Identification and Compensatory Control of Time-varying Volumetric Errors in Machining Centers

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Abstract: A real time error compensation system which can compensate for the time-varying volumetric errors due to thermal errors is studied by monitoring the machine temperatures. Volumetric errors due to squarness errors and linear thermal expansions of slides are formulated through the HTM (homogeneous transformation matrix). Measuring and identification methods for principal components of 21 geometric errors and thermal errors are proposed. The time-varying volumetric errors are modeled as functions of position and temperature variation by using the least square method and the GMDH (group method of data handling) algorithm. The experimental results showed that the positioning accuracy along the diagonal axes was better than ±5μm, while the accuracy without compensation was greater than ±100μm. It is confirmed that the volumetric error model proposed in this study is effective for precision manufacturing using this RTVEC (real time volumetric error compensation) system under no-load conditions.

Keywords: GMDH algorithm, Least square method, Real time volumetric error compensation system, Time-varying volumetric error

1. Introduction

The performance of machine tools in terms of accuracy is defined by the error of the relative movement between the cutting tool and the ideal cutting point on a workpiece. For a 3-axis machine tool, this relative error is called the volumetric error and can vary widely over the workpiece due to geometric errors and time varying thermal changes of machine tools. Peltenik remarked that thermal errors could comprise 40-70 percent of the workpiece error in precision machining.[1] Therefore, there have been extensive researches on formulation and compensation for the thermal error of machine tools. In this paper, identification of principal components of the time-varying volumetric errors due to thermal errors and an error compensation system which can compensate for them by monitoring the machine temperatures are studied.

2. Identification of thermal deformation

2.1 Thermal error model

In general, machine tools are built by the combination of fixed links and prismatic joints. These components comprise a closed chain between the tool contact point and the workpiece. The HTM method [2] offers an effective approach to the ideal thermal error model. Let's consider the case of a solid link. With a translational vector \( \{a, b, c\}^T \), the shape error matrix across the ideal link is given by

\[
\Phi_{\text{err}} = \begin{bmatrix}
1 & -a(x,t) & b(x,t) \\
0 & 1 & c(x,t) \\
0 & 0 & 1
\end{bmatrix}
\]

(3)

For a linear slide, errors are generated as functions of position along the joint axis. Angular errors along the moving axis cause straightness errors in perpendicular directions. Under the assumption of small errors, the resultant joint error matrix of the joint of \( X \) axis is

\[
\Phi_{\text{err}} = \begin{bmatrix}
1 & -a(x,t) & b(x,t) & x + f(x,t) \\
0 & 1 & c(x,t) & g(x,t) \\
0 & 0 & 1 & 0
\end{bmatrix}
\]

(3)

where, \( a, b \) and \( c \) are dimensions along each axis.

In practice, a rigid body may have three rotational \( \{\alpha', \beta', \gamma'\} \) and three translational \( \{\delta a, \delta b, \delta c\} \) error components along the reference coordinate axes. Under the assumption of small errors, the resultant HTM across the actual link with respect to its ideal position is given by

\[
T_{\text{err}} = \begin{bmatrix}
1 & -\alpha'(t) & \beta'(t) & a + \delta a(t) \\
0 & 1 & -\gamma'(t) & b + \delta b(t) \\
0 & 0 & 1 & c + \delta c(t)
\end{bmatrix}
\]

(2)

where, \( a, b \) and \( c \) are dimensions along each axis.