ABSTRACT

The demand for high quality of products along with improved productivity has necessitated research on enhancing dynamic performance of machine tools. Polymer concrete or epoxy granite based alternate materials are becoming more popular over the past two decades for beds, bases, and other structures of precision machine tools, owing to their excellent damping characteristics. Epoxy granite has a low elastic modulus; to maintain the same static rigidity as cast-iron structures, Steel-Reinforced Epoxy Granite (SREG) structures are more successful than designing bulk structures. But, due to the vast differences in the thermal properties of steel and Epoxy Granite (EG), the use of SREG structures are likely to cause higher magnitudes of thermal error.

The primary objective of this research work is to investigate the thermal behaviour of a Computerized Numerical Control (CNC) lathe built with a novel dynamically enhanced SREG bed and compare its performance with the lathe with a cast iron bed.

To achieve the primary objective of the research work, initially experiments are conducted on a lathe that was originally constructed with a cast iron bed, with the Cross-Feed drive (CF) idling. Subsequently, the experiments are repeated on the lathe fitted with a newly developed SREG bed instead of the original cast iron bed. International Organization for Standardization (ISO 230-3) provides methods for a systematic examination of the thermal behaviour of machine tools. Although various machining operations on the machine tool have varying load cycles, according to the standard, the feed drive should operate for 6 hours at the specified load cycle

comprising traverse at a maximum speed of 20 m/min for three minutes and idling for one minute. Thermal analysis of lathe with a CI bed and lathe with SREG bed in closed Environmental Temperature Variation Chamber (ETVC) conditions at 20ºC and 40ºC were investigated to understand the impact of internal heat sources on newly replaced bed on thermal error. Results reveal that the thermal error in the CNC lathe with SREG bed is 1.68 times that of the lathe with Cast Iron (CI) bed at 20 ºC and 1.8 times at 40ºC ETVC conditions. It could be identified that the heat generated in the CF is conducted to the steel guideways embedded in the SREG bed, but further heat transfer to the EG portion of the bed is impeded, and hence the heat accumulation that occurs in the guideways leads to higher magnitude of the thermal error.

Secondly, numerical investigations were carried out using solid models of both lathes. In order to provide boundary conditions to the numerical models, analytical heat calculations are used to approximate the same amount of heat generated in real-time. For the lathe with SREG bed, at the joint interface of steel and EG, thermal contact conductance value was provided by adopting the analytical equations developed by (Bahrami *et al*. - reference@). The developed numerical model was validated using the experimental results, and used for further investigations such as idle running of Longitudinal Feed drive (LF) and idle running of LF and CF. The simulation results showed that idle running of LF resulted in a thermal error 1.3 times the thermal error under idle running of CF, while simultaneous idle running of both CF and LF resulted in a thermal error 1.9 and 1.4 times that of CF and LF, respectively. The findings of this research will help in the development of strategies to reduce thermal error in machine tools with SREG structures.

From the thermal analysis it is clear that the thermal error in the lathe with SREG is higher than that in the lathe with CI bed. Hence there is a necessity to reduce the thermal error in the lathe with SREG bed to enhance the prolific use of SREG structures in machine tools. To reduce the thermal error in lathe with SREG bed a method of thermo-structural optimization has been adopted. The proposed method is a design strategy with an objective of selecting a set of optimised design variables of the steel reinforcement to enhance the convection capacity. To do so, a genetic algorithm based multi objective optimization technique was performed and its efficiency was verified using numerical simulations. Thermo-mechanical analysis by simulation reveals that a 32% reduction in thermal error can be achieved with the optimized SREG bed.

By using the method of thermo-structural optimization, the thermal error could be reduced to some extent, but there is a necessity to further reduce thermal error. Towards this, another strategy named energy efficient cooling strategy has been adopted by incorporating cooling circuits inside the epoxy granite bed to remove the required amount of heat by the supplying coolant through it. The concept of energy efficient cooling strategy lies in providing a cooling power to a specified location which is prone to higher temperature rise than a set temperature. The SREG bed alone is considered for the analysis. The entire bed is divided into 20 blocks (4 rows x 5 columns-T1-T20), including steel and EG portions. The overall length of LF is 670 mm, one block length is taken as 167.5 mm. Variance based sensitivity analysis is performed for the SREG bed by creating block diagrams in MATLAB Simulink. The results indicate that cooling circuit is sufficient to be located at the 4 steel structures (T2, T4, T7, and T9), and coolant supply be provided after a time span of 30 min to compensate the thermal error by bringing down the temperature of the structures.

To verify the validity and practical feasibility of thermal error control using the proposed energy efficient strategy, the SREG bed built with the optimised steel reinforcement and bed dimensions (SREG-2 bed) is fabricated. Experimental modal analysis was performed on the bed and the dynamic characteristics were verified.

The energy efficient cooling strategy developed using model-based simulation with MATLAB Simulink has been verified by experimental investigations conducted on SREG-2 bed. It is evident that by developing a PID based cooling system, the temperature can be controlled effectively and successfully to maintain required temperatures. By maintaining uniform temperature in the bed, the thermal error will not progress beyond a set value, Further, the validated simulation model is used to evaluate the effective flow parameters for the developed cooling strategy.