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A study of thermal deformation in the carriage of a permanent magnet direct drive linear motor stage

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HIGHLIGHTS

► Deformation occurs in carriages which are mounted with linear motor.
► The convective coefficient, which is assumed to be 10 W mm^{-2}, is shown to be invalid.
► The perfect contact conductance is shown to be invalid too.
► To have an accurate thermal model, boundary conditions have to be realistic.
► Boundary conditions are the heat source, convective and conductance values.

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ABSTRACT

Carriage deformation due to temperature gradients within the materials of the carriage affects the accuracy of precision machines. This is largely due to the indeterminist temperature distribution in the carriage's material caused by the non-linearity of heat transfer. The joule heat from the motor coil forms the main heat source. When coupled with the heat loss through convection and radiation, the temperature variation in the motor's carriage also increases. In this study, the Finite Element Analysis was used together with a set of boundary conditions, which was obtained empirically, to analyze the distortion of the motor's carriage. The simulated results were compared with those obtained through experiments. The study shows that it is important to know, rather than to assume, the thermal boundary conditions of the motor's carriage of a precision machine in order to accurately estimate the thermal deformation of the carriage in precision machining.

1. Introduction

The inaccuracy of precision machines is caused by static and dynamic errors. Generally, static errors are mainly due to geometrical part tolerance and assembly errors. Such errors are usually deterministic and can be compensated by controlled methods. On the other hand, dynamic errors are present in different processes even when the same machine is used. They change with time and require a model to characterize and compensate for the errors. Two well-known dynamic errors are vibration and thermally induced errors. In ultra-precision machines, thermal errors can account for as much as 70% of the total machining errors [1]. In recent years, precision machines having better performance are increasingly equipped with linear motors, which replace conventional ball-screw mechanisms. While these linear motors are able to provide higher speed and better precision over ball-screw mechanisms, they produce more heat and, in turn, transfer it to the carriage. The heated carriage deforms non-linearly according to its temperature profile which is influenced by the carriage geometry and convective heat loss [2].

Thermal analysis on precision stages or carriages equipped with linear motors has not been thoroughly conducted. Compared with mechanisms with ball-screw stages, the study on the thermal effect of linear motors appears to be fewer. Several studies on carriage deformation using finite element analysis and carriage temperature profiles using one-dimensional lumped model had been investigated. Eun [3] examined the thermal behavior of asynchronous and synchronous single sided linear motors. Trade-offs between available torque and high motor coil temperature for choice of motors were discussed. Kim et al. [4] studied the thermal behavior and positional error in the spindle of a machine tool, which was equipped with linear motors for its *X*, *Y* and *Z* linear motions. In their work, Jang et al. [5] analyzed the heat transfer of a single axis linear

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