ABSTRACT

Machine tool sector plays an important role in the manufacturing of a variety of products. The major expectations from modern machine tools are high productivity, high precision and reliability. High static stiffness and high damping together with light weight construction are the primary requirements for the design and development of precision machine tools. Vibration is an undesirable effect in machine tools which results in poor quality of finished components, reduction in tool life and unpleasant noise. The dynamic behaviour of machine tools can be enhanced by minimizing the intensity of the sources of vibration and by improving the damping and static stiffness of the structures. Even though vibration affects all the components of a machine tool, it is highly desirable to minimize the amplitudes of vibration in the primary structures, viz., base, column, spindle head and X-Y tables. The base, being one of the main structural parts of a Vertical Machining Centre (VMC), is taken up for the present investigation.

Even though active and passive dampers could improve the system dynamics, the use of such dampers has its limitations due to design complexity and cost. Moreover, a variety of dampers is required for machining of different components in a wide range of frequency. Hence, it has prompted researchers to search alternate materials with favourable damping property for building the structural components. Cast Iron (CI) and steel are the conventional materials that are widely used in machine structures. Though the above materials exhibit good mechanical properties, they lack in damping property which is one of the primary requirements for realizing precision components.

Polymer Concrete (PC) has been widely used in the manufacture of machine tool structures for its good damping characteristics, higher workability, high strength-to-weight ratio, low thermal conductivity and low co-efficient of thermal expansion. Epoxy Granite (EG) is a PC based material used for machine building applications as a replacement for CI. EG has very good dynamic properties whose damping ratio is one order higher than CI. Since the Young's modulus of EG is 3.6 times lesser than CI, the machine tool structures made of EG have inadequate stiffness. In the present work, steel is used as a reinforcement for the EG base to improve the static stiffness.

The primary objective of the research work is to design, analyze and develop EG base for VMC to improve the dynamic response without compromising the static rigidity as that of CI base.

Experimental Modal Analysis (EMA) was carried out on CI base to determine the natural frequencies and damping ratio. Subsequently, a Finite Element (FE) model was developed to perform numerical modal analysis under free-free condition. The numerical results were validated with experimental data and the validated FE model was used for further static analysis. Numerical static analysis of CI base was performed under worst case machining conditions and considering eccentric locations of X-Y tables. The maximum deformation pertaining to the above machining conditions is used as baseline data for the design of EG base. Multiple design configurations of steel reinforcement for EG base were explored with the objective of obtaining comparable stiffness as that of CI base. The design configuration which satisfies the static rigidity and dynamic performance requirements with manufacturing ease is finalized for fabrication.

Since steel reinforcement as part of EG base may reduce the damping ratio, a specimen level study has been carried out to quantify the effect of addition of steel on the stiffness and damping properties of the composite. An optimum reinforcement ratio was obtained from the study. It was ensured that the mass of steel used in the final design configuration of EG base is well within the optimum reinforcement ratio to comprehend the damping benefits of EG.

In order to assess the improvement in static and damping characteristics, a scaled down model of the finalized design configuration of the EG base was fabricated. Experimental study was undertaken to validate the assumption made in numerical analysis that EG is isotropic and homogeneous. The load-deflection characteristics of the EG base revealed that numerical analysis data are in close agreement with experimental results. Hence, the need for modelling of EG composite as coarse and fine granite aggregates with epoxy resin is eliminated by the above validation. EMA was performed on EG base to obtain the modal parameters. Similitude relations were used to predict the modal parameters of scaled CI base and the results are compared with scaled EG base. The results revealed that the EG base exhibited sixteen times higher damping compared to CI base.

The influence of EG base on the overall dynamics of VMC was assessed by performing pre-stressed FE modal analysis, considering the loads arising from the moving and dead weights of the primary structures. Subsequently, harmonic analyses were performed and the results are compared to VMC with CI base. A five-fold and seven-fold improvement in dynamic stiffness of VMC with EG base was observed in X and Y directions. Stability Lobe Diagram (SLD) was used to compare the chatter stability of

both the VMCs. The results of SLD revealed a three-fold improvement in material removal rate for VMC with EG base compared to VMC with CI base. The proposed steel reinforced configuration of EG base has demonstrated a better dynamic performance of VMC without compromising static rigidity. Hence, EG is established as a viable alternate material for machine tool applications.