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Error compensation and accuracy improvements in 5-axis machine tools using the global offset method☆

Jie Gu*, John S. Agapiou, Sheri Kurgin

General Motors R&D, United States

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ABSTRACT

To enhance the machine tool accuracy, the Global offset method is developed for compensating the five-axis machine tool errors based on the measurement results of one or more identical machined parts. The machined features of a part are measured in a CMM and evaluated by a compensation processor, based on which the Global offset parameters, representing the machine tool errors, are estimated. The methodology is capable of compensating the overall effect of all position-dependent and position-independent systematic errors which contribute to particular workpiece accuracy. The developed technique and software are based on the Global offset method which interprets the computed deviations between the measured and nominal dimensions of the part through the analysis, synthesis and modeling of a fixture and rotary tables errors. The proposed model-based error compensation method is simple enough to be implemented in five-axis CNC machine tools. Production results exhibit effective compensation and remarkable improvement in the workpiece accuracy of the five-axis machine tools.

1. Introduction

CNC (Computerized Numerical Controlled) Machine tools are being used increasingly for high to medium volume manufacturing [1]. Five-axis machines are multitasking because they provide maximum flexibility for machining complex parts in a single setup and produce three dimensional free forms. These machines allow manufacturers to adjust for changing product designs and volume requirements, and are very accurate. Automotive, aerospace, die and mold, and biomedical industries are benefiting from 5-axis machines.

High accuracy of the machine tools is essential to meet the challenges of today's manufacturing precision part assemblies. It is well understood that machining process variation leads to non-conforming components and high quality costs. Therefore, machine performance assessment and calibration is often necessary to align the machine's performance with the process requirements. It has been found often very challenging and very time consuming to identify and control variation in a factory environment. Five-axis machine tools have three linear axes and two rotary axes in various arrangements with 43 independent geometric errors whose compensation is a complex task. The error of a linear axis affects the position of the cutting tool, while the error of a rotary axis affects the position and orientation of the cutting tool. Typically, the largest component of a positioning error is the inaccuracy in the two rotary tables, because the errors quickly increase depending on the distance the programmed point lies from the center of rotation. The compensation of a rotary axis is quite difficult, complex and cumbersome to compensate compared to a linear axis [1].

Machine accuracy is directly related to the systematic geometric errors of the machine tool, fixture errors, part clamping distortion, part cutting distortion, tool and spindle deflection, machine tool thermal deformation, etc. There are several methods to evaluate and compensate a machine tool as discussed in details in several references [2–9]. Traditional acceptance test procedures, based on direct measurement of machine tool errors to improve accuracy are slowly replaced with indirect measurement techniques to reduce the evaluation and calibration time required to assess the volumetric accuracy of machine tools. The evaluation and calibration techniques are available in literature [10–12], while the laser tracker is highlighted as the latest technology [11]. Even though machine tool accuracy assessment

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* Corresponding author.
E-mail addresses: Jie.1.gu@gm.com (J. Gu), John.agapiou@gm.com (J.S. Agapiou), sheri.kurgin@gm.com (S. Kurgin).

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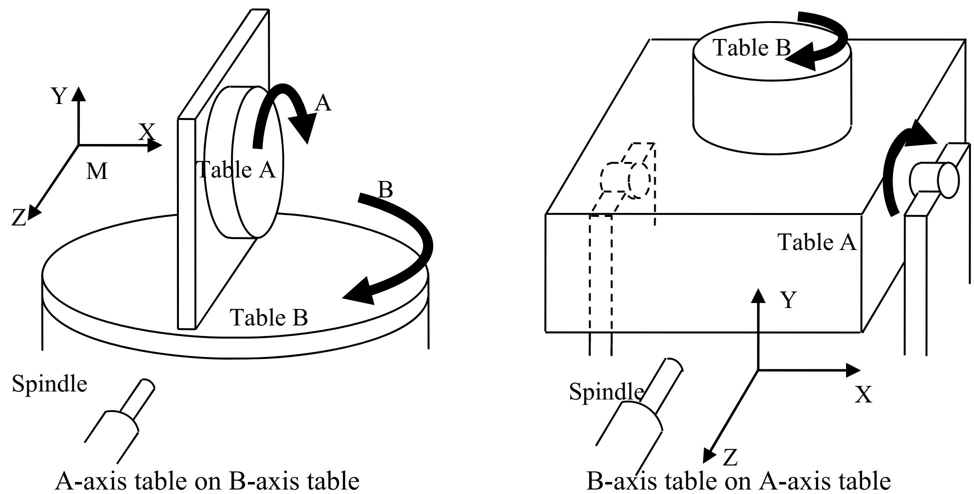

Fig. 1. Illustration of 5-axis machine tool.

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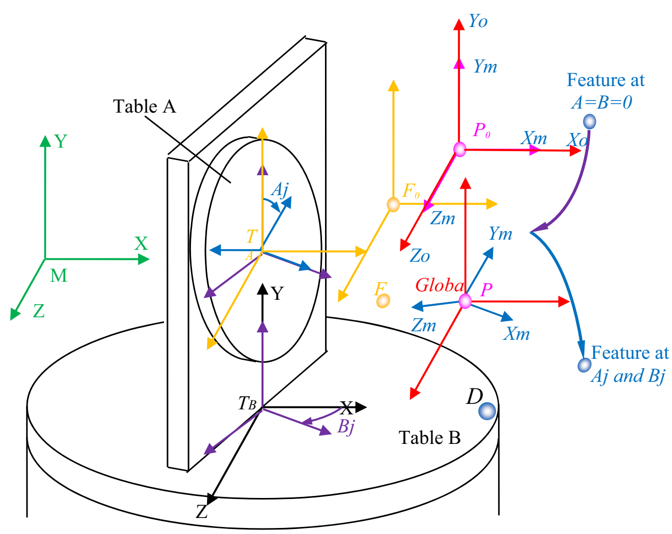

Fig. 2. Global-machine-CMM coordinates, 5-axis A- and B-tables machine.

often requires complex sets of measurements, unfortunately, there is no reliable short-cut method (or single parameter) that can be used to assess the volumetric accuracy of machine tools. The specific details of testing are found in the various standards developed [13–15].

The aim of this paper is to introduce an innovative compensation method called Global Offset for 5-axis machine tools. The strategy behind this method is to utilize the geometrical and profile measurement errors of a part that are used for compensating the machining process for identical parts. This new automated compensation method for 5-axis machine tools is based on the dimensional measurements of identical parts in a CMM (Coordinate Measurement Machine); it estimates the offsets in the WCS (Work Coordinate System) to compensate the machine tool errors including the fixture and table/pallet errors together with some of the dynamic errors due to part clamping, tool deflections, and average temperature changes in the workspace. The compensation method is based on error correction through software and interfacing the NC program with macro variables without generating new NC Codes. The compensation processor utilizes the Global offset parameters to offset the cutter locations specified in the NC Codes. It is successfully implemented to attain the desired part accuracy as the simulation and production parts compensation results have shown.

2. Error model of five-axis machine tools

Consider a horizontal five-axis machine tool with A and B-rotary tables whose spindle and table motion are programmed in a coordinate system as illustrated in Fig. 1. Also, consider a part located on the fixture that sits on the A table (with A-axis table on B-axis table). Fig. 2 illustrates the various coordinate systems for this machine. The objective of the error model is to evaluate the position and orientation of the cutting tool in the workpiece coordinate system by superimposing the errors for the fixture and table assembly into nine parameters. Each parameter corresponds to a work offset variable.

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