INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN 2278 – 0211 (Online)

Automation in CNC Code Generation and Tool Path Optimization for Micro-milling Machine

M. Prakash
Research Scholar, Department of Manufacturing Engineering
College of Engineering Guindy, Anna University, Chennai, India
P. Hariharan
Professor, Department of Manufacturing Engineering
College of Engineering Guindy, Anna University, Chennai, India
M. Kanthababu
Associate Professor Department of Manufacturing Engineering
College of Engineering Guindy, Anna University, Chennai, India

Abstract:
Recent scenario and technology moving rapidly towards the development of micro- devices in the millimeter to sub-millimeter range. Micro manufacturing plays an important role in recent development and application of miniaturized products. One of the tool based micro manufacturing process known as microendmilling has become an established process for manufacturing micro components in metal and metal alloys. For the complicated contouring applications, manual part programming becomes cumbersome and is prone to errors. In this work an attempt has been made to overcome these problems by use of specially designed software. This software automatically generates CNC part programs, when the part geometry is defined. It reduces the time consumed by the operator to enter the program manually and also eliminate the programming errors. This software automate the computer numerical control (CNC) programming for micro-endmilling machine to perform point to point operation, straight cut operation and contouring operation. The development of this technique leads to reduce the cost of fabrication for the most of the microstructures and at the same time reduces the product time to market. Optimized tool path for pocket milling operation are also identified as parallel plane method based on surface roughness and machining time.

Key words: *Computer Numerical Control (CNC), Micro-endmilling, Part Programme, Tool Path, Surface Roughness*

1. Introduction

The demand for micro products and micro components is rapidly increased in recent years in many industries like medical (bio implants, diagnostic devices, micro dosage), electronics (micro switches, micro chips, micro actuators and printing heads), biotechnology (flow cytometry, lab on a chip) and automotive (Micro pump, micro injector, micro engines) sectors [1]. To meet this demand, various micro manufacturing techniques to produce a miniature devices and components with complex micro structure on a variety of materials have emerged. Tool based micromachining (TBMM) is one of the key micro manufacturing techniques for creating the three dimensional complex micro components on a variety of engineering materials (i.e. metals, metal alloys, polymer, ceramics and composites) by material removal process [2].

TBMM utilizes downscaled version of conventional tools (drilling, milling and turning) to produce the micro components less than 500μm irrespective of the size of the component machined [3]. Microendmilling is one of the TBMM processes for fabricating micro components in many fields and industries, including defense, biomedical, telecommunication engineering etc.

To enable effective industrial application of microendmilling process, there is a need of repeatability and reliability in this process. An increasing variety of products and a decrease in average batch size requires today's manufacturers to implement computer aided manufacturing systems for economic reasons. Computer aided manufacturer (CAM) utilizes a computer to aid the manufacture or production of a part independently of design process. CAM requires the use of geometrical description and motion control part programming language to generate the necessary command to control the machine tool [4]. Computer numerical control (CNC) programming is the procedure by which the sequence of processing steps will be performed on the CNC machine [5-7]. It starts with process plan, where entire tool path is shown schematically on a scaled drawing. By properly selecting the type of machine, the axis system is fixed and the part program is written in preparatory commands and miscellaneous function (G and M codes respectively). The main disadvantage of constructing part programs from the process plan is the increase in production time and cost. This is more elegant in the case of components involving repetitive machining operation.

One prerequisite in the utilization of CNC machines in the mass and complicated contour production is the efficient and timely production of faultless machining programs. Based on this fact, many authors (Gatalo et al., 1988, Lee et al., 1998, Bieterman, 2000, Anotaipaiboon et al., 2005) have attempted to develop several types of software that can handle these two independent problems together [8-11]. Weck et al. (1994) introduced a new linear tool-path pocketing strategy to correct the existing pocketing routines in a CAD/CAM system by planning chatter free axial depth and radial width of cuts that are automatically selected from the stability data bank during NC tool path generation. Vosniakos (1998) have been developed an integrated graphics exchange system (IGES) post-processor to interface the system to any computer aided design (CAD) system, and then a conversion program sought to obtain solid modeling geometry from the wire frame model. Lee and She (1998) presented an approach for tool path generation based on homogeneous coordinate transformation and conjugate surface theory. Puif et al. (2003) Implemented a flexible and versatile architecture, which reads and interprets the CNC program code that controls the machine, it computes the positions and the motion of components and it translates the sequence of machining operations into Boolean operations and that allows simulation directly from CNC code, through a filtering and compilation preprocess that minimizes geometric computations. **Omirou et al. (2005)** were developed new programming capabilities and tested in the framework of a PC-based milling machine controller. Namely, tool-motion along space curves, cutter offsetting for free-form curves and two machining cycles for revolved (external or internal) surfaces with free-form profiles, constitute the new characteristics proposed to be integrated into the system of a CNC milling machine.

Recently, many modeling software systems have the inbuilt module for generating CNC programs for the designed solid model. But all these software's are high cost and not suitable for all the controllers of the CNC machine [16].

The CNC program has a particular structure that the controller can understand, but it must follow a specific syntax. Writing CNC programs is an error-prone process. Debugging a program of any sizable length is usually very tedious. Some important commands of a program could be missing, or the program could be incomplete or incorrect with regard to factors like spindle speed, offset, depth of cut, feed rate and tool path [17]. These mistakes could cause damage to the tools, the machine and injuries to the operator and other people as well. For these reasons, an interactive software system especially for micro-endmilling machine is developed to improve the machining accuracy and to avoid the most time consuming task to enter the program manually in to the system [18].Most of the published results in this area are based on the interfaces like DXF, IGES, etc., available with the drafting package [19-23]. DXF file gives suitable codes for the various entities.

In this present approach, three modules of the software generate two dimensional drawing of the component features and then arrange the entities in the sequence as they appear in the drawing, then encodes the every entity. Another module is used to obtain the machining parameters like, speed, feeds and depth of cut. The third module of the software generate the CNC part program incorporating preparatory functions (G) and miscellaneous function (M) codes, which is necessary to generate the required profile on the workspace using micro-milling machine.

2. Methodology

The proposed automatic part program generation technique is implemented using generalized software written in JAVA language. It has three basic modules; they are: (a) Machining Parameters (b) Drawing (c) CNC Code generation. The flow of information within this software and their logics are briefly explained by the flow chart (Fig.1).

The functions of the software for the generation of CNC part program are

- *Parametric Data Entry Via Dialogue Box:* The parameters like coordinate value of points, line, arc, position of holes and machining conditions like speed, feed and depth of cut are entered via dialog box.
- *2D Drawing Generation:* Based on the data entered via dialog box the required profile is generated in the drawing area.
- *Automatic Generation of CNC code:* The generated CNC program is a simple text file and it is saved with an extension of .cnc. This can be loaded in to the machine controller software for further operations.

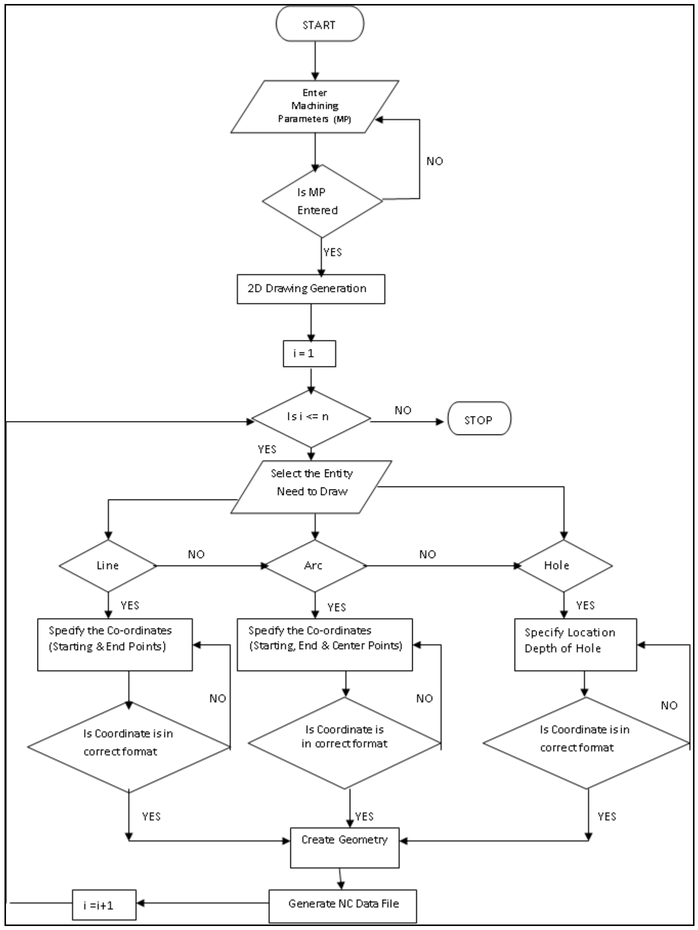


Figure 1: Flow chart for interactive graphics software

2.1. 2D Drawing Generation

To recognize the entities present in the drawing viz. lines, circles and arcs the coordinate is analyzed by the java program. In case of recognized entity is a line, from the comparative value of the starting and ending (X,Y) co-ordinates the status of the line (i.e., horizontal, vertical or inclined) is identified as below.

- If, start X- co-ordinate = end X-co-ordinate, then the line is vertical
- If, start Y- co-ordinate = end Y-co-ordinate, then the line is horizontal
- If the none of the above is true, then the line is inclined
- If the recognized entity is an arc, the aspects of the arc, starting and end angles, radius and center are noted down
- In order to bring the line and arc in common platform the start and end angle of an arc are calculated using trigonometric relation.

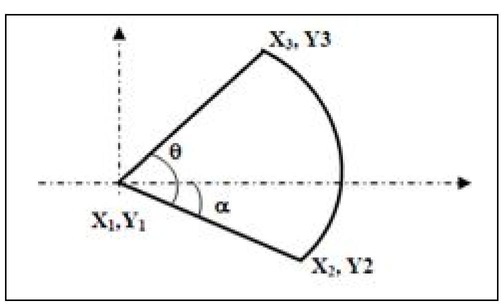


Figure 2: Angle representations for the arc generation

Fig. 2 show the starting and end angle representation for generating the arc. The angle α and θ are starting and ending angle of arc respectively, it can be calculated from the known co- ordinates of centre, starting and end points by using following relations 1 and 2.

- $\alpha = \tan^{-1}(m)$ where $m = \dfrac{X_2 - X_1}{Y_2 - Y_1}$ (1)
- $\theta = \cos^{-1}[(L^2 - 2r^2)/2r^2]$ (2)

Where $r = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$

$L = \sqrt{(X_3 - X_2)^2 + (Y_3 - Y_2)^2}$

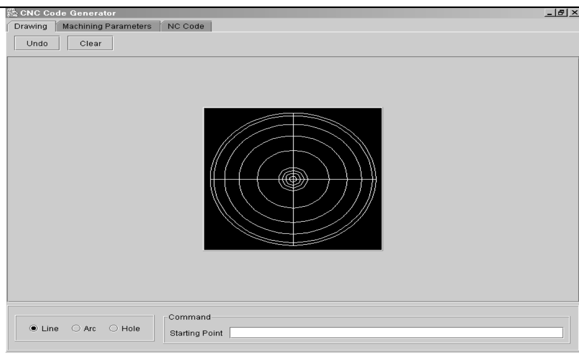
Where (X_1, Y1), (X_2, Y2), (X_3, Y3) center, starting and end points respectively.

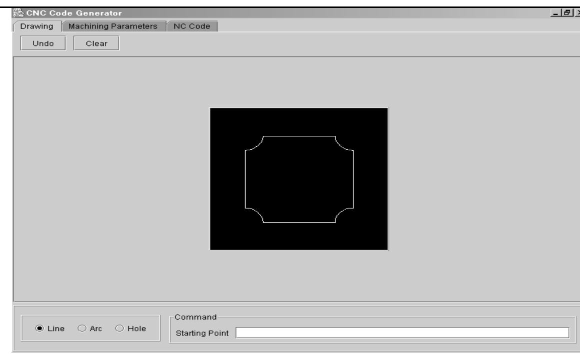
2.2. NC Code Generation

The information about an operation that has to be conveyed to the controller consist of

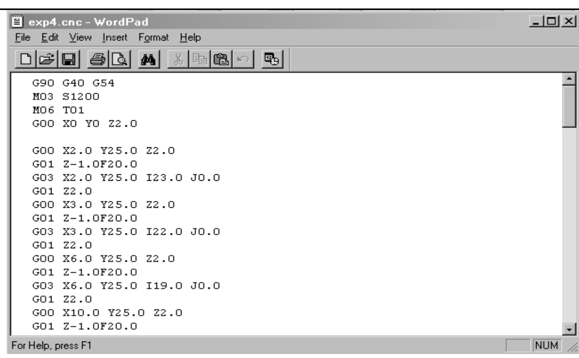
- The operation code.
- The coordinate for position
- Tool information
- The speed and feed for operation
- Miscellaneous information such as coolant on/off, spindle clockwise/counter clockwise, etc.

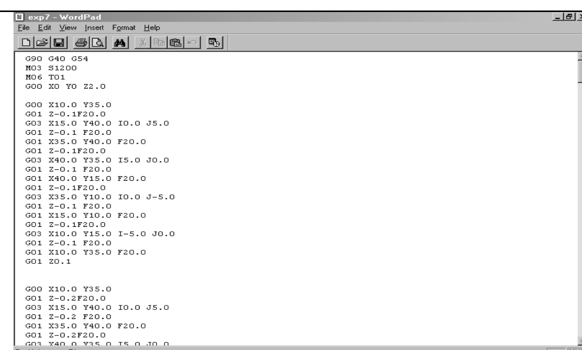
Circular and Linear Interpolation: | *Contour Cutting:*



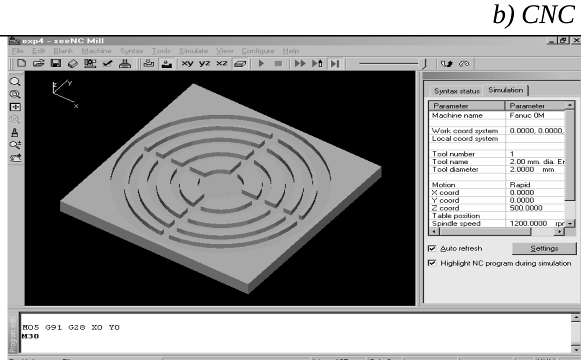


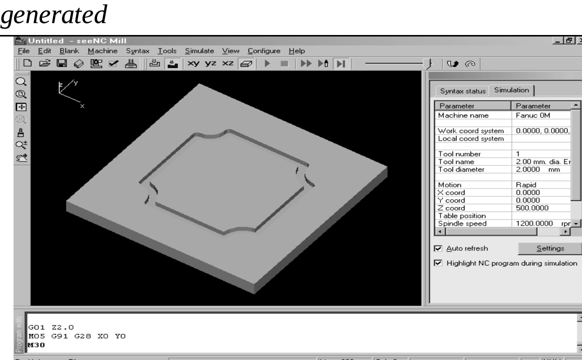
a) 2d drawing





b) CNC code generated





c) CNC part program verified by the Simulator

Figure 3: Typical circular and linear Interpolation programme generated by the software

This information in a program is usually referred as the block. Here each element of information is prefixed by the letter formatting the controller to convey it to a particular register. The preparatory functions G90 and G91 are used for specifying that the data in the following block are in absolute mode or incremental mode respectively. Like preparatory function words, some miscellaneous function words (M words) are used, for example, to start the spindle or to set its rotation in clockwise or counter clockwise. The machine tool represent immediately as soon as the miscellaneous function instruction is processed

Two type of interpolation is possible in most of the CNC machines i.e. Linear and circular. In linear interpolation, the coordinate of the destination is provided in the block along with the code G01 and other relevant machining parameters. The data processing unit calculates the slop and intercept for the straight line along which the tool is supposed to move. For circular interpolation, besides the destination coordinates, it is required to provide the coordinates of the center of the arc with respect to the starting point of the arc. The data processing unit calculates and determines the various points required for the interpolation.

For example G01 X10 Y20 F100 instruct the cutter to proceed a point (10, 20) along the straight line, and further G03 X40.0 Y40.0 I10.0 J10.0 makes the cutter proceed along an arc of the circle whose center circle (20,20) to a point (40,40). Here I and J correspond to the coordinates of the center with respect to the starting point (10,10).

Figure 3a-3c shown the 2D drawing generation, CNC code generated by the software and CNC code verified by the SeeNC mill – 6 simulator for circular, linear interpolation and contour profile machining respectively. Experimentation also carried out to verify the CNC code and to optimize the tool path for rectangular pocket milling.

3. Experimental Procedure

Experiments were carried out in MIKROTOOLS made DT110 Integrated Multi Process micromachining machine tool driven by a 100 W AC servo drive motor with the speed range of up to 5000 rpm. The machine tool has maximum traverse range of 200 mm (X-axis) x 100 mm (Y-axis) x 100 mm (Z-axis). The X-Y table has optical linear scale with resolution of 0.1 µm. The photograph of the experimental setup used in this work is shown in Fig. 4. Speed Tool made flat microendmill (Model: UMIE 3052) made of tungsten carbide of size 500 µm diameter with 35^0 helix angle and flute length of 0.8 mm is used in this work (Fig. 5). The microendmill is coated with Aluminum Titanium Nitride (AlTiN) of 400 nm thickness. The experiments were carried out in dry condition.

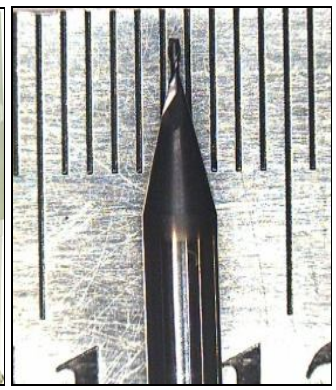



Figure 4: Micromachine tool & Figure 5: 0.5 mm microendmill

The dimension of the machined surface is measured using a non-contact video measuring system (Model: 2010F). The video measuring system has the resolution of 0.001mm with the magnification ranges from 34 - 220 X. The surface roughness of the machined surface is measured using stylus type surface roughness tester (Make: Kosaka) at the centre of the machined surface with a cut of length of 0.25 mm.

4. Tool Path Optimization for Rectangular Pocket Milling

Tool paths, defined by the locus of contact points between the cutter and the surface, must satisfy the requirements of surface integrity and accuracy of the component to be machined. For the manufacturing of 3D profile using a three axis or five-axis CNC machine, the tool path for generation of profile is divided into two main categories such as isoparametric tool path generation and non isoparametric tool path generation. Fig. 6 shows the schematic representation of all types of tool path.

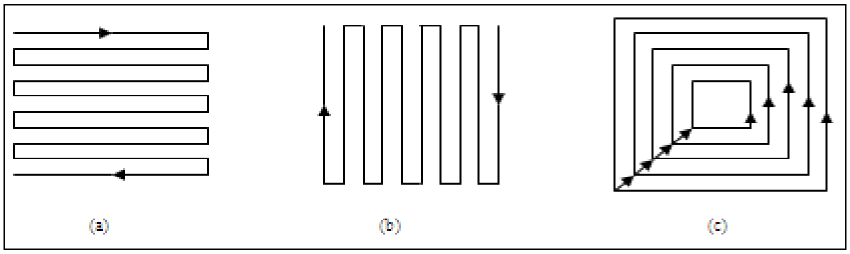


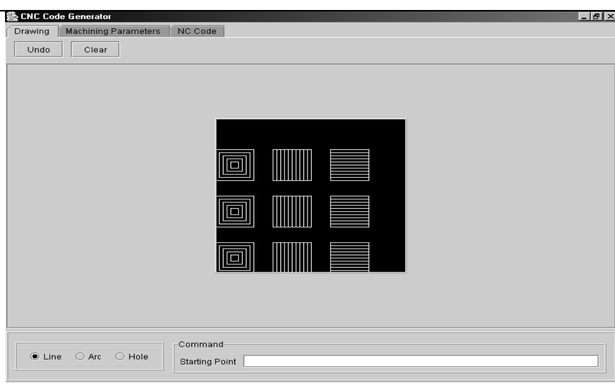
Figure 6: Tool path (a) Isoparametric u direction (b) Isoparametric v direction (c) Non isoparametric (parallel plane method)

Optimum tool path for rectangular pocket milling is identified from the machined rectangular pocket in the size of 12 × 12 mm in the various tool path directions like parallel plane method, isoparametric v direction and isoparametric u direction. Fig. 7a – Fig. 7d explained about the automatic CNC part program generation and their simulation of rectangular pocketing for different tool path.

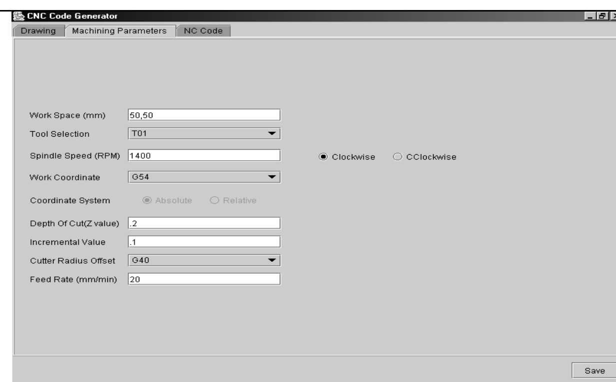
By analyzing the various factors like dimensional accuracy, surface roughness and total machining time during rectangular pocket milling using different tool path, an optimum tool path is identified. The experimental results of three trials are tabulated in the Table 1.

Trials	Different tool paths	Rectangular pocket Dimension (mm)		Ra (μm)	Machining time (min.)
		D1	D2		
I	Isoparametric u direction	12.162	12.162	0.480	8.53
	Isoparametric v direction	12.085	12.162	0.482	8.53
	Parallel plane method	12.092	12.157	0.187	7.34
II	Isoparametric u direction	12.152	12.162	0.460	8.53
	Isoparametric v direction	12.125	12.14	0.541	8.53
	Parallel plane method	12.092	12.067	0.247	7.34
III	Isoparametric u direction	12.127	12.047	0.515	8.53
	Isoparametric v direction	12.085	12.162	0.458	8.53
	Parallel plane method	12.092	12.034	0.165	7.34

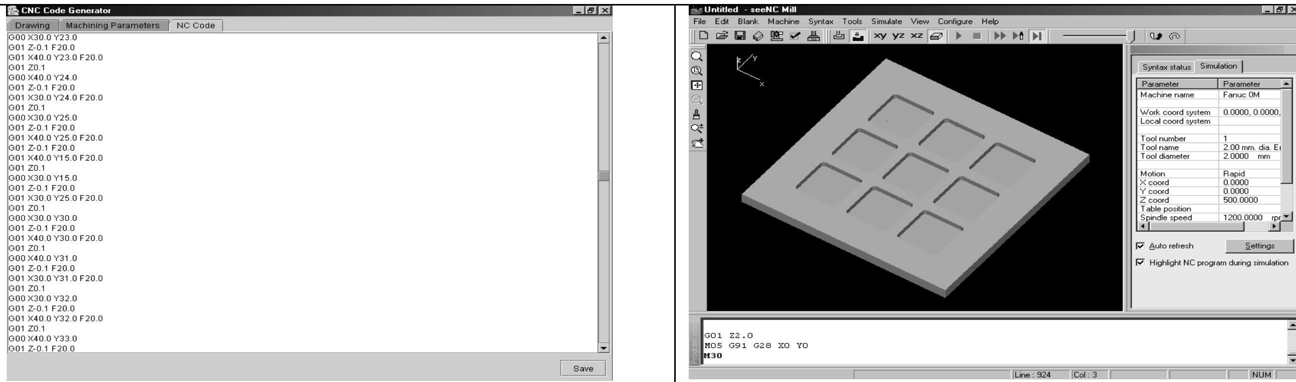
Table 1 Experimental results



a) 2D drawing



b) Machining parameters



c) Generated CNC part program

d) Simulated profile

Figure 7: Rectangular pocket-milling CNC path programme generation

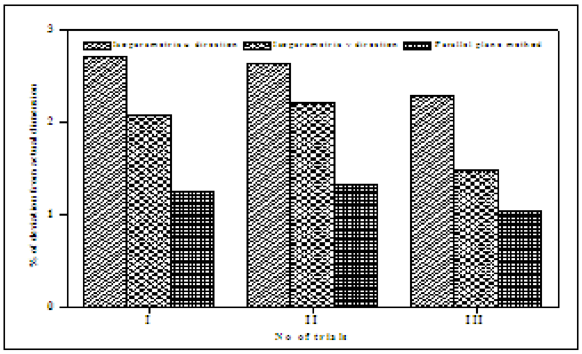


Figure 8: Comparison graph of % of deviation from actual dimensioning

Fig. 8 shows the dimensional accuracy of the rectangular pocket machined by various methods of tool path directions, which give the comparison of dimensional accuracy in the form of percentage of deviations of actual dimension from the required dimension of rectangular pocket milling. It is observed from that parallel plane method give the better dimensional accuracy than that of other two methods.

Fig. 9 give the comparison of the machining time by various tool paths direction methods and it is observed from that parallel plane method required lesser machining time compared with other two methods.

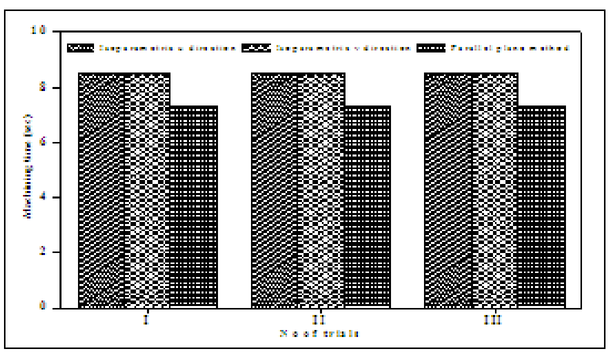


Figure 9: Comparison graph for total time for machining

From Fig. 10, it is observed that parallel plane method give the better surface roughness compared with other two methods of rectangular pocket milling.

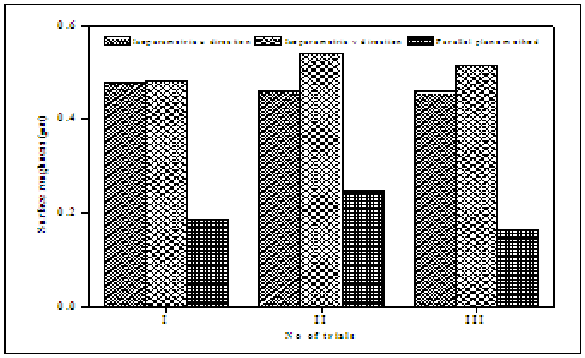


Figure 10: Comparison graph for surface roughness

It is observed from above analysis of dimensional accuracy (Fig. 8), Machining time (Fig. 9) and surface roughness (Fig. 10) rectangular pocket milling obtained by the parallel plane tool path method give the better result compare with other two tool path methods.

5. Conclusion

An interactive graphic user friendly software system for automatic generation of both 2D drawing and the CNC part program has been developed and illustrated with some examples. This paper has highlighted need of the interactive software system for performing high accurate micromachining along with tool path optimization. The optimized tool path for rectangular pocket milling is identified as parallel plane method. The work can be further expanded to three dimensional drawing generations with cutter path simulation.

6. References

1. Alting, L., Kimura, F., Hansen, H.N., Bissacco, G. (2003) ‘Micro engineering’, Annals of CIRP, Vol.52, No.2, pp.635 – 657
2. Asad, A.B.M.A., Masaki, T., Rahman, M., Lim, H.S., Wong, Y.S. (2007) ‘Tool-based micro-machining’, Journal of materials processing technology, Vol.192, pp.204 – 211.
3. Anotaipaiboon, W and Makhanov, S. S. (2005) ‘Tool Path Generation for five axis NC machining using space filling curves’, International Journal of production research, Vol. 43, No. 8, 1643–1665
4. Balic, J. (2004) ‘Neural-Network-Based Numerical Control for Milling Machine’ Journal of intelligent and robotic system, Vol. 40, pp. 343 – 358
5. Brousseau, E.B., Dimov, S.S and Pham, D.T. (2010) ‘Some recent advances in multi-material micro- and nano-manufacturing’, International journal of advanced manuf acturing technology, Vol.4, pp.7161-180
6. Bieterman, M. (2000) ‘Mathematics in Manufacturing: New Approach Cuts Milling Cost’, From SIAM News, Vol. 34 No.7
7. Chang. T.C and Chen. J. C. (1992) ‘The Cost-Effective CNC Part Program Verification Development for Laboratory Instruction’ Journal of technologies studies, Vol.2, pp. 56 -63
8. Gatalo, R., Hodoli, J., Zeljkovi, M., Milo, V and Konjovi, Z. (1988) ‘Achievements in the development and future development of SAPOR-S systems for automatic programming of NC lathes’, Journal of robotics and computer integrated manufacturing, Vol.2, No. 1- 2, pp.91-102
9. Lee, R and She, C. (1998) ‘Tool path generation and error control method for multi-axis NC machining of spatial cam’, International journal of machine tools and manufacturer, Vol.38, pp.277-290
10. Lee, J.N., Huang, C.B and Chen, T.C. (2008) ‘Toolpath generation method for four-axis NC machining of helical rotor’ Journal of Achievements in materials and manufacturing engineering, Vol 31, No.2, pp. 510-517
11. Lauwers, B., Dejonghe, P and Kruth J. P. (2003) ‘Optimal and collision free tool posture in five axis machining through the tight integration of tool path generation and machine simulation’, Journal of computer aided design, Vol. 35, pp. 421 – 432
12. Li, S.X and Jerard1, R.B. (1992) ‘Non-isoparametric Three Axis NC Tool Path Generation for Finish Machining of Sculptured Surfaces’, In proceeding of: Geometric Modeling for Product Realization, Selected and Expanded Papers from the IFIP TC5/WG5.2 Working Conference on Geometric Modeling, Rensselaerville, NY, USA, 27 September - 1 October 1992
13. Mutapcic, E., Iovenitti, P and Hayes, J. (2001) ‘Automatic NC Part Programming Interface for a UV Laser Ablation’ http://www.swinburne.edu.au/engineering/iris/pdf/profiles/EmirMutapcic.pdf
14. Mak, K.L., Lau H. Y. K and Wong S.T. W. (1999) ‘An object – oriented prototyping tool for automated manufacturing systems’, Journal of computers in industry, Vol. 43, pp. 43-60
15. Omirou, S.L and Barouni, A.K. (2005) ‘Integration of new programming capabilities into a CNC milling system and lathes’ Journal of robotics and computer integrated manufacturing, Vol.21, No.6, pp. 518 - 527
16. Puif, A., Perez- vidal, L and Tost, D. (2003) ‘3D simulation of tool machining’, Journal of computer and graphics’, Vol. 27, pp. 99- 106.

17. Potthast, A., Ellinger, H and Kobe, P. (1998) 'Possibilities of graphic simulation of NC programs' Journal of robotics and computer integrated manufacturing vol.4, No. 1-2, pp. 83 - 90
18. Roy, U. (1999) 'Computation of geometric model of machined part from its NC machining programs', Journal of computer aided design, Vol.31, pp.401 – 411
19. Roy, U and Xu, Y. (1998) '3-D object decomposition with extended octree model and its application in geometric simulation on NC machining', Journal of computer-integrated manufacturing, Vol.14, pp. 317-327
20. Srinivas, J. (2004) 'Automatic generation of numerical control part programs using object- oriented software', Proceedings of the institution of mechanical engineers, Part B: Journal of engineering manufacture, Vol.218, No.2, pp. 239-244
21. Vaupotic, B., Kovacic, M., Ficko, M and Balic, J. (2006) 'Concept of automatic programming of NC machine for metal plate cutting by genetic algorithm method', Journal of achievements in materials and manufacturing engineering, Vol.14 No.1-2, pp. 131 -139
22. Vosniakos, G. (1998)'An intelligent software system for the automatic generation of NC programs from wire frame models of 2-1/2D mechanical parts', Journal of computer integrated manufacturing system ,Vol. 11, issue 1-2, pp. 53- 65.
23. Weck, M., Altintas, Y and Beer, C. (1994) ' CAD assisted chater-free NC tool path generation in milling', International journal of machine tools and manufacturer, Vol.54, No. 6 pp.879-891