TITLE OF THE THESIS: INVESTIGATIONS ON STATIC AND DYNAMIC CHARACTERISTICS OF MACHINE TOOL STRUCTURE

ABSTRACT

Machine tool industry forms the backbone of many of the major sectors of industrial activity in any country in the traditional manufacturing context. The primary users of machine tools are the automotive sector, electrical, electronics, and multi-product engineering companies. Therefore, the machine tool sector plays a very vital role in manufacturing sectors in globally. The vibration behaviour of a machine tool can be improved by reducing the intensity of the sources of vibration and by enhancing the effective static stiffness and damping values. Even though, vibration affects every part of the machine tool structure, it is more desirable to reduce the vibration levels in the major parts. The bed is the main part of the machine that acts as a base to the machine tool structure. The main objective of this research work has been to enhance the static and dynamic properties of existing cast iron CNC machine tool bed using alternative materials and various form design modification methods.

Initially, the static and dynamic characteristics of a conventional cast iron CNC machine tool of Midas lathe bed were analysed numerically and determined experimentally. In the static method, a finite element model of a cast iron machine tool bed was analysed and it was observed that the longitudinal strain of 111.06 microstrain was obtained for a load of 2100 N. The numerical analysis was repeated upto 7000 N and the longitudinal strains were extracted. An experimental set-up was developed and the longitudinal strain of 115 microstrain was obtained for a load of 2100 N. The

experimental was repeated upto 7000 N. The simulation results were in very close agreement with the experimental static analysis results. The measured value of bending stiffness of CNC machine tool bed was 270 N/µm. The dynamic analysis was carried out to extract the fundamental natural frequencies of the cast iron bed and the same were found to be 863 Hz, 1155 Hz, 1203 Hz and 1215 Hz. An experimental set-up was developed and the natural frequencies were found to be 830 Hz, 1130 Hz, 1260 Hz and 1320 Hz. The percentage of deviation of results being less than 8 %. Damping ratios were also estimated and it was found to be 0.0060, 0.0035, 0.0039 and 0.0057 respectively.

Further, different form designs of hollow box construction with stiffeners and different orientations were investigated. The static deflection characteristics and modal characteristics of the eight different topological of typical form designs of cantilever beams were analysed numerically and experimentally. In static analysis, the results of deflections and bending stiffness values for various form designs (Topology A to H) were extracted. Modal analysis was carried out to find the first five natural frequencies and mode shapes of topologies A to H. Based on the numerical results, the eight different configurations of beams were fabricated. Experimental static analysis was conducted to determine the bending stiffness of the various form designs. Hollow box with slots on sides (Topology E) has the best bending stiffness value of 10322.5 N/mm which is 22.5 % higher than that of the hollow box section (Topology A). Hollow box with longitudinal stiffeners (Topology F) shows 18.7 % higher bending stiffness than hollow box section (Topology A). Following the above, experimental dynamic analysis was conducted. For topology D, for example, natural frequencies were 945 Hz, 1150 Hz, 2450 Hz, 3250 Hz and 4250 Hz. The damping ratios were estimated for all the beams and they were found to the in the range of 0.00492 to 0.00645. Thus, from the experimental results it can be concluded that the hollow section with longitudinal stiffeners along the length

(Topology F) is the best replacements for hollow section to increase the bending stiffness and damping ratio of machine tool structures.

In addition, a bed made up of polymer concrete filled steel structure was designed and fabricated. For static analysis, a 3D model of polymer concrete filled steel structure bed was developed. From the numerical static analysis, the longitudinal strain of 12.73 microstrain was obtained for a load of 2100 N. The dynamic analysis was carried and frequencies were found to be 935 Hz, 1193 Hz, 1409 Hz and 2054 Hz. Based on the numerical results, polymer concrete filled steel structure bed was fabricated to the actual size of existing cast iron bed. From the experimental static analysis, the longitudinal strain of 13 microstrain was measured for a load of 2100 N. The measured value of bending stiffness of polymer concrete filled steel structure bed was 2400 N/µm. Experimental dynamic analysis was conducted and natural frequencies were found to be 1030 Hz, 1215 Hz, 1390 Hz and 1725 Hz. The measured damping ratios of the machine tool bed were 0.0170, 0.0045, 0.0048 and 0.0070.

The polymer concrete filled steel structure bed was compared with the existing cast iron bed. It was observed that the longitudinal strain value of the polymer concrete filled steel structure bed was 80 % lower than the existing cast iron bed. The bending stiffness of polymer concrete filled steel structure bed was found to be 8.6 times better than that of cast iron bed. It was also observed that the fundamental natural frequency of the polymer concrete filled steel structure bed was 24 % higher than that of the existing cast iron bed. The damping ratio of the polymer concrete filled steel structure bed was 172 % higher than that of the existing cast iron bed. Damping characteristic of the polymer bed has also been significantly improved. These tests confirmed the suitability of polymer concrete filled steel structure bed as a replacement for cast iron bed. Finally, various form designs of existing cast iron machine tool bed with different ribs configurations and different orientations of machine tool bed were designed to increase the static and dynamic properties. The modelling of various form design of machine tool beds (Configuration I to VI) were carried out. In numerical static analysis, the bending loads were increased gradually from 140 N to 7000 N and the total deformation and specific stiffness values were extracted. Specific stiffness of six different configurations of beds was found to be in the range of 0.350 GPa.kg^{-1}mm^{-1} to 0.501 GPa.kg^{-1}mm^{-1}. From the numerical static analysis results, the estimated stiffness is improved by 43 %, which shows the cross vertical ribs configuration bed model is stiffer than the existing model. From the dynamic analysis, the natural frequencies of existing bed were obtained as 863 Hz, 1155 Hz, 1203 Hz and 1215 Hz and those of cross vertical ribs configuration bed were 941 Hz, 1131 Hz, 1265 Hz and 1310 Hz. From the results of the dynamic analysis, the natural frequency of cross vertical ribs configuration bed was increased by 10 %, which improves the structural dynamic performance.

Based on the numerical analysis results, existing and cross vertical ribs configuration beds were fabricated using rapid prototyping method. Experimental static analysis was conducted to determine the static stiffness of the systems. The experimental set-ups for both the beds were developed. The load was applied in steps from 140 N to 2100 N. As a result, the cross vertical ribs configuration bed model has improved static structural stiffness about 8 %, with a weight reduction of 3.6 %. The first order natural frequency of cross vertical ribs configuration bed got increased by 7.2 %, which can improve the structural dynamic performance. The above results show slight improvements of specific stiffness and natural frequency of the cross vertical ribs configuration bed. The tests confirm the suitability of cross vertical ribs configuration model of bed as a suitable replacement for existing form design of machine tool bed. From the investigations, it is concluded that the static and dynamic characteristics of existing conventional cast iron bed are improved by form design and material modification methods.