Coupled Fluid-Thermal-Structural Analysis of Motorized Spindle

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Abstract

The spindle is regarded as the heart of the CNC machine tool. Typically, the spindle is operated using the belt or gear drives to realize the relative motion between workpiece and cutting tool. However, they cannot be operated at high speeds due to power transmission losses, thus limiting the productivity of machine tool. To overcome this problem, nowadays motor is built into the spindle unit. This, however, will result in the build-up of heat within the motorized spindle, leading to its significant thermal distortion and ultimately, the reduced precision of machined products. In order to attenuate such an effect, forced cooling of the spindle is employed through an externally operated cooler unit. To understand and improve the effectiveness of external cooling, it is first necessary to characterize the heat sources in a motorized spindle.
The present study involves the estimation of heat sources in a motorized machine tool spindle using COMSOL Multiphysics® optimization module and experimentally obtained temperatures. The heat generation rate in the in-built motor and the spindle supporting bearings depends on the operating conditions such as spindle speed and load. Appropriate functional forms for the heat generation rate are assumed and the model is fitted using the inverse method. For this purpose, Levenberg-Marquardt and Conjugate Gradient methods are used in conjunction with the experimental temperature measurements at various critical points in the spindle unit. The procedure is repeated for different spindle speeds and a relation between spindle speed and heat generation rate is obtained through curve fitting. The next part of the work constituted optimization of cooling channels to reduce spindle growth as well as angular deformation of the spindle in a coupled fluid-thermal-structural modeling framework in COMSOL Multiphysics®. The existing coolant channel design is made so as to cool the motor and then the front bearings: specifically, the coolant enters the spindle and cools the motor through its circulation around the stator region of the motor unit and then enters the front bearing region for cooling and then exits the front bearing region. Although the geometry of spindle is axisymmetric, the cooling is not symmetric and therefore complete 3D modeling involving simulation of incompressible fluid flow, heat transfer and finally, structural mechanics module of COMSOL Multiphysics® is performed. The results showed that acute angle between the entry and exit point of coolant near front bearing is the main contributor for significant angular distortion of spindle. Optimization of coolant channels is then performed by making an angular shift between the coolant entry and exit points to result in lower thermal distortion of spindle when compared with the existing design.

Figures used in the abstract

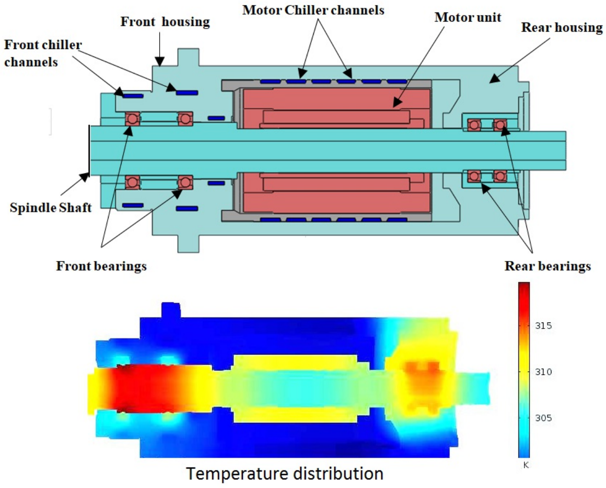

Figure 1: Schematic of motorized spindle along with the temperature distribution