Advanced Materials Research Vols 622-623 (2013) pp 525-530 *Online: 2012-12-27*
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.622-623.525

A Five-Axis CNC Machine Postprocessor Based on Inverse Kinematics Transformation

Tran Duc Tang

Le Quy Don Technical University

100 Hoang Quoc Viet Str., Cau Giay Dist., Hanoi City, Vietnam

Email: tangtd@gmail.com

Keywords: Five-Axis CNC Machine, Postprocessor, Inverse kinematics, CL data, NC Program, CAD/CAM.

Abstract. This paper presents a postprocessor for five-axis milling machine that capable of converting CL (cutter location) data to machine control data (NC program). The proposed postprocessor method is based on inverse kinematics transformation and postprocessor module is programmed in Visual Basic language. The Deckel Maho DMU 50 eVoluion five-axis machine with two rotary axes (B and C) on the table is modeled and verified in software VERICUT® to validate the NC data generated by proposed postprocessor.

Introduction

Five-axis CNC machine tools are becoming increasingly used because of their ability to machine parts with complex geometries efficiently and achieve higher dimensional accuracy. Since two additional rotational axes are introduced in five-axis CNC machines, five-axis NC machining offers many advantages over 3-axis ones, such as faster material removal rates, reduced machining time and improved surface finish. Programming of five-axis machining needs a postprocessor that converting CL data to machine control data (NC program). However, because of the two additional rotation axes, five-axis NC post-processing is more complex than that of the 3-axis machine.

A variety of postprocessor methods for five-axis machines has been investigated. Jung Y.H. et al. [1] developed algorithms for NC-postprocessor for typical five-axis milling machine of table-rotating/tilting type. She and Chang [2] focused on developing a five-axis postprocessor system with a nutating head. She [3] then also developed a postprocessor for two five-axis machine tools each with a nutating head and table configuration. Lee and She [4] developed a postprocessor for three types of five-axis machine tools. Kruth and Kelwais [5] developed a program of interference free with the modification of the CL by simulating NC data that are post-processed.

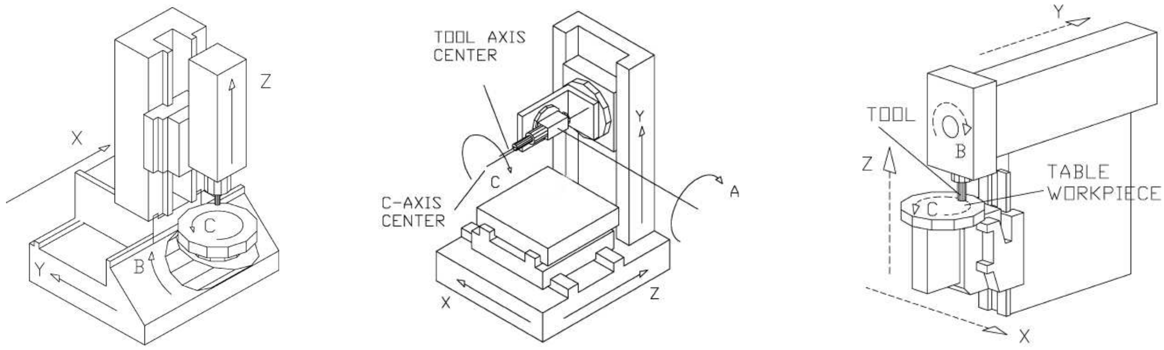
This paper develops a postprocessor for five-axis machine with two rotary axes on the machine table based on inverse kinematics transformation. A postprocessor software module is developed; generated NC data is then verified using commercial software VERICUT® to validate the proposed postprocessor.

Types of Five-Axis Milling Machines

The five-axis CNC machines can be classified according to the place where the rotation axes are implemented. Based on the location of the rotary axes, Bohez [7] classified the CNC machines into three main types:

(i) Five-axis machine tool with two rotary axes on the machine table - type A (Fig.1a): This kind of machine, the two rotary axes carry the workpiece and the tool axis can be fixed or carried by one, two or three linear axes. The tool axis during machining is always parallel to the Z-axis. Therefore the drilling cycles can be executed along Z axis of the machine. Circles under a certain orientation of the workpiece are always executed in the XY plane of the machine. These mentioned functions can be executed in the simple 3-axis numerical control mode. The disadvantage of this machine is the transformation of the Cartesian CAD/CAM coordinate (xyzijk) to the machine axes positions (XYZAB or C) is dependent on the position of the workpiece on the machine table. This means that in case of the position of the workpiece on the table is changed this can not be modified by a translation of the axes system in the NC program. They must be recalculated. In case the control of the NC machine cannot transform Cartesian coordinates to machine coordinates, a new CNC program must be generated with the postprocessor of the CAD/CAM system every time the position of the workpiece changes.

(ii) Five-axis machine tool with two rotary axes on the tool spindle - type B: For this type of machine, as shown in Fig.1b, the two rotary axes carry the tool. These machines can machine very large workpieces. Machine axis values of the NC program X, Y, Z depend on the tool length only. A new clamping position of the workpiece is corrected with a simple translation. A change in the tool length cannot be adjusted by a zero translation in the control unit; often a complete recalculation of the program (or post-processing) is required.



a) b) c)

Fig. 1 Types of 5-axis milling machines (source of Fig. [7]): a) Type A; b) Type B; c) Type C

(iii) Five-axis machine tool with a rotary table and a rotary tool spindle - type C: In this type of machine, one rotary axis is implemented in the workpiece kinematics chain and the other rotary axes in the tool kinematics chain, as shown in Fig.1c. This machine type is combining most of the disadvantages of both previous types of machines and is often used for the machining of smaller workpiece.

Inverse Kinematics Transformation Method

Forward kinematics is the process of calculating the position in space of the end of a linked structure, given the positions of all the joints. Inverse kinematics does the reverse. Given the end point of the structure, what positions do the joints need to be in the achieve that end point. This process is extremely useful in five-axis machine.

In five-axis machine, the CL data generated by CAM software are the cutter location (x, y, z) and orientation (i, j, k) defined in workpiece coordinate system. This x, y, z, i, j, k data must be transformed to the machine coordinates X, Y, Z, and (B, C) or (A, B) or (A, C) which control the motion of the machine. By the inverse kinematics transformation method, once the CL data is obtained, three linear joint motions (X, Y, Z) and two rotary joint motions (B, C) or (A, B) or (A, C) can be determined. The geometry transformation will transform from the workpiece coordinate system to the machine coordinate system.

As an example to illustrate the method; inverse kinematics transformation for five-axis machine in this paper is applied to the machine of type A (Fig.1a). The kinematics chain diagram of this machine is shown in Fig.2. The reference systems are selected in such away that the transformation from workpiece coordinates to machine coordinates can be done in simple steps. These intermediate reference systems are (Fig.3):

O_0 ($x_0y_0z_0$): located in the center of the table surface C, when B = C = 0^0. z_0-axis coincides with the C-axis centerline.

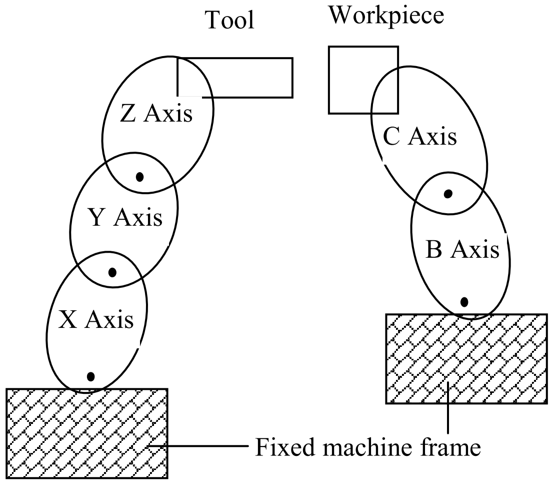


Fig. 2 Kinematics chain diagram

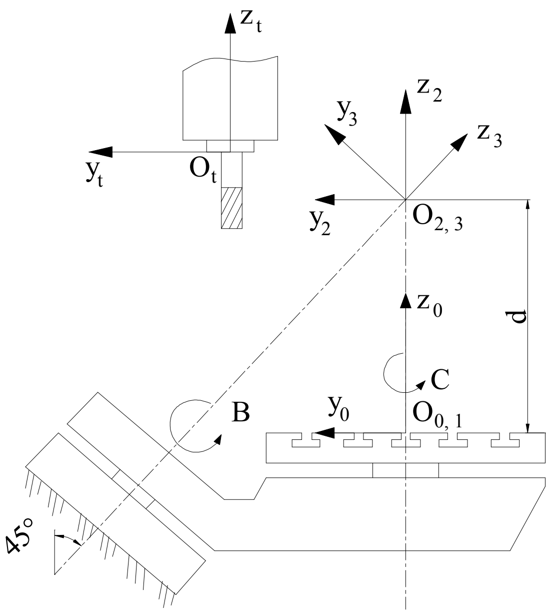


Fig. 3 Intermediate reference systems

O_1 ($x_1y_1z_1$): Obtained by rotating ($x_0y_0z_0$) around z_0 at an angle C
O_2 ($x_2y_2z_2$): Obtained by translating ($x_1y_1z_1$) at a distance d along z_0
O_3 ($x_3y_3z_3$): Obtained by rotating ($x_2y_2z_2$) around x_2 at an angle $+45^0$
O_4 ($x_4y_4z_4$): Obtained by rotating ($x_3y_3z_3$) around z_3 at an angle B
O_5 ($x_5y_5z_5$): Obtained by rotating ($x_4y_4z_4$) around x_4 at an angle -45^0
O_w ($x_wy_wz_w$): Obtained by translating ($x_5y_5z_5$) at a distance -d along z_4
O_t ($x_ty_tz_t$): Machine coordinate system fixed to the tool spindle tip.
Step 1: Rotation around z_0 at an angle C

$$x_1 = x_0 \cos C - y_0 \sin C$$
$$y_1 = x_0 \sin C + y_0 \cos C \qquad (1)$$
$$z_1 = z_0$$

Step 2: Translation $O_1 \rightarrow O_2$ along z_0 axis at a distance d

$$x_2 = x_1 + x_{o1o2}$$
$$y_2 = y_1 + y_{o1o2} \qquad \text{Where } z_{o1o2} = d \qquad (2)$$
$$z_2 = z_1 + z_{o1o2}$$

Step 3: Rotation around x_2 at an angle $+45^0$

$$x_3 = x_2$$
$$y_3 = y_2 \cos 45^0 + z_2 \sin 45^0 \qquad (3)$$
$$z_3 = -y_2 \sin 45^0 + z_2 \cos 45^0$$

Step 4: Rotation at an angle B around z_3

$$x_4 = x_3 \cos B + y_3 \sin B$$
$$y_4 = -x_3 \sin B + y_3 \cos B \qquad (4)$$
$$z_4 = z_3$$

Step 5: Rotation around x_4 at an angle -45^0

$$\begin{aligned} x_5 &= x_4 \\ y_5 &= y_4\cos 45^0 - z_4 \sin 45^0 \\ z_5 &= y_4 \sin 45^0 + z_4\cos 45^0 \end{aligned} \qquad (5)$$

Step 6: Translation at a distance -d along z_5

$$\begin{aligned} x_w &= x_5 + x_{o5ow} \\ y_w &= y_5 + y_{o5ow} \qquad \text{Where } z_{o5ow} = -d \\ z_w &= z_5 + z_{o5ow} \end{aligned} \qquad (6)$$

x_w, y_w, z_w can be solved by the above equations (6) to (1). The solutions for X, Y, Z of the NC data are found by solving:

$$\begin{cases} X = x_t = x_w \\ Y = y_t = y_w \\ Z = z_t = z_{O_wO_t} - z_T + z_w \end{cases} \qquad \text{Where } Z_T \text{ is the tool length} \qquad (8)$$

With $\cos B = 2k_0 - 1$, X, Y, Z can be expressed as:

$$X = \left[-y_0\sqrt{2\left(k_0 - k_0^2\right)} - x_0 + 2x_0k_0\right]\cos C + \left[x_0\sqrt{2\left(k_0 - k_0^2\right)} + 2y_0k_0 - y_0\right]\sin C + (d - z_0)\sqrt{2\left(k_0 - k_0^2\right)} \qquad (9)$$

$$Y = \left[x_0\sqrt{2\left(k_0 - k_0^2\right)} + y_0k_0\right]\cos C + \left[y_0\sqrt{2\left(k_0 - k_0^2\right)} - x_0k_0\right]\sin C - z_0 + d - dk_0 + z_0k_0 \qquad (10)$$

$$Z = \left[x_0\sqrt{2\left(k_0 - k_0^2\right)} + y_0k_0 - y_0\right]\cos C + \left[y_0\sqrt{2\left(k_0 - k_0^2\right)} - x_0k_0 + x_0\right]\sin C + d - dk_0 + zk_0 \qquad (11)$$

Where $x_0, y_0, z_0, i_0, j_0, k_0$ are tool tip position and tool orientation given in CL data.

By the same method and noted that $\begin{cases} i_4 = 0 \\ j_4 = 0 \\ k_4 = 1 \end{cases}$, the solutions for C-axis and B-axis can be found:

$$C = \arctan\left[(1 - k_0)i_0 + \sqrt{2\left(k_0 - k_0^2\right)}j_0, (k_0 - 1)j_0 + \sqrt{2\left(k_0 - k_0^2\right)}i_0\right] \qquad (12)$$

$$\cos B = 2k_0 - 1 \;\Rightarrow\; B = \arccos(2k_0 - 1) \qquad (13)$$

Based on the above inverse kinematics transformation method the equations to generate NC data for other types of five-axis machine tools can also be determined.

Implementation and Verification

A window-based postprocessor software module has been developed in Visual Basic language. The user interface of the software is shown in Fig. 4; the user can enter relevant parameters. The CL data is loaded and opened by clicking the "LoadCLFile" and "ViewCL" button. The corresponding NC data is generated by clicking the "Convert" button. The NC data is displayed by clicking "ViewResult" button.

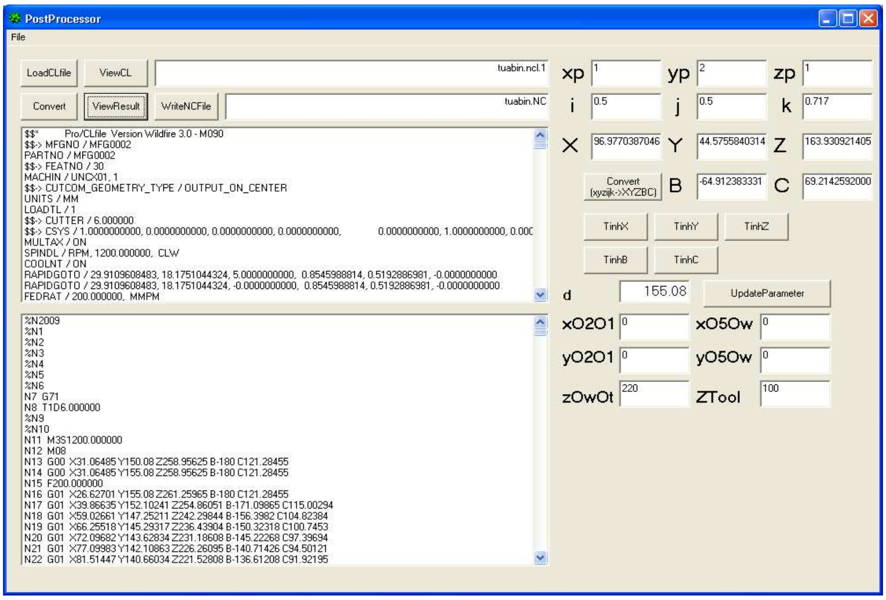


Fig. 4 User interface of the proposed postprocessor software

A turbine blade (Fig.5) is used to illustrate and validate the correctness of NC data generated by proposed postprocessor. The CL data is generated by the commercial CAD/CAM, Pro/engineer software. The solid cutting simulation by VERICUT© is shown in Fig.6

Fig. 5 Real turbine blade and its 3D model

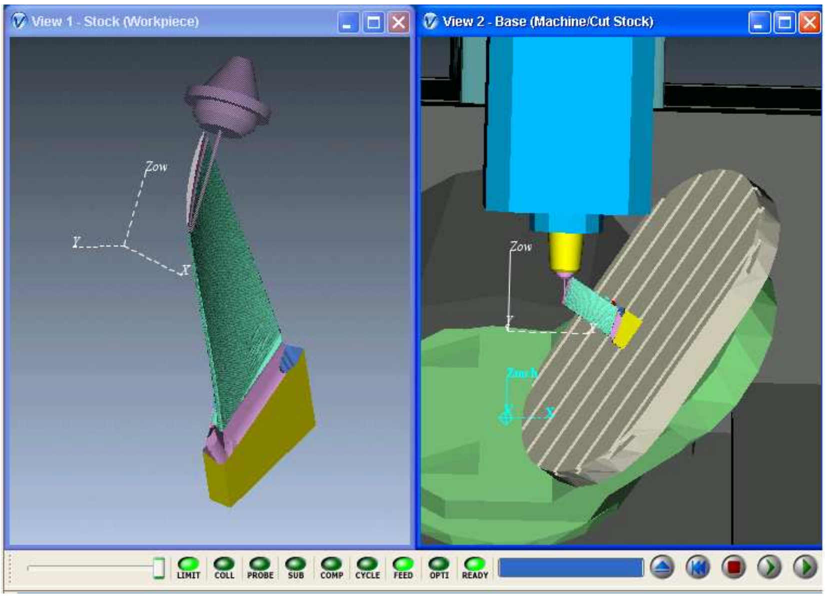
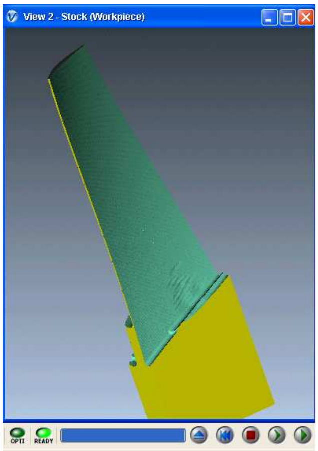


Fig. 6 In progress solid cutting simulation of the turbine blade in VERICUT® software

The results of the cutting simulation of the CL data and generated NC data are the same (Fig. 7.a and 7.b). This proved that the tool path of the NC data generated by postprocessor is correct.



a)

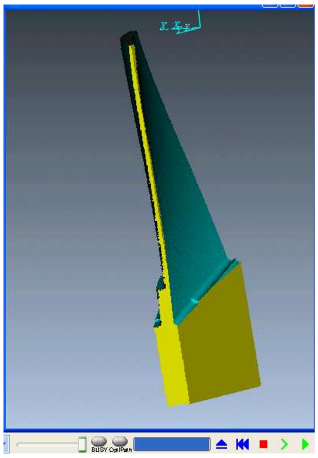

b)

Fig. 7 a) Cutting simulation by CL data; b) Cutting simulation by generated NC data

Conclusion

This paper has presented a postprocessor method based on inverse kinematics transformation. The CL data obtained from CAM software is transformed into five-axis reference inputs for controller of the five-axis machine using the inverse kinematics transformation. The proposed methodology can be utilized for various types of five-axis machine tools. The verification result in VERICUT® software proved that the proposed postprocessor is reliable.

Acknowledgement

The author is grateful to the National Foundation for Science and Technology Development (NAFOSTED) of Vietnam for supporting this research under grant No. 107.04.2011.09

References

[1] Jung, Y.H., Lee, D.W., Kim, J.S., Mok, H.S.: NC Postprocessor for 5-axis milling machine of table-rotating/tilting type. Journal of Materials Processing Technology 130-131 (2002), p641-646

[2] Chen-Hua She, Chun-Cheng Chang: Development of a Five-Axis Post-processor System with A Nutating Head. Journal of Materials Processing Technology 187-188 (2007), p60--64

[3] Chen-Hua She, Zhao-Tang Huang: Postprocessor Development of A Five-Axis Machine Tool with Nutating Head and Table Configuration. International Journal of Advanced Manufacturing Technology 38 (2008), p728—740

[4] Lee, R.S., She, C.H.: Developing a Postprocessor for Three Types of Five-Axis Machine Tool. International Journal of Advanced Manufacturing Technology 13 (1997), p658—665

[5] Kruth, J.P., Kelwais: NC-Processing and NC-Simulation for Five-Axis Milling Operations with Automatic Collision Avoidance. Proceeding of the International Manufacturing Engineering Conference, 1996.

[6] Knut Sorby: Inverse Kinematics of Five-Axis Machines Near Singular Configurations. International Journal of Machine Tools & Manufacture 47 (2007), p299-306

[7] Bohez, E. L. J.: Five-axis milling machine tool kinematics chain design and analysis. International Journal of Machine Tools & Manufacture 42 (2002), p505-520.

Manufacturing Science and Technology III
10.4028/www.scientific.net/AMR.622-623

A Five-Axis CNC Machine Postprocessor Based on Inverse Kinematics Transformation
10.4028/www.scientific.net/AMR.622-623.525