac{t_2 - t}{t_2 - t_1}p(t_1) + \frac{t - t_1}{t_2 - t_1}p(t_2)\dots eq.$$

where: $p(t_1)$, $p(t_2)$: end points for line segment.

p(t): interpolated point.

t: parametric variable.

3D Contour Matrix Oriented Roughing:

The creation of *3D* contour matrix and column vector of surface could be defined on a rectangular grid, and produce contour map with nth contour levels, which also can be used as tool path lines for finishing process. Finishing process is made by tracing curves or contours on the surface as accurately and precisely as possible with limitation set by the cutter size tolerance and machine capability. The number of contour levels can be changed with the demand for accuracy of the surface.

The contouring function treats the input matrix as a regularly spaced grid, with each element connected to its nearest neighbors. To calculate the contour matrix, the algorithm scans input matrix comparing the values of each block of four neighboring elements (i.e. cell) in the matrix with the contour level values. If contour level falls within the cell, the algorithm performs а linear interpolation to locate the point at which the contour crosses the edge of the cell. The algorithm connects these points to produce a segment of contour line. To determine the heights of the contour lines with respect to a plane, the algorithm produces twoSurface matrix based Machining Planes Determination Milling Process (Roughing Stage)

row matrix specifying all the contour lines. Each contour line defined in this matrix begins with a column that) contains the value of the contour, and the number of (x,y) vertices in the .(Exponential contour line. Fig.(2) shows the basic contouring algorithm.

The math form of this method, (10), is based on considering the surface plotted on rectangular grid in u-wplane, taking values in three space, eq.(2):

$$S(u, w) = \sum_{i,j=0}^{3} \binom{3}{i} \binom{3}{j} u^{i} (1-u)^{3-i} w^{i}$$
$$(1-w)^{3-i} P_{i,j} \dots eq.(2)$$

where:

$$(0 \le i, j \le 3)$$

 $u, w \in [0,1]$

 $P_{i,j}$: control points of the surface S(u,w).

Flow Line Oriented Roughing:

This method is useful to generate tool path for 3D roughing process. In three axes sculptured surface machining the usual procedure is to determine cutter paths by indexing along the *u*-*w* parameters of parametrically defined surface, see Fig.(3). The tool follows the natural parametric flow lines of the surface.

The mathematical form of this method, (9), is based on cubic Bezier curve for each flow line, equation (3):

$$p(u) = \sum_{i=0}^{n} p_i B_{i,n}(u) \dots eq.(3)$$

where:

$$B_{i,n}(u) = \frac{n!}{i!(n-i)!} u^{i} (1-u)^{n-i}$$

 $u \in [0,1]$

n = number of control points.

 p_0, p_n : end points for curve segment.

This method would be simple to use if the entire surface consist of a single patch, see fig.(4). If the part consists of many patches this creates the possibility of accidentally gouging adjacent patches.

Results and Discussion:

To review the methods followed in the previous sections, two models drawn in a CAD system, Fig.(5), Fig.(6), have been taken. The data set for both models have been shown in table (1), (2) for models (1), (2) respectively. The applications of all methods explained in this paper are done though preparing program using Matlab platform (Matlab, R.12, V.6.0). The machining strategy may be categorized in terms of tool path generation mechanism. Some tool path generation mechanisms generate the tool path by slicing the cutter lines (CL) surface with planes. The slicing type tool paths mainly include two sub-types for three axis NC machining, one is direction parallel type, Matrix oriented roughing, Figs.(7), (8), and the other is the Zconstant contour type, (3D contour oriented roughing), Figs.(9), (10). The direction parallel type uses 'vertical planes' to slice the CL-surface, whereas the Z-constant contour type uses 'horizontal planes'. As a result, the Z-constant contour tool path is appropriate for cutting vertical or slant walls and the direction parallel is good for cutting flat areas.

By slicing the CL-surface, the contours (tool path elements) can be obtained. Usually, the slicing is performed by a number of equally spaced horizontal planes, and the distance between two consecutive slicing planes is often called a 'plane-

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step'. While the two previous methods are powerful to generate 2 axis tool path using in 2D CNC machines, the third method, flow line oriented roughing, is useful in 3D CNC machines, figs.(11), (12).

The results of applying all proposed methods have been summarized in table (3) at same machining conditions. The number of G-codes blocks as a significant parameter to show the difference between applied methods, which is reflecting the complexity of applied methods and time required to machine the workpiece.

Conclusion:

In this paper, three methods have been presented to solve the machining plane determination problem. Each method has its significant impact to reduce the total machining time for roughing process in milling machining.

From table (3), 3D contour matrix oriented roughing method requires the biggest number of blocks to accomplish the required shape. This means the smoothest roughing resultant surface can be obtained from the 3D contour method than the others. On the other hand Flow Line Oriented Roughing method represents the easiest (less number of G-codes blocks) and fastest (less required time for roughing) way to accomplish the roughing process. So that, it could be concluded that, in spite of considering roughing process as pre machining step before finishing step, applying the presented methods makes a significant change in both criterions of machining, i.e. quality of machined surface and time required to 3D machining. contour matrix oriented roughing method could

satisfy an acceptable demand of quality for the machined surface and preparing the surface to fast post finishing process. While the other two presented methods, matrix and flow line oriented roughing; reflect the major role of roughing which is fast machining and preparing the workpiece to finishing process. So that all presented methods could enhance the manufacturing process though minimizing the overall time required for machining.

This paper shows the importance of using matrix map description of the surface for representing both workpiece profile and tool paths. This kind of representation can be used later to simulate the process of machining, and to enhance verification process through graphical simulation, which depends mainly on matrix representation of workpiece surface. Another benefit of implementing these methods is easily providing all tool path points which in turn control cutting tool movements. The applied three methods can be used to approximate any class of tool paths, i.e. linear or nonlinear, because their dependency is on point data set of the surface to be machined.

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Fig.(1): Block diagram for the applied methods for the machining planes determination process for CNC milling machining (Roughing stage).





Fig.(2): Basic contouring algorithm



Fig.(3): u-w parameters of parametrically defined surface patch.



Fig.(4): Representation of surface patch.



Fig (5): Surface Representation of Model No 1



Fig.(6): Surface Representation of Model No.2.



Fig.(7): Matrix oriented tool path generation for Model No.1.



Fig.(8): Matrix oriented tool path generation for Model No.2.



Fig.(9): 3D contour plot for Model No.1. [Number of contours =



Fig.(10): 3D contour plot for Model No.2. [Number of contours =





Fig.(11): Flow line machining paths for Model No.1.



Fig.(12): Flow line machining paths for Model No.2.

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-	- 1 20, 525	2 9.52 284	- 9.035 9.09.	8.51	7.94 8.105	•» •2	5.95 5.136	4.69 4.7759	3.2) 2.235	1.V 1.VeV	0
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-	1 20, 522 1, 8)4 1, 8, 017	λ 9.52 284 149 .1.50	- 9.035 9.09. 9.09. 11.67	8.51 5.6% 7.8% 9.8	7.9% 8.105 8.214 0.37	0.13 0.12 0.303 7.614	5.95 5.134 5.735 7.787	6,89 6,759 5,010 5,019	8.2) 2.255 (.49, 1.707	1. V 1. VeV 0. 048 7. 10	0 0.0.24 . 169 1.120
	1 10, 525 1, 8 (4 13, 0 (7 1), 17	λ 9.50 1.284 1.319 11.50 15.724	9,035 9,035 9,09, 17,67 11,091	8.51 5.6% 5.8% 9.8 17.370	0.94 8.205 8.414 0.35 9.07	0.13 0.12 0.818 7.614 0.130	5,95 5,2% 5,2% 5,2% 5,2% 5,2%	e, 59 e, 7559 5, 810 5, 919 5, 919	8.2) 2.295 4.49, 1.707 1.777	1, 7 1, 757 0, 048 1, 10 3, 015	0 0.0.24 1.189 1.120 1.160
	1 10, 522 1, 8, 4 13, 677 15, 15	8 9,22 1,284 1,149 11,50 11,174 14,199	- 9.035 9.09. 17.6* 11.0* 13.037	8.51 5.6% 5.8% 6.8 17.573 11.76	7.9% 8.105 8.414 0.57 %.07 10.344	0.15 0.12 0.313 7.614 0.133 8.777	5,95 5,234 5,735 5,735 5,785	4.59 4.759 5.010 5.010 5.010 6.616	8.2× 2.2×5 4.44. 1.447 1.477 5.304	1. V 1. VeV 0. 048 7. 10 3. 013 8. 854	0 0.0.24 1.780 1.780 2.2536
	10, 525 1, 8, 62 1, 8, 62 1, 7, 77 15, 15 16, 0, 8	8 9.50 1.284 1.309 1.30 17.724 14.109 15.117	9.035 9.09. 9.09. 11.6* 11.0* 13.037	8.51 5.6% 5.8% 6.8 17.575 11.76 12.958	7.94 8.105 8.414 0.57 9.07 10.344 11.585	0.15 0.12 0.373 7.674 0.175 8.777 10.156	5, 95 5, 234 5, 234 7, 237 7, 237 7, 237 8, 55	4.59 4.1059 5.010 5.010 5.616 5.616 7.449	8.2× 2.2×5 ** 1.70* 5.304 5.182	1. V 1. VeV 0. 048 1. 10 3. 015 8. 854 4. Ves	0 0.0.24 1.59 1.580 1.560 2.2536 3.27
	10, 522 1, 872 1, 874 1, 77 1, 77 15, 15 16, 0, 8 16, 976	8 9.52 1.284 1.389 1.30 1.30 1.30 1.30 1.30 1.30 1.30 1.30	- 9,0% 9,0% 17,6% 11,0% 13,0% 1%,11 1%,11	8.51 5.6% 5.8% 4.8 17.5% 11.56 12.958 14.07	7.94 8.205 8.212 0.57 9.07 10.344 11.585 12.164	0.15 0.12 0.343 7.654 0.155 8.777 10.155 10.155 11.417	5, 95 5, 234 5, 234 7, 237 7, 237 7, 237 8, 35 9, 95	 4.59 4.759 5.010 5.010 5.616 7.449 5.42 	8.2) 2.2)8 1.49, 1.707 1.777 5.304 5.182 1.2	1. 7 1. 757 0. 048 1. 76 3. 675 3. 854 4. 755 5.57	0 0.0.14
	1 10, 525 1, 8, 4 13, 0, 7 14, 7 15, 15 16, 9, 8 16, 9, 6 17, 0, 7	λ 9,52 1,284 1,309 11,50 15,124 14,109 15,127 15,145 13,577	9,035 9,09, 11,67 11,67 13,037 14,1, 15,129 16,10	8.51 5.6% 5.8% 6.8 17.555 11.56 12.955 14.017 5.56	7.94 8.105 8.414 0.57 4.07 10.344 11.585 12.764 17.5	0.13 0.12 0.373 7.674 0.173 8.777 10.175 10.125 11.417 13.673	5.95 5.23 5.73 5.73 5.73 5.73 5.75 8.55 9.95	 4.59 4.759 5.616 5.42 5.417 	8.2× 2.2×5 4.44. 1.707 5.304 5.182 4.2 1.77	1. V 1. VeV 0. 048 1. 00 3. 075 8. 854 4. Ves 6. eV 7. 175	0 0.0.14
- - - - - - - - - - - - - - - - - - -	1 20, 525 1, 8, 4 1, 8, 4 1, 8, 4 1, 8, 5 1, 8, 5 1, 9, 5	2 9,552 1,264 1,019 11,60 17,774 14,159 16,147 16,148 13,777 13,547 10,577	9,035 9,09, 17,67 11,09 13,037 14,1, 13,129 16,107 17,067 10,007	8.51 5.6% 4.8% 17.5% 11.5% 12.95% 14.01% 7.5% 15.7%	0.9% 8.205 8.212 9.07 10.346 11.585 12.7% 15.7% 15.7%	0.13 0.12 0.373 7.674 0.153 8.777 10.156 11.4.7 13.673 15.075	5,95 5,2% 5,2% 5,2% 7,2% 7,2% 7,2% 7,2% 9,95 7,2% 7,2% 7,2%	 4.59 4.759 5.410 5.476 5.616 7.469 5.62 7.447 1.78 8.557 	8.2) 2.238 3.44, 1.44, 5.77 5.304 5.182 5.182 5.182 5.182 5.182 5.182 5.182 5.182 5.182 5.182 5.182 5.182	1. V 1. VeV 0. 0+8 1. 0 3. 075 3. 854 4. Ves 5. eV 7. 175 1. 10 10. 071	0 0.0.24 1.70 1.70 2.2536 3.07 4.40 7.739 7.739 7.770
- - - - - - - - - - - - - - - - - - -	1,804 1,804 1,804 1,804 1,804 1,804 1,808 1,908 1,908 1,907 1,007	2 9,50 1,284 1,569 1,569 1,569 1,577 1,577 1,577 1,577	9,035 9,09, 11,67 11,64 13,037 16,1, 16,10 17,06	8.51 5.6% 7.8% 9.8 17.5% 11.56 12.9% 14.0% 13.56 14.0% 15.1% 15.1%	7.9% 8.100 8.414 0.57 9.07 10.344 11.585 12.1% 17.5 15.705	0.13 0.12 0.373 7.674 0.173 8.777 10.175 10.175 11.417 13.673 10.076	5,95 5,25 5,25 5,25 5,25 5,25 5,25 5,25	 4.89 4.10 5.41 6.616 7.420 5.42 5.447 11.72 5.437 12.537 3.957 	8.2) 2.2)8 (,44, 1.707 5.304 5.182 (,277 5.707 5.707	1. 0 1. 00 0. 048 7. 10 3. 854 4. 055 5. 60 7. 115 7. 10 10. 071 160	0 0.0.14 . m ⁰ 1.120 2.2536 3.100 4.42 7.120
- - - - - - - - - - - - - - - - - - -	1 10, 525 1, 8, 6 1, 8, 6 1, 8, 6 1, 7, 7 15, 15 16, 0, 8 16, 9, 6 17, 67 10, 67 10, 67 20, 326 21, 155	2 9,555 1,284 1,1,40 11,40 12,174 14,179 15,14715,147 15,147 15,147 15,147 15,14715,147 15,147 15,14715,147 15,	9.032 9.09 9.09 11.67 11.68 13.03 14.1 15.12 16.10 17.66 10.00 15.95	8.51 2.606 805 9.80 17.575 11.76 12.955 14.077 15.76 17.679 15.174 15.1.9	0.99 8.202 8.212 0.37 9.07 10.346 11.585 12.49 17.5 13.705 15.107 17.195 18.202	0.13 0.12 0.333 7.634 0.133 8.777 10.138 11.417 13.653 15.057 15.157 15.157	5.95 5.23 6.23 7.22 7.23 7.35 7.35 7.35 7.35 7.25 7.25 7.25 1.52 1.52 1.52 1.52 1.52 1.52 1.52 1	 4.89 4.759 5.810 5.447 5	8.2) 2.258 3.40, 3.777 5.304 5.182 4.2 5.777 5.777 5.777 5.777 1.777 1.777 1.2.5 1.4.88	1. (*) 1. (*) (*) (*) 1. (*) 3. (*) 4. (*) 5. (*) 7. (*) 7. (*) 1. (*	U U,U,24 1,109 1,100 2,2536 3,277 4,422 7,120 7,120 7,170 1,510 1,510
- - - - - - - - - - - - - - - - - - -	1 10, 522 1, 8, 4 1, 7, 7 15, 15 16, 0, 8 16, 9, 6 7, 0, 7 10, 6, 7 10, 6, 7 20, 326 21, 155 22, 15	2 9,522 1,284 1,1,40 11,40 12,174 14,179 15,145 15,177 15,5777 15,5777 15,5777 15,5777 15,5777 15,5777 15,5777 15,57777 15,57777 15,57777777777	9,035 9,039 9,09, 17,67 11,64 13,037 14,11 13,120 16,10 7,067 15,05 15,95 19,905 20,885	8.51 5.646 5.848 9.848 17.573 11.76 12.958 14.077 15.776 15.174 15.119 1146 20.0	<pre>%.9% %.100 %.414 0.37 %.01 10.346 11.585 12.16% 17.5 13.107 16.107 17.195 18.102 19.485</pre>	0.13 0.12 0.333 7.634 0.133 8.777 10.136 11.437 13.653 15.077 15.157 15.157 15.157 15.157	5.95 5.73 6.73 7.73 7.73 7.73 8.35 9.95 7.77 7.75 7.75 15.25 15.25 15.25 15.25	 4.89 4.759 5.80 5.42 5.554 5.554 5.554 	8,2) 2,2)5 3,60, 3,77 5,304 5,204 5,204 7,77 5,767 1,777 5,767 1,777 1,2777 1,2777 1,2777 1,2777 1,2777 1,27	1. 17 1. 197 1. 197 1. 19 3. 054 4. 195 5. 07 7. 175 7. 175 1. 19 1. 195 1. 195 1. 255 1.	0 0.0.24 1.160 1.160 2.2536 3.27 4.42 7.170 1.516 1.516 1.516 1.516
- - - - - - - - - - - - - - - - - - -	1 10, 525 1, 8, 4 13, 0, 15 15, 15 16, 0, 5 16, 0, 5 10, 657 10, 657 10, 657 10, 657 20, 926 c1, 155 12, 15 12, 15 13, 15 14, 15 15,	2 9,525 1,284 1,264 1,264 1,264 1,264 1,264 12,124 12,124 13,127 13,277 13,277 13,277 13,277 13,277 13,277 13,277 13,277 13,277 13,277 13,277 13,277 14,179 21,37 21,3 31,177	- 9,035 9,09, 11,67 11,64 13,037 14,14 13,129 16,107 17,067 15,95 19,905 20,885 11,907	8,51 1,000 -,803 0,8 17,575 11,76 12,955 14,07 75,76 17,076 17,076 17,174 15,119 1,1166 20,2 71,76	<pre>></pre>	0.13 0.12 0.33 7.674 0.133 8.777 10.136 11.477 13.673 15.677 15.157 15.157 15.157 15.157 15.157	5.95 5.73 5.73 5.73 5.73 5.73 5.73 5.75 7.77 7.77	 4.89 4.80 5.810 5.816 7.420 5.42 5.42	8,12) 2,235 4,44, 1,477 5,204 5,182 4,12 7,477 5,167 1,177 1,167 1,177 1,167 1,177 1,167 1,177 1,167 1,177 1	1. V 1. VeV 0. 0+8 7. 10 3. 854 4. Ves 5. eV 7. 175 1. 15 1. 152 1. 2. 26 15. eL 17. 178	0 0.0.24 1.19 1.120 2.2536 3.27 4.42 7.120 7.120 1.1516 1.1516 1.1516 1.1516 1.1516
- - - - - - - - - - - - - - - - - - -	10.522 1.832 1.832 1.307 1.177 15.15 16.0.8 16.93 17.077 10.677 10.77 20.326 21.155 12.125 12.125 12.125	8 9,500 1,284 1,349 1,34	- 9.035 9.09, 17.67 11.04 13.037 14.1, 15.129 16.10 17.067 15.95 19.905 20.885 11.407 12.47	8,51 1,000 -,808 9,2 1,55 1,55 1,07 1,56 1,07 1,16 1,16 1,16 20,0 -,170 2,45 -,2,45 -,2,56 -,2,57 -,	<pre>7.9% 8.20% 8.21% 0.5% 4.0% 10.346 11.5% 10.346 11.5% 15.70% 16.70% 10.19% 18.20% 19.4% 10.11% 10.13%</pre>	0.13 0.12 0.33 3.757 10.126 11.47 13.673 15.675 15.675 15.127 1.28 15.60 19.050 3.71	5,95 5,75 5,75 5,75 5,75 5,75 5,75 5,75	 (19) (19) (10) <li< td=""><td>8,22 2,235 4,44, 4,77 5,204 5,284 4,27 7,77 1,777</td><td>1.17 1.787 2.088 7.10 3.854 4.788 5.87 7.173 7.173 1.1.82 1.2.82 1.</td><td>U U.U.24 1.169 1.160 2.2536 3.27 4.42 7.176 1.42 1.516 1.516 1.516 1.516 1.516</td></li<>	8,22 2,235 4,44, 4,77 5,204 5,284 4,27 7,77 1,777	1.17 1.787 2.088 7.10 3.854 4.788 5.87 7.173 7.173 1.1.82 1.2.82 1.	U U.U.24 1.169 1.160 2.2536 3.27 4.42 7.176 1.42 1.516 1.516 1.516 1.516 1.516
- - - - - - - - - - - - - - - - - - -	100,522 10,522 10,522 10,07 10	8 9,500 1,284 1,449 1,469 1,469 1,469 1,477 1,477 1,477 1,477 1,477 1,477 1,477 1,477 2,4777 2,4777 2,4777 2,47777777777	- 9.035 9.09. 17.67 11.04 13.037 14.1. 13.129 16.10 17.067 15.95 19.905 20.885 11.407 12.97 1.407	8,51 1,000 1,803 0,2 17,555 12,055 14,057 15,056 15,059 15,05	V.94 8.202 8.212 0.37 9.07 10.344 11.585 13.707 16.707 16.707 17.195 18.202 19.432 70.117 11.737 23.17	(1.13 (1.12) (1.313) (1.13) (1.13) (1.13) (1.13) (1.14) (1	5,95 5,75 5,75 5,75 5,75 5,75 5,75 5,75	 (19) (17) (10) <li< td=""><td>3, 2) 2, 258 3, 20, 3, 70 5, 204 5, 32 4, 2 5, 32 5, 32, 32 5, 32 5, 32, 32 5, 32, 32 5, 32, 32, 32, 32 5, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32</td><td>1.77 1.767 1.767 1.767 3.854 4.755 5.677 7.173 1.767 1.767 1.757 1.775 1.775 1.757 1.757</td><td>0 0.0.23 1.09 1.720 2.2536 2.2536 7.729 7.729 7.729 1.516 1.516 1.516 1.516 1.516 1.516 1.516</td></li<>	3, 2) 2, 258 3, 20, 3, 70 5, 204 5, 32 4, 2 5, 32 5, 32, 32 5, 32 5, 32, 32 5, 32, 32 5, 32, 32, 32, 32 5, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32	1.77 1.767 1.767 1.767 3.854 4.755 5.677 7.173 1.767 1.767 1.757 1.775 1.775 1.757 1.757	0 0.0.23 1.09 1.720 2.2536 2.2536 7.729 7.729 7.729 1.516 1.516 1.516 1.516 1.516 1.516 1.516
	10, 542 1, 8, 42 1, 8, 42 1, 8, 42 1, 8, 42 1, 8, 42 1, 1, 57 10, 677 10, 677 10, 677 10, 677 10, 677 10, 677 10, 677 10, 677 10, 677 10, 577 20, 526 21, 155 22, 527 23, 527 23, 524	8 9,522 1,284 1,149 1,14	- 9.032 9.09 11.67 11.64 13.037 14.16 13.037 13.120 13.120 13.120 13.007 13.90 20.307 13.07 13.07 13.07 13.07 13.07 14.117 23.335	8,51 5,646 5,845 6,2 15,55 12,555 12,555 12,555 15,176 15,176 15,176 15,176 15,176 20,2 71,776 12,76 20,2 71,776 12,76 20,776 12,7776 12,776 12,776 12,776 12,776 12,7776 12,776 12,776 12,776 12,776	V.94 8.202 8.212 0.37 9.07 10.344 11.585 12.764 17.3 15.707 16.707 17.192 18.202 19.432 70.113 11.737 20.17	0.13 0.12 0.33 7.634 0.153 8.777 13.156 13.633 15.637 15.157 15.157 15.157 15.157 15.157 15.257 15.257 15.257 15.257 15.257 15.257	5,95 5,735 5,735 5,735 5,735 7,737 7,777 7,2,57 12,105 12,105 12,105 12,105 12,105 12,105 12,105 12,105 12,105 12,105	 (19) (17) (10) <li< td=""><td>3, 2) 2, 235 3, 241, 3, 707 5, 206 5, 282 1, 2 7, 77 4, 767 1, 737 1, 6, 75 2, 6, 02 2, 7, 67 3, 7, 75 2, 75</td><td>1. V 1. VeV 0. 048 1. 10 3. 854 4. VeV 5. 155 7. 155 1. 155 1</td><td>0 0.0.124 1.160 2.2536 3.027 4.422 7.1720 1.1510 14.520 14.520 14.520 14.520 14.520 14.520 14.520 14.520</td></li<>	3, 2) 2, 235 3, 241, 3, 707 5, 206 5, 282 1, 2 7, 77 4, 767 1, 737 1, 6, 75 2, 6, 02 2, 7, 67 3, 7, 75 2, 75	1. V 1. VeV 0. 048 1. 10 3. 854 4. VeV 5. 155 7. 155 1. 155 1	0 0.0.124 1.160 2.2536 3.027 4.422 7.1720 1.1510 14.520 14.520 14.520 14.520 14.520 14.520 14.520 14.520
- - - - - - - - - - - - - - - - - - -	10, 500 10, 500 20, 100 20, 10, 100 20, 100 20	8 9,520 1,284 1,149 1,14	- 9.035 9.09, 11.67 11.64 13.037 14.14 13.037 16.16 17.66 17.66 17.66 10.005 12.95 10.905 20.355 10.905 12.97 12.97 12.97 12.97 12.95 12.9	8,51 5,646 -,848 6,2 1,755 1,176 1,176 1,176 1,176 1,179 1,176 20,12 -1,76 2,45 2,55 2,45 2,	V.99 8.202 8.212 0.37 4.07 10.346 17.5 15.707 16.707 16.707 17.99 18.202 19.495 70.717 21.75 23.17 24.85 26.55	1,13 7,12 7,574 7,674 7,674 8,777 10,135 11,477 13,675 15,675 15,675 15,157 15,157 15,157 15,157 15,157 15,157 15,157 15,556 15,656 15,5566 15,5566 15,5566 15,5566 15,5566 15,5566 15,5	5,95 5,737 7,737 7,737 7,737 7,737 7,737 7,737 12,299 14,299 14,11914,119 14,119 14,119 14,119 14,119 14,1	 4.59 4.759 5.810 5.914 5.616 5.747 7.749 5.747 7.749 5.747 7.749 5.957 5	8,25 2,255 2,375 5,304 5,185 5,185 5,185 5,185 5,185 5,185 5,185 5,185 1,175 1	1. v 1. vev 0. 0448 1. vev 0. 0448 1. vev 3. 8544 4. ves 5. ev 7. 175 1. 175 1. 2. ev 15.	0 0.0.24 1.50 2.2536 3.277 4.42 7.170 1.510 1.210 1.210 1.210 1.210 1.210 1.210 1.210 1.210 1.210 1.210 1.210 1.210 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.2000 1.20000000000
	10, 542 1, 8, 42 1, 8, 42 1, 8, 42 1, 8, 42 1, 8, 42 1, 1, 57 10, 677 10, 677 10, 677 10, 677 10, 677 10, 677 10, 677 10, 677 10, 677 10, 577 20, 526 21, 155 22, 527 23, 527 23, 524	8 9,522 1,284 1,149 1,14	- 9.032 9.09 11.67 11.64 13.037 14.16 13.037 13.120 13.120 13.120 13.007 13.90 20.307 13.07 13.07 13.07 13.07 13.07 14.117 23.335	8,51 5,646 5,845 6,2 15,55 12,555 12,555 12,555 15,176 15,176 15,176 15,176 15,176 20,2 71,776 12,76 20,2 71,776 12,76 20,776 12	V.94 8.202 8.212 0.37 9.07 10.344 11.585 12.764 17.3 15.707 16.707 17.192 18.202 19.432 70.113 11.737 20.17	0.13 0.12 0.33 7.634 0.153 8.777 13.156 13.633 15.637 15.157 15.157 15.157 15.157 15.157 15.257 15.257 15.257 15.257 15.257 15.257	5,95 5,735 5,735 5,735 5,735 7,737 7,777 7,2,57 12,105 12,105 12,105 12,105 12,105 12,105 12,105 12,105 12,105 12,105	 (19) (17) (10) <li< td=""><td>3, 2) 2, 235 3, 241, 3, 707 5, 206 5, 282 1, 2 7, 77 4, 767 1, 737 1, 6, 75 2, 6, 02 2, 7, 67 3, 7, 75 2, 75 2,</td><td>1. V 1. VeV 0. 048 1. 10 3. 854 4. VeV 5. 155 7. 155 1. 155 1</td><td>0 0.0.124 1.160 2.2536 3.027 4.422 7.1720 1.1510 14.520 14.520 14.520 14.520 14.520 14.520 14.520 14.520</td></li<>	3, 2) 2, 235 3, 241, 3, 707 5, 206 5, 282 1, 2 7, 77 4, 767 1, 737 1, 6, 75 2, 6, 02 2, 7, 67 3, 7, 75 2,	1. V 1. VeV 0. 048 1. 10 3. 854 4. VeV 5. 155 7. 155 1. 155 1	0 0.0.124 1.160 2.2536 3.027 4.422 7.1720 1.1510 14.520 14.520 14.520 14.520 14.520 14.520 14.520 14.520

Table (2): Sample of Data set for Model No.2	
Array X {size 21x11}	

Array Z {size 21x11}

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Surface matrix based Machining Planes Determination Milling Process (Roughing Stage)

10 00 00 U											
	•	3	- Z - 1	1	1	3		- n	4	10	
1	-	V	-	v	-	V	-	v	-	v	-
2	1, 702	1.0	1.644	1.170	1.71	1.0	1.00	1,903	2,095	2.22	2,)55
3	0.87	3. 25	·	$3 : \leq n$	5.45	3.79	5.75	3.479	9.18	4.127	·I. n.₹ ·
4	4.055	4,326	4,643	4.59	5.147	\$.387	5.612	\$1708	6, 2800	5.6	7,003
5	5.11	5.70	5.001	6.72	5.015	7.09	7,405	7.68		0.545	9.27
•	÷+	0.545	7.025	7.554	8. LAL5	8.58	.0.1.0	9.585	10.02.	10.529	4:
7	7.031	7.74	D. 091	0.506	9, 1001	10.12	10.911	11.79	10.105	18,770	
*	1.97.	8,42				11.213	12.035	13,224	13.955	.4. 186	15.675
•	0, 13 33	9,000	10.091	10.03	11.091	17.6	10.601	14,125	15.711	16,174	17.611
10	1.662	10.59	وريب	11.88	-2. :	18.518	14.8.4	10.123	17,13,	18.209	1.0, 455
	10.5	11,175	11,991	12,196	10.095	14,992	13,135	15.4	10.631	10,970	21.215
10	1345	10.1 A	14.935	13.51	14.972	n. 93	17,43,	8,000	01.139	01.20	04.8 4
1)	12,155	12.94	10.05	14.910	16.1	17.007	10,725	20.120	21.625	22.097	24.23
14		3	. 1-		17.24	0.252	21.01	210	1.4	4.59	2.5
15	13.911	14.8	15.87	17.08	13,414	19,564	21, 417	22.85	23.812	25.215	26.73
16	11.015	17.0	· ·	10.770	19.651	21.2	27.27	tautea.	21.691	16,123	27.71
17	15.55	10.20	15,134	19.467	2	21.020	22.55	24.07	25.44	2014	25.52
10	15,951	10.02	19.011	20,79	с° , 17	18,113	27.375	24.01	25.95	17.510	59.15
19	15.12.	19,59	20,705	21.120	21.785	20.5eV	23.744	24.59		27.1 >	252
20	19,455	20.71	TO. 5	11,124	21.95	12.174	20,975	25.75	23.615	20.71	T9. 5
21	۷.	20.58	20,955	01,59	22.35	22.1>	24.34	25.51	25.74	25.3	5.

Table (3): Comparison between the applied methods with respect to number of Gcodes blocks and time required for roughing, at same machining conditions

codes blocks and time required for foughing, at same machining conditions.								
Surface matrix based machining Method	Number of G-codes blocks							
	(time required for roughing in minutes)							
	Model No.1	Model No.2						
Matrix Oriented Roughing	904	388						
	(52)	(47)						
3D Contour Matrix Oriented Roughing	17826	20588						
	(70)	(84)						
Flow Line Oriented Roughing	802	269						
	(30)	(22)						

[Machining Conditions: Spindle speed = 9549 rpm, Feed rate= 1146 mm/min, Ball nose mill cutter, Tool diameter = 1 mm, Tip radius= 0.5 mm, Tool material= High Speed Steel, Workpiece material= Steel St33]