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Interpolation of Toolpath by a Postprocessor for Increased Accuracy in Multi-Axis Machining

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Abstract

The article focuses on the issue of generating points of the toolpath for multi-axis machining. In multi-axis machining, it is possible to control the toolpath using the coordinate transformations of tool center point (TCP) in the control system, or these transformations in the control system are not available and it is necessary to use the transformations in the postprocessor. However, without the use of TCP, the required toolpath tolerance is not respected. Therefore, an algorithm has been proposed in the postprocessor that dynamically generates new toolpath points so as to maintain the required tolerance and to ensure manufacturing accuracy. This algorithm has been verified by implementation in the postprocessor and generation of NC programs for machining of impeller blades. By the postprocessor recalculated tool path meets the required tolerance.

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Keywords: Machining; Tool path; Accuracy; Multi-axis; Postprocessor

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1. Introduction

Multi-axis machining of complex shape parts (e.g. an impeller in Fig. 1) is one of the most complex technologies. Many errors entering the machining process are involved in the resultant error of machined parts. These errors can be caused by specific accuracy of the machine tool, tools, the effects of stiffness of the machine tool – tool - workpiece system as well as thermal behavior. However, there are also errors resulting from data processing, whether on the level of the control system or CAD / CAM system. The issue of proper preparation of data for machining complex parts has been dealt with by many authors.

One method for compensating geometrical errors in the five-axis machining process is described for example in lit. [1]. The method first deals with compensation of geometric errors caused by rotational axes of the machine tool and then with compensation of errors caused by linear axes. The issue of minimizing deviations arising after machining is dealt by authors of lit. [7]. In this paper, the optimization of tool path in multi-axis machining is discussed with respect to two different approaches. One optimization algorithm is designed with respect to the achievement of minimum strain energy in the process of machining and the criterion is surface smoothness. The second optimization algorithm is based on minimizing deviations arising after machining of the surface. Extensive research on this issue was conducted by the authors of lit. [2] and [5].

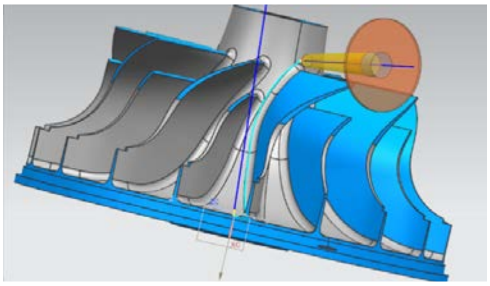

Fig. 1. Typical complex shape part: impeller

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These papers dealt with the proposal of a computational model for the prediction of cutting forces during machining. This issue is handled by authors of [10] or [3] too. Their papers also contain proposals of computational models for the prediction of cutting forces during machining. However, the model in lit. [10] is based on the knowledge of CL-data which are received from the CAM system. Using the proposed software, cutting forces can be predicted.

Authors of lit. [4] reported, that the use of spline interpolation has the effect of increasing the surface quality and also saving machining time. However, this function can be used only when using CAM CATIA and control system Sinumerik.

The toolpath for multi-axis continuous machining can be prepared in two ways. The first can be based on using transformations called Tool Center Point (TCP), which are included in the control system (such as TRAORI, or TCPM, etc.). In the second case the toolpath can be computed with the transformations in the postprocessor. The transformations TCP in the control system cannot be used in some cases. The main reason why it is not possible to use TCP is that the kinematical configuration of machine tool axes is not supported in the control system. The second reason is that the technologist does not want to use TCP because the toolpath can be very difficult to modify by the machine tool user.

According to the authors of lit. [6], geometric errors are also caused by the movements of the rotary axes near the so-called stationary points. These are the points at which the tool reaches parallelism with the rotational axis of the machine tool. At these points the machine tool performs additional movements of rotary axes so that the next point in the NC program can be achieved by linear interpolation. However, it will cause errors on the part surface. The error is dependent on the actual radius of rotation of the reference point of the tool towards the axis of rotation. A method is presented in the above-mentioned paper to minimize the occurrence of these errors. The sections of the tool path are replaced by a different tool path that avoids the stationary points. The algorithm is suitable only for point milling, not for flank milling, where it is necessary to accept the toolpath as calculated by the CAM system. Another solution is offered by the author of lit. [8], which deals with the same issue by additional interpolation of tool path points. Thanks to this, the orientation of the tool axis to the workpiece surface is maintained along the tool path so as to avoid undercutting of the workpiece surfaces. However, the algorithm is based only on the assumption of a pre-established maximum possible change in angular coordinates in two consecutive blocks of the NC program. This change is then constant for all cases of computation of the relative positions of the reference point of the tool and the current axis of rotation. The number of newly interpolated points of the tool path is not controlled by the required tolerance of toolpath. If we assume that the change in angular coordinates will be identical in the next two blocks, then the same number of points is interpolated at greater distances between the reference point of the tool and the current axis of rotation as at shorter distances. This may have an impact on the characteristic of feed rate, because when too many points of toolpath are interpolated, it leads to very small increments in machine tool axes.

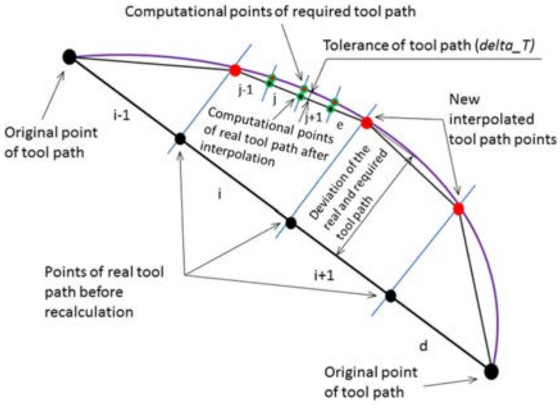

Fig. 2: Real and required path of tool reference point

Consequently, it is possible that the control system is not able to achieve the required feed rate. It is necessary to emphasize that these errors may arise also in other areas of the toolpath. The main deficiency is that the algorithm is not controlled by the required tolerance of toolpath, specified by the user. Therefore, in the following part of this paper, a method for interpolation of the tool path in the postprocessor is presented, which is controlled by the given toolpath tolerance.

2. Interpolation of tool path points

The interpolation of the tool path is based on the fact that the real tool path as well as the required tool path can be calculated by the postprocessor. The Fig. 2 shows the points of the real path of the reference point of the tool, but also the points of the required tool path, with new points (red points) that are necessary to meet the required tolerance of the tool path. For the interpolation of these points transformation equations are used. These must be prepared for each of the kinematic configuration of the machine tool axes. The following equations are examples for the machine tool with rotary axes *B* and *C* on the machine table. For this machine tool the CL data (coordinates *CL_X*, *CL_Y*, *CL_Z*) from the CAM system have to be transformed to coordinates of the NC program (coordinates *X*, *Y*, *Z*) using the following matrix notation (1). The matrix $T_{WCS \to MCS}$ is the resulting transformation matrix and can be computed as product of the matrix $T_{\varphi(C)}$ and $T_{\varphi(B)}$ which are the matrices for angular transformation, see (2) and (3).

$$r_{MCS} = T_{WCS \to MCS} \cdot r_{WCS} = T_{\varphi(C)} \cdot T_{\varphi(B)} \cdot r_{WCS} \tag{1}$$

$$T_{\varphi(C)} = \begin{bmatrix} \cos C & -\sin C & 0 & 0 \\ \sin C & \cos C & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) \qquad T_{\varphi(B)} = \begin{bmatrix} \cos B & 0 & \sin B & 0 \\ 0 & 1 & 0 & 0 \\ -\sin B & 0 & \cos B & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$r_{MCS} = \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad (4) \qquad r_{WCS} = \begin{bmatrix} CL\_X \\ CL\_Y \\ CL\_Z \\ 1 \end{bmatrix} \quad (5)$$