Virtual cutting to improve the product tolerances of 5 axes machine tools

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Abstract

The aim of this research is to predict the tolerance and surface finish of a machined product thanks to the study of the dynamic behavior of a 5 axes machine tool and to correct the toolpath and process parameters (i.e. feed) in order to meet the specifications. To reach this goal will be realized an approach to evaluate the dynamic stiffness of the machine, the forces during machining (both cutting and inertial forces) and the tool displacement. The analysis of the static and dynamic behavior of the machine will be predicted thanks to the development of a flexible multi-body model with special care to joints characterization. Some variables of the model will be characterized experimentally on the machine and will be conducted specific machining tests to validate the model. The paper reports also some preliminary results for a 3 axes milling machine.

Keywords: Flexible multi-body simulation, Toolpath optimization, Machine Tool dynamics

1 INTRODUCTION

The numerically controlled (NC) machine tool's history is not very long. Research started from the early beginning of NC machine tools when the Massachusetts Institute of Technology (MIT) first introduced the machine tools for the United States Air Force in 1950. In the past many aspects of the CNC machine have been studied by researches all over the world but only recently the topic of error modeling and compensation has been conducted in an attempt to enhance the accuracy of multi-axis CNC machine tools. The final objective was to understand, model and calculate the errors of the manufactured workpiece on respect to the designed one in order to verify the tolerances and, eventually to reduce the errors and improve the accuracy. The main sources of these errors are programming and interpolation algorithm, the driving mechanisms, workpiece-tool and machine tool deflections due to the cutting and inertial forces, and thermal deformations. Taking into account these sources many authors have proposed different methods to compensate the errors. Many use different methods to evaluate the mean error of the machine in the work space, eventually creating an error map, and post process the data in order to use a fit compensation strategy, some instead use predictive approach to preprocess the toolpath data.

Anjanappa et al. [1] developed a method for cutting force independent error compensation based on the assumption that the machine and workpiece could be considered as rigid bodies. Kiridena and Ferreira focused their efforts on the analysis of the quasi-static errors of a machine tool [2], and proposed a general kinematic model [3], and an approach for the proposed model parameters measurements [4], thanks to which could be developed a computational approach for three-axis machine tools compensation [5]. Srivastava [6] used the Denavit-Hartenberg transformation to build a compact volumetric error model, which considers the shape and joint transformations of inaccurate links and joints using small angle approximations. Suh [7] focused on the rotary table of five-axis machine tools and presented a complete error model for it, and Sakamoto [8] used a telescoping ballbar to inspect and diagnose the error origins. Bohez [9] proposed an approach on how to compensate for the systematic errors for five-axis NC machining based on the closed loop volumetric error relations. Lei and Hsu [10] developed the 3D probe-ball and spherical test method for measuring and estimating link errors: it was proved that the accuracy of five-axis machine tools could be dramatically improved by using a model-based real-time error compensation method.

Some authors proposed also methods to improve the accuracy thanks to a different control on the process parameters. Chuang and Liu [11] proposed an adaptive feedrate control strategy based on estimated contour error so that the desired feedrate could be adjusted adaptively. Yun and Jeon [12] proposed a feedrate control approach that exploits the idea of inverse mapping, in which the relationship between contour error and feedrate is identified using a multi-layer neural network. Tarng et al. [13], and Huang and Lin [14] developed feedrate regulators based on fuzzy logic to reduce contour error.

Through improving machining accuracy from toolpath generation, Bohez et al. [15] minimized the errors introduced in the cutter location file (CL file) and postprocessor by approximating the surface with the real curved tool-path instead of using a piecewise linear approximation. Aekambaram and Raman [16] improved the toolpath generation with CAM by reducing the interpolation error. They assumed that the real toolpath on the machine between two CL-points was linear. Considering the effect of friction, Mei et al. [17] proposed a simple approach for compensating friction error of high-precision tables.

The core of all these developed approaches is the search for a model for the error evaluation; this model has to be representative of the output error but not too complex in order to be easy set up. Most of the models proposed are just descriptive of the effect of error on machined surfaces while few try to model the manufacturing process and the sources of errors. Thanks to the ever increasing computational power of the modern workstation and the development of advanced simulation strategies now it is possible to simulate, in a reliable way, not only the effect of error but the whole machining process and the machine behavior during cutting operations, including tool deflection and vibration. This dynamic simulation model of a machine tool is fundamental in order to improve farther the performance that the modern machine tool has to meet in order to be competitive. These approaches are already