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Design Optimisation of CNC Special Purpose Machine Bed.

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ABSTRACT

In this paper, a machine bed (Manufacturer: M/s Precision Tooling's chakan) is selected for the complete analysis for both static and dynamic loads. Then investigation is carried out to reduce the weight of the machine bed without deteriorating its structural rigidity and the accuracy of the machine tool by adding ribs at the suitable locations. In this work, the 3D CAD model for the base line and the optimized design has been created by using commercial 3D modeling software Solid works. The 3D FE model has been generated using Ansys. The analyses were carried out using ANSYS and Design Optimization is done with the help of Ansys.The results were shown with the help of graphs to analyze the effect of weight reduction on the structural integrity of the machine bed before and after the weight reduction and conclusions were drawn about the optimized design.

Keywords- **Structural integrity, Design optimization, Dynamic Analysis**

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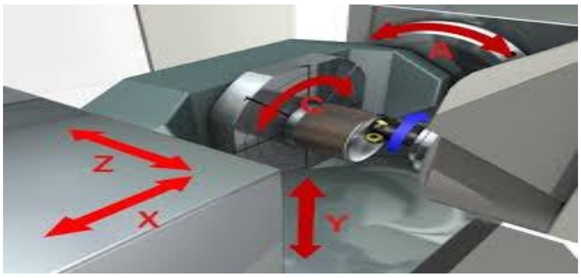
I. INTRODUCTION

The machine bed plays a crucial role in providing the strength and rigidity to a machine. It accommodates all the accessories and cutting tools and other necessary equipments for the running of the machine. It issubjected to various static and dynamic forces during the machine operation. Its design is vital for the performance and accuracy of the machine tool.

1.1 TYPES AND NOMENCLATURE

Mill orientation is the primary classification for milling machines. The two basic configurations are vertical and horizontal. However, there are alternate classifications according to method of control, size, and purpose and power source.

1.2Horizontal Mill



In the vertical mill the spindle axis is vertically oriented. Milling Tools are held in the spindle and rotate on its axis. The spindle can generally be extended (or the table can be raised/lowered, giving the same effect), Allowing plunge cuts and drilling.There are two subcategories of Horizontal mills: the bed mill and the turret mill.

A turret mill has a stationary spindle and the table is moved both perpendicular and parallel to the spindle axis to accomplish cutting. The most common example of this type is the Bridgeport, described below. Turret mills often have a quill which allows the milling cutter to be raised and lowered in a manner similar to a drill press. This type of machine provides two methods of cutting in the vertical (Z) direction: by raising or lowering the quill, and by moving the knee. In the bed mill, however, the table moves only perpendicular to the spindle's axis, while the Spindle itself moves parallel to its own axis.

Turret mills are generally considered by some to be more versatile of the two designs. However, turret mills are only practical as long as the machine remains relatively small. As machine size increases, moving the knee up and down requires considerable effort and it also becomes difficult to reach the quill feed handle (if equipped). Therefore, larger milling machines are usually of the bed type. Also of note is a lighter machine, called a mill-drill. It is quite popular with hobbyists, due to its small size and lower price. A mill-drill is similar to a small drill press but equipped with an X-Y table.

2.0 MODELING AND SIMULA TION

The major dimensions of the machine bed are as follows:

Length = 1700 mm (in X-direction)
Width = 1100 mm (in Y -direction)
Height = 550 mm (in Z-direction) (up to the table level)Height = 800 mm (in Z-direction) (total height)Bed width (between guide ways) = 350 mm (in Y -direction)Total Bed width = 300 mm (in Y – direction)

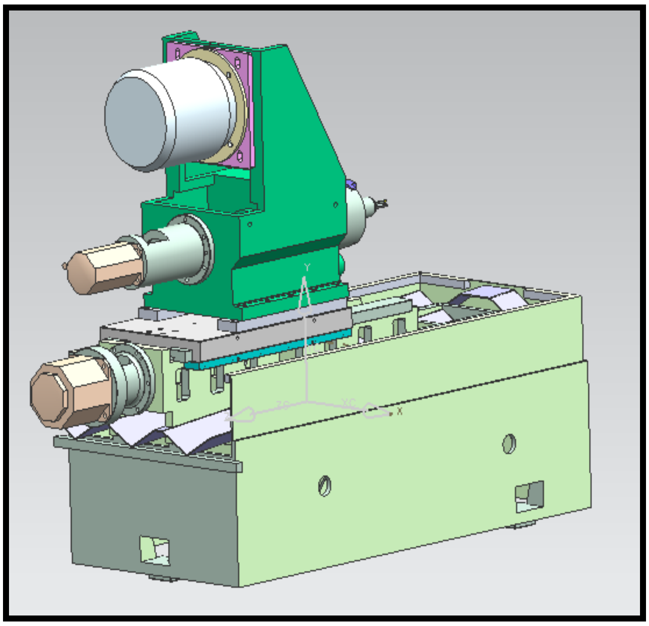
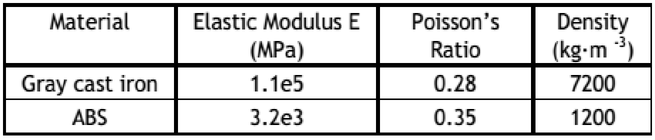


Fig No.2 3-D CAD Model of Special Purpose Machine Bed

- FEM SIMULATION AND EXPERIMENTS

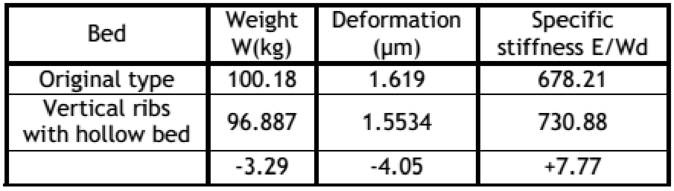
FEM simulation was carried out using ANSYS software to analyse both the conventional and the cross and vertical ribs with hollow bed, in terms of static and dynamic characteristics studies. The 3-D models were established in a CAD system, Pro/E Wildfire 5.0, and were imported into ANSYS. The models were then modified or simplified to meet the FEM requirements. The material used was gray cast iron and the material specifications are listed in table 2. All DOFs of bottom surface were restricted and external loads were applied to corresponding positions of bed.

Table 2. Material properties



Material	Elastic Modulus E (MPa)	Poisson's Ratio	Density (kg·m $^{-3}$)
Gray cast iron	1.1e5	0.28	7200
ABS	3.2e3	0.35	1200

Table 3. The comparison of simulation results



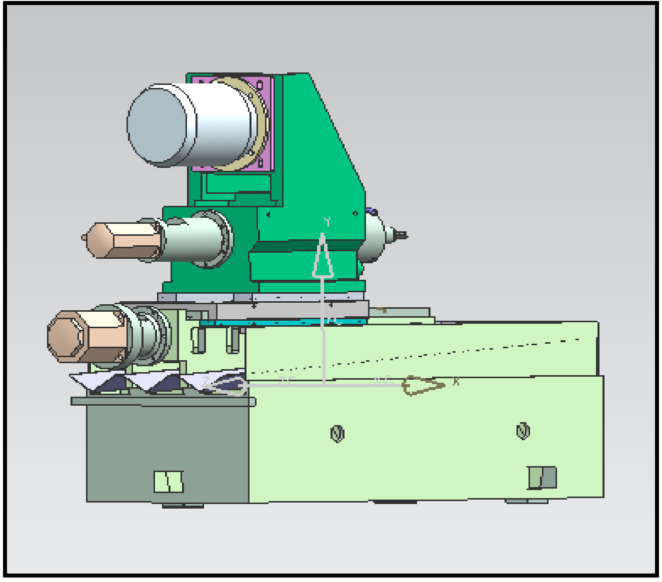
Bed	Weight W(kg)	Deformation (μm)	Specific stiffness E/Wd
Original type	100.18	1.619	678.21
Vertical ribs with hollow bed	96.887	1.5534	730.88
	-3.29	-4.05	+7.77

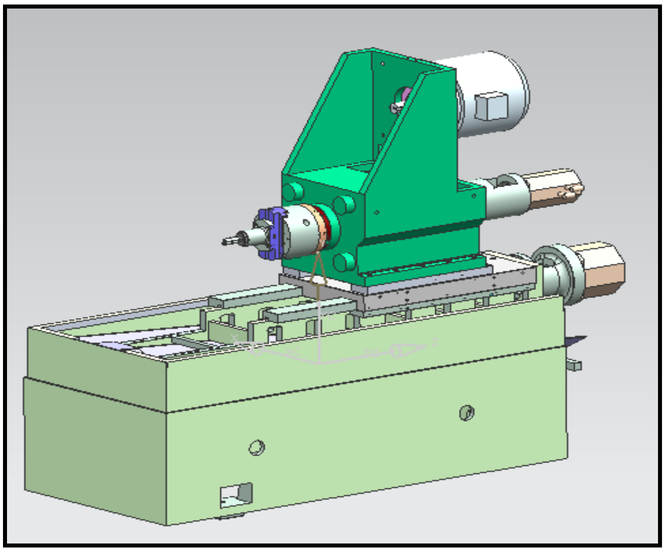
- Modal Analysis to get Natural frequencies of component

- Import geometry
- Assign materials
- Meshing
- Contacts
- Boundary conditions
- Post processing

- Boundary conditions

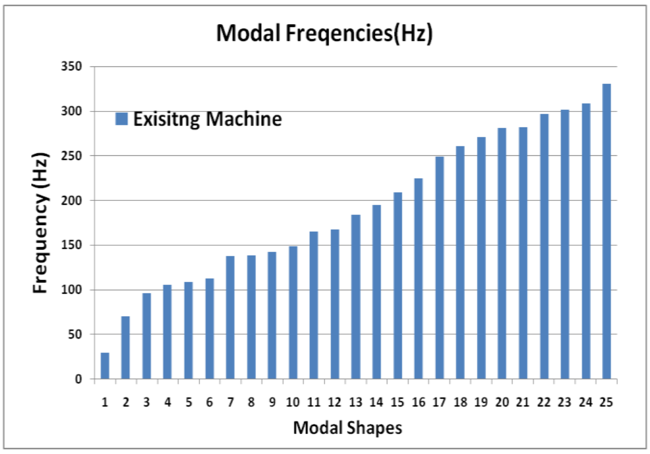
2^{nd} order Tetra mesh has been used to accurately predict the natural Frequencies.





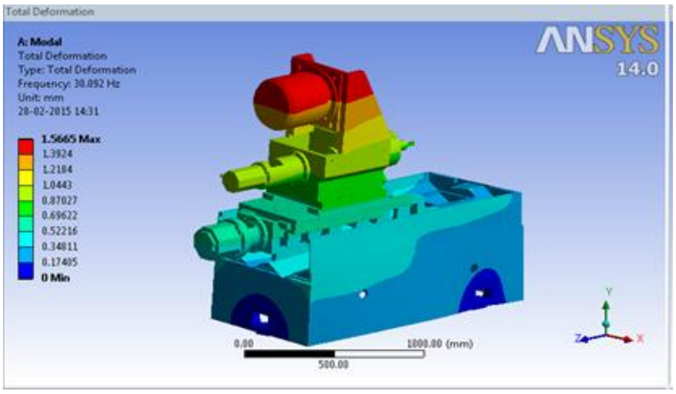
- All contacts defined are bonded contacts.
- First 25 Mode shapes has been calculated because low frequencies are critical for job operation
- Critical mode shapes will affect the job quality. So it is required to check if there is any resonance.
- After analyzing the mode shapes of existing machine, modification will be tried to shift resonance frequencies

- Modal Frequencies

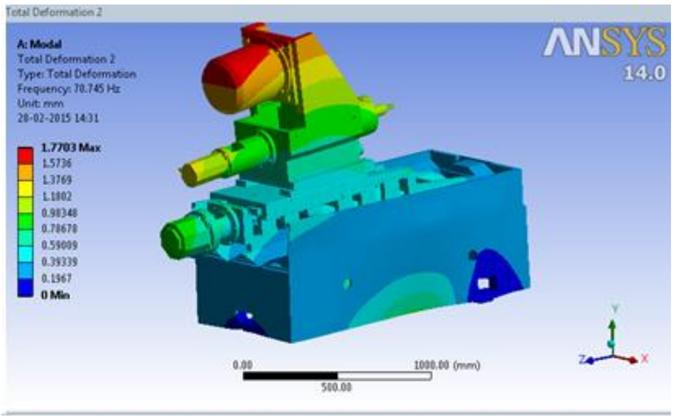


- Results-

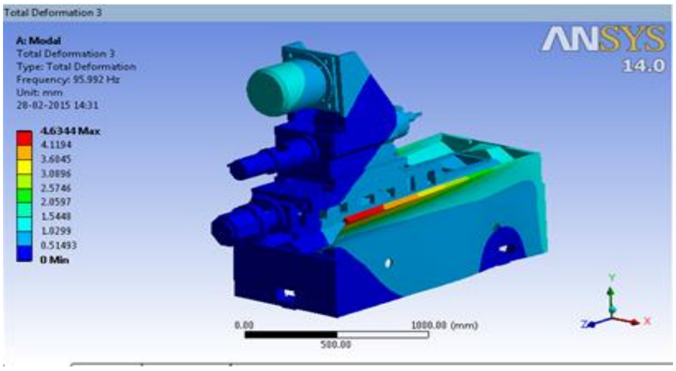
Mode Shapes



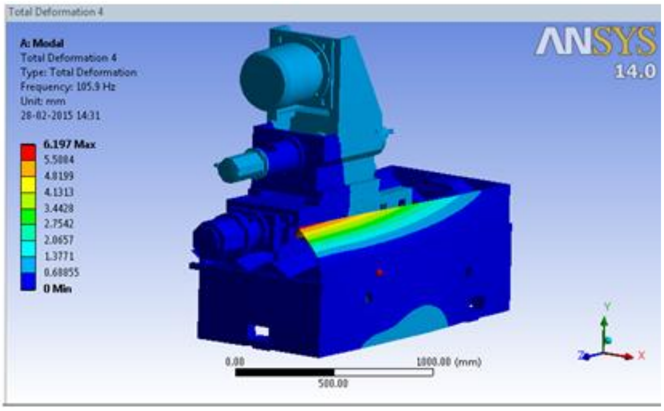
Global mode shape A



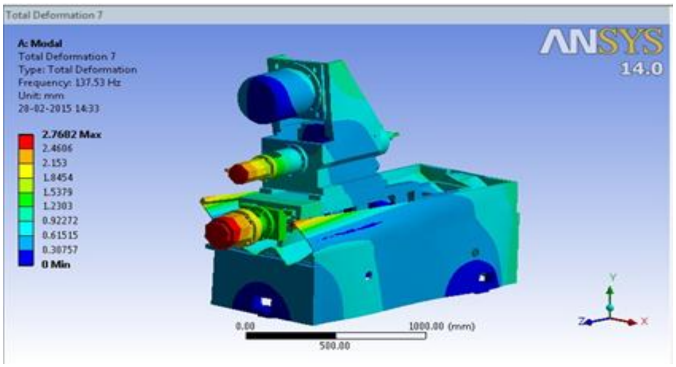
Global mode shape B



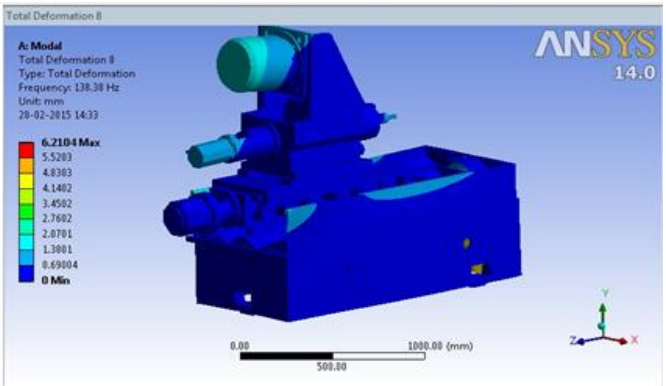
Local Fluttering mode shape A



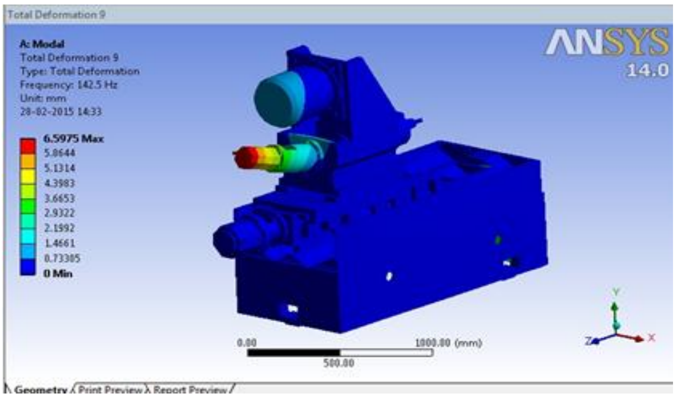
Local Fluttering mode shape B



Fluttering + bending mode shape

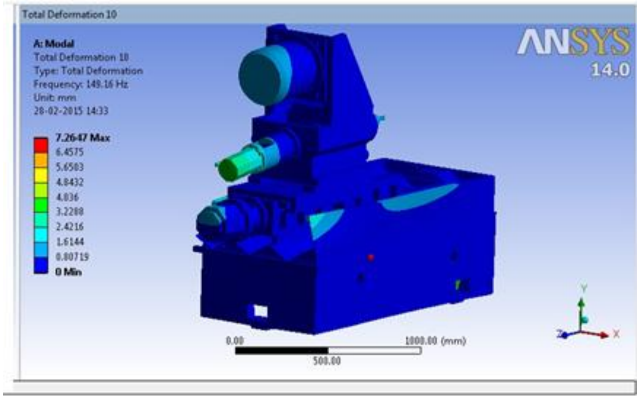


Global mode shape C


Total Deformation 9

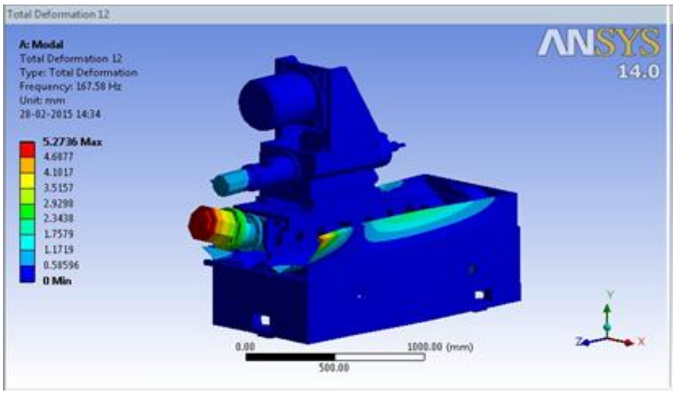
A: Modal
Total Deformation 9
Type: Total Deformation
Frequency: 142.5 Hz
Unit: mm
28-02-2015 14:33

Bending Mode Shape


Total Deformation 10

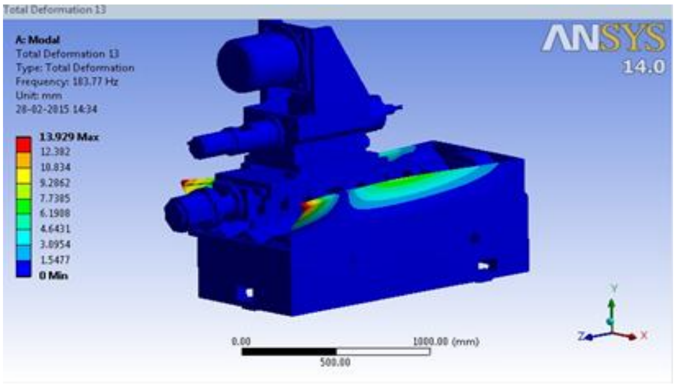
A: Modal
Total Deformation 10
Type: Total Deformation
Frequency: 149.16 Hz
Unit: mm
28-02-2015 14:33

Bending Mode shape A


Total Deformation 12

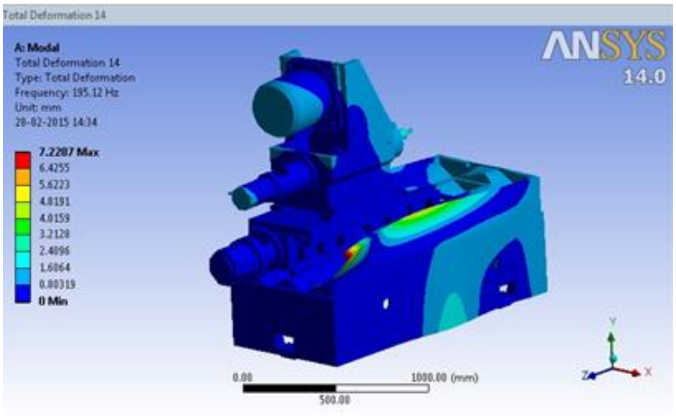
A: Modal
Total Deformation 12
Type: Total Deformation
Frequency: 167.58 Hz
Unit: mm
28-02-2015 14:34

Bending Mode Shape B


Total Deformation 13

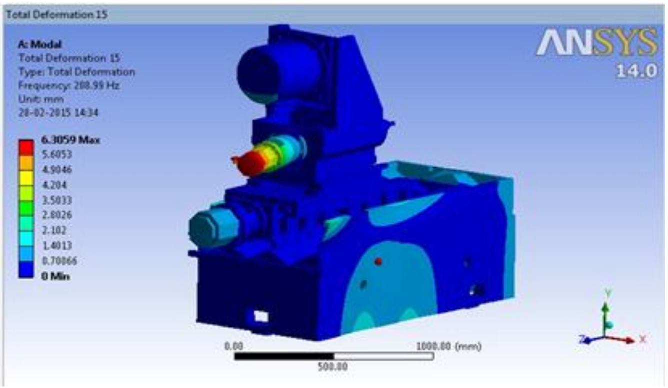
A: Modal
Total Deformation 13
Type: Total Deformation
Frequency: 183.77 Hz
Unit: mm
28-02-2015 14:34

Local Fluttering mode shape C


Total Deformation 14

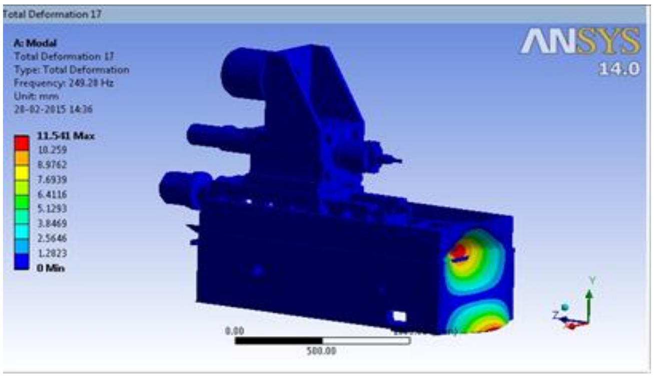
A: Modal
Total Deformation 14
Type: Total Deformation
Frequency: 195.12 Hz
Unit: mm
28-02-2015 14:34

Local Fluttering mode shape D


Total Deformation 15

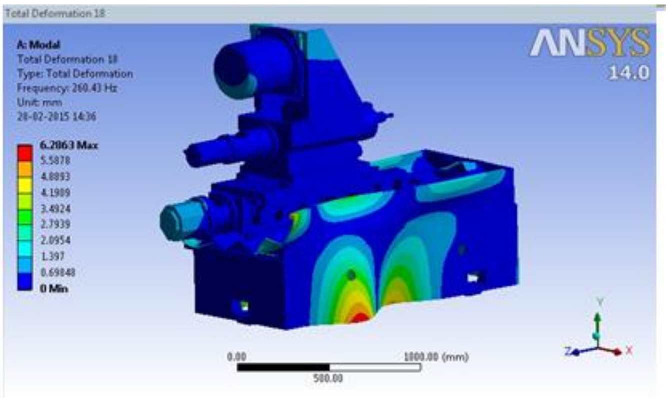
A: Modal
Total Deformation 15
Type: Total Deformation
Frequency: 208.99 Hz
Unit: mm
28-02-2015 14:34

Bending mode shape


Total Deformation 17

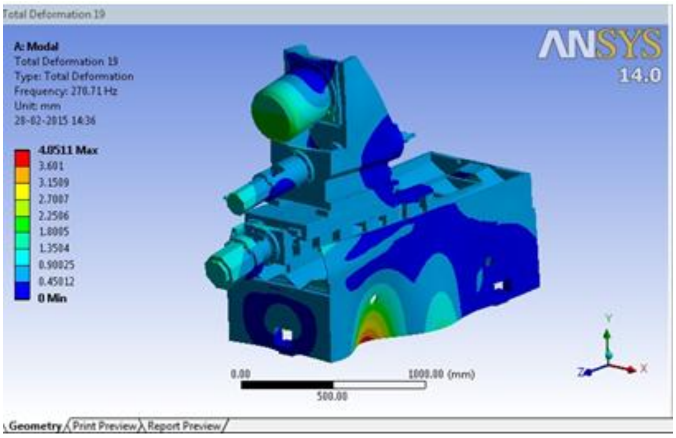
A: Modal
Total Deformation 17
Type: Total Deformation
Frequency: 249.28 Hz
Unit: mm
28-02-2015 14:36

Drumming mode shape

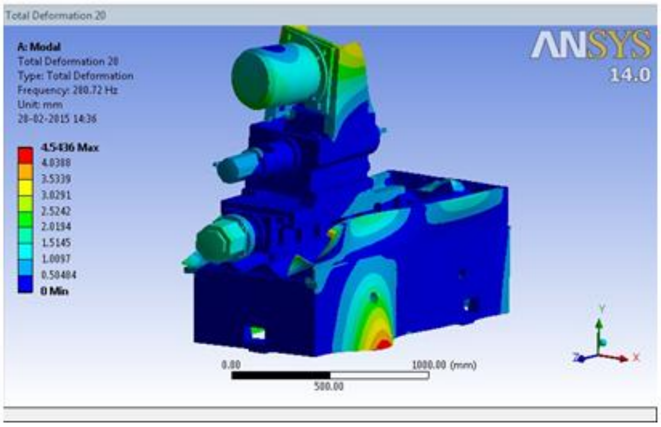

Total Deformation 18

A: Modal
Total Deformation 18
Type: Total Deformation
Frequency: 260.43 Hz
Unit: mm
28-02-2015 14:36

Drumming mode shape



Drumming+Bending mode shape



Drumming+Twisting mode shape

EXPERIMENTAL MODAL ANALYSIS OF EXISTING BED

Among the many different methods to validate the CAD model, the natural frequency based evaluation method was adopted. The natural frequency of the bed was found experimentally through the impact hammer test (ASTM C215-91) using a piezoelectric accelerometer, NI PXI 1042Q, LabVIEW software, etc. The impact pulse indicating the magnitude of the input force was generated by the impact hammer. The frequency domain response was obtained by using signal analyzer available in sound and vibration toolkit of Lab VIEW. The experimental setup and response of the bed captured in time and frequency domains as shown in figure 5.The values of natural frequencythus obtained experimentally were then compared with the results of modal analysis conducted using ANSYS. The results were found to be almost similar to each other. The comparison is shown in table5.

Table 5. Comparison of modal frequencies

Mode		1	2	3	4
Existing bed - Natural frequency(Hz)	Analytical	872.05	1175.88	1280.52	1340.48
	Experimental	840	1140	1260	1320

RESULTS AND DISCUSSIONS

After three times of repeated experiments, the measured displacements were averaged. Final results are listed in given table. It shows that the maximum displacement of vertical ribs with hollow bed model was reduced by about 8.08% with 3.66% mass reduction. The reductions of structural weight and deformation were more significant than the results of simulation. The possible reasons might be that the bed material in the experiments was ABS plastics rather than cast iron. In any case, however, the vertical ribs with hollow bed model achieved higher specific stiffness, indicating more efficient material, distribution than the conventional ones.

Bed	Weight W (kg)	Deformation (μm)	Specific stiffness E/Wd
Original type	0.138	1.619	14.331
Vertical ribs with hollow bed	0.133	1.5534	15.489
	-3.66%	-4.05%	+8.08%

The first natural frequencies of vertical ribs with hollow bed one were increased by about 31.23 %. But the remaining frequencies were lower than those of original type. However, the lowest modal shapes are usually most important for structural vibration. In addition, the first order mode shapes were the bending of bed along the Y direction, which would be critical for machining precision. So it could be concluded that the vertical ribs with hollow bed type reached better dynamic performance. There are several limitations associated with the scaled-model tests due to the different material and technological level. However, the focus is more on the relative effectiveness between original and vertical ribs with hollow bed models. So with the results comparison, the vertical ribs with hollow bed design have improved the static and dynamic performance of the bed, which is encouraging for further study. Casting can be used for manufacture.

CONCLUSIONS

(1) Based on the configuration principles, the existing bed was redesigned to improve the static and dynamic performances. Simulation results show that the static and dynamic performances of vertical ribs with hollow bed have been improved.

(2) Scale-down models were used to verify the improvements of vertical ribs with hollow bed design.Static and dynamic experiments show that the mass and deflection are reduced by 3.66% and 8.08%% respectively and the lower order natural frequencies are increased. Experimental results agree qualitatively with the FEM simulation.

(3) Structural vertical ribs with hollow offers a method to improve the conventional design of machine structure. Based on structural modifications, ribs parameters and distributions can be further optimized.

(4) Twisting and bending mode shapes are critical which can be optimized Resonance can be predicted by frequncy response analysis by giving excitationin longitudinal, lateral and Vertical direction.frequency should be higher than our operation frequency so that condition of resonance is omitted.

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