ABSTRACT

The accuracy of machine tool is very much essential for realizing quality products since all the metal components undergo machining at some stages in their production. The precision in machining is affected by the thermo-elastic behavior of the machine tool due to transient variation in temperature. The accuracy of thermal error compensation reduces as the twisting and bending of machine components occur along with deformation. The reduction in power loss from various heat sources is not possible beyond a certain limit and hence achieving control over the flow of heat gives a better solution.

Experimental investigations were carried out in a two-axis slant bed CNC lathe with the spindle rated at 7.5kW power and 2800 rpm maximum speed. The chucking cylinder placed on the rear side of the spindle rotates along with the spindle. The front bearings of the spindle which are a combination of double row cylindrical roller bearings and angular contact ball bearings help to handle radial and axial loads whereas the cylindrical roller bearings in rear support the pulley and the chucking cylinder. Sensors are mounted on the key locations of the machine tool by thermal grease which ensured proper thermal conductivity and foam insulated sensors from the environment. The measurement of thermal displacement at TCP (Tool Center Point) was carried out on the invar rod mounted on the spindle nose with the aid of displacement sensors mounted on the turret. The measurement of thermal displacement at TCP arising from the thermal deformation of axis feed drive system was carried out by rearranging the above set up since the thermal error measurement could not be accomplished during machining.

Two different load cycles were chosen for the spindle and axis feed drive assembly based on the different operations performed in the machine tool. The temperature and thermal error measurements were made at intervals of 5 minutes. The spindle was operated at varying speeds from 0 to 2800 rpm. The sensor measurements indicated that a maximum temperature of 41°C is attained at the front bearing while the temperatures at the rear bearing and chucking cylinder bearing are 39°C and 70°C respectively. The temperature variation in the X-axis ball screw system is due to the flow of heat from the drive motor and support bearings into the ball screw. The maximum temperature at the X-motor is 49°C. Maximum displacements of 6 microns, 50 microns, and 39 microns were recorded in X, Y and Z directions of the headstock assembly respectively. The measured temperature and the thermal error data are further utilized to validate the results of the finite element model.

A finite element model of CNC lathe is developed to obtain the temperature distribution and transient thermal deformation using ANSYS software. The variation of temperature obtained from the numerical analysis follows a similar pattern of load cycle considered for experiment and the results are found to be in good agreement with the experimental results. The finite element model is used to carry out the numerical analysis for the machining operation with the estimated thermal loads and convective heat transfer coefficients. The pattern of load cycle considered for machining is same as that of free running condition. The maximum temperature at the front bearing for machining condition is of 43°C. The displacement of X-axis in location X_2 closer to TCP reaches a maximum of 13 microns while the displacement of Y-axis and Z-axis is found to be 71 microns and 49 microns respectively.

Numerical analysis is carried out to investigate the influence of machining heat generation on the temperature rise in the spindle system, by replacing the invar rod with workpieces made of medium carbon steel and brass. The temperature rise closer to machining zone is found to be higher, and there is no influence of machining heat generation on the temperature rise in the spindle nose as the cutting fluid carries away much of the heat generated during machining and a similar trend is observed for brass.

The displacement of 13 microns in X-axis is found to be significant for the form error of the machined component that is attributed primarily to the deformation of the bed. The insulation of bed from the heat sources is found to reduce the deformation of the bed. A finite element model of CNC lathe, with composite plate sandwiched between the headstock and the bed, is developed to investigate the thermal behavior and the proposed model results in a near zero displacement along the X-axis of the spindle. The thickness of the laminate is determined based on the temperature drop at the interface of headstock and the bed. The composite plates sandwiched between the housing and X-motor as well as between Z-motor and housing prevent the flow of heat into the ball screw system. A temperature drop of 5°C was observed at the ball screw support bearing after insulation.

Further, from the numerical analysis carried out by insulating the spindle-head from the column of vertical machining center, a marginal increase in the maximum temperature is predicted in the spindle-head. The cantilever bending of the spindle head and column, each individually, contributes for the deformation of equal magnitude in the opposite direction, and the insulation material has almost no contribution.