Dynamic characteristic of thermally affected high speed spindle

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Key Words : Angular contact ball bearing, thermal expansion, centrifugal expansion, heat generation, bearing stiffness, natural frequency

1. Introduction

The failure and vibration of high speed spindles in machine tools have been studied to predict the behavior of machining elements before manufacturing. As the rotational speed increases, dynamic characteristics of bearings such as contact loads, stiffness, contact angle, axial displacement and thermal effect. In particular, thermal behaviors of machine tool spindles can qualify the subsequent manufacturing processes. Heat sources include the heat inside the bearings, motor, and the heat generated between tools and workpieces. This study analyzes bearing heat generation in the bearings and built-in motor, then the subsequently dynamic characteristics of the spindle. Heat is generated due to friction in the contact areas between the ball-inner ring and ball-outer ring. The heat is then transferred to surfaces of bearing rings-housing, the inner rings-shaft and the air. Radial thermal expansion of ball, inner ring-spindle and outer ring-housing are computed based on the rotational speed of the spindle. The formulation contains thermal expansion and dynamics of each ball in a bearing while the shaft is rotating and the bearing stiffness matrix is obtained using the Newton-Raphson method. The behavior of bearing stiffness is then used in a finite element model to investigate frequency responses of the spindle system.

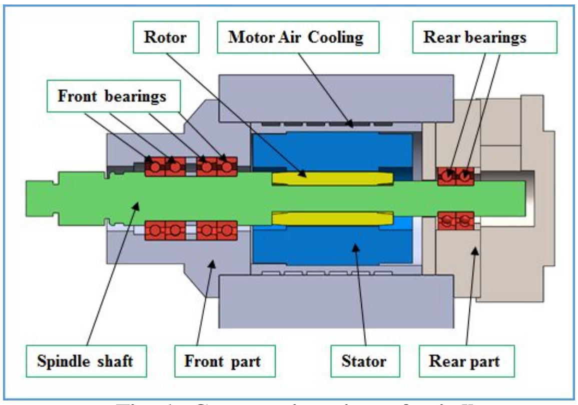

Fig. 1. Cross section view of spindle

2. Research objective

Heat generation in the spindle system in this study includes the amount of heat generated in bearings and in built-in motor. Heat generation as spindle speed increases can be found analytically as in Figure 2, for front bearings (NSK 7904C) and rear bearings (NSK 7001C). In order to predict bearing stiffness precisely, however, a large number of elements need to be considered, including centrifugal force, centrifugal expansion, velocity of balls, Hertzian contact, thermal expansion, solid or flexible couplings as well as friction force.

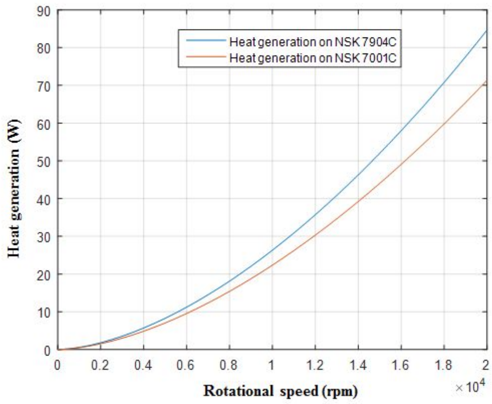

Fig. 2. Heat generation in bearings

A component of bearing stiffness matrix of the front bearing as spindle speed changes is presented in Figure 3. The changes of bearing stiffness matrix due to the increases of speed and thermal expansion are then used to find frequency response changes.

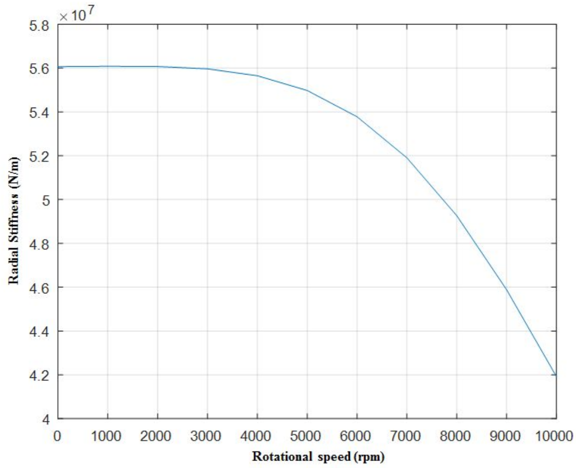

Fig. 3. Axial stiffness of the front bearing

3. Results

The changes of dynamic stiffness lead to changes of frequency response. It is observed that natural resonants are shifted when the bearing stiffness decreases.

References

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