Topology optimization of a Column of VMC

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Abstract: The basic requirements of machine tool column are high stiffness. In machine tools major percentage of the weight is due to components like column and bed. Hence, column has been selected for the optimization purpose. The selection of the column material, its cross-section and proper distribution mass result in high stiffness. Machine tools column are subjected to bending, shearing and torsional shear stresses. The basic objective of the present work is to reduce the weight of column of a VMC.

Machine tools column are subjected to bending, shearing and torsional shear stresses. In order to determine the loading conditions for the worst loading case, forces are determined for various operations which can be performed on VMC. Based on the worst loading conditions and deflection constraints topology optimization has been carried out with optistruct slover after meshing the component in HyperMesh.

Topology optimization of column is carried out with limiting deflection as constraint which gives reduction in weight by 2%.the FE analysis shows the reduction in deflection by 7.74%. The modal analysis has been carried out which shows 52.33 % increase in natural frequency.

Keywords - *column, topology optimization, vertical machining center.*

1.0 INTRODUCTION

The columns are made of thin-walled box sections structure with number of openings and are strengthened by means of stiffeners. The cross sectional area of the column increases towards the base where bending moment is maximum. Machine tool column experiences bending in two perpendicular planes, shearing in two perpendicular planes and torsion (shear). In order to determine the loading conditions for the worst loading case, forces are determined for various operations which can be performed on VMC. Based on the worst loading conditions and deflection constraints topology optimization has been carried out with optistruct slover after meshing the component in HyperMesh. Figure 1 shows the structure of the column of a vertical machining center. The structural optimization requires various techniques viz. topology, topography, and shape and size optimization. Topology optimization technique yields a new design and optimal material distribution. Topology optimization is performed on a column, resulting in a design that is lighter in weight, and also increase in natural frequency.

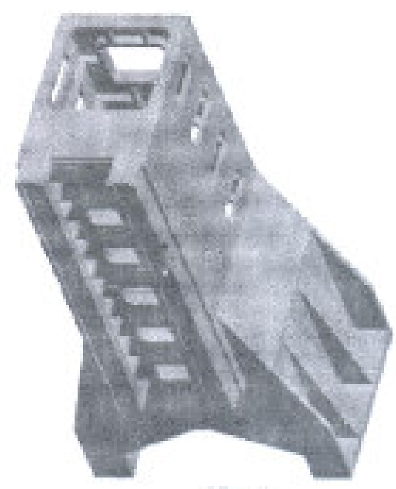

Fig.1. Structure of the column

2.0 FINITE ELEMENT ANALYSIS OF COLUMN

For evaluating the performance regarding the strength point of view, Finite Element Analysis method has been used. As the basic objective is to optimize the design of the column that part only has taken in consideration for Finite Element Analysis. The CAD model of the column was prepared and analyzed the same using CAE Software package HyperMesh. The column was meshed using 3D TETRA element. As the element is a tetrahedron element, it can map the intricate solid geometry reasonably with good accuracy.

The physical properties of the Cast Iron grade 25 are as below.

Density=7.19e3 kg/m^3
Young's modulus (e) = 1.048e5 Mpa
Poissions ratio= 0.25

The model was evaluated for the static load and moment. The load calculation is given bellow.

2.1 Maximum Thrust For Drilling Operation:

Diameter of cutter = 50mm
Material to be cut = cast iron
Revolution per minute of spindle: 600
Feed per tooth: 0.075
Feed per revolution: 0.15
Material factor k = 2.05
Power at the spindle [10],

$N = 1.25 D^2 k n (0.056+1.5 S) \times 10^{-5}$

$N = 7.8$ kw

Maximum cutting force,

$T = 1.16 K d (100 S)^{0.85}$

$T = 8176.9$

2.2 Force Calculation During Drilling Operation:

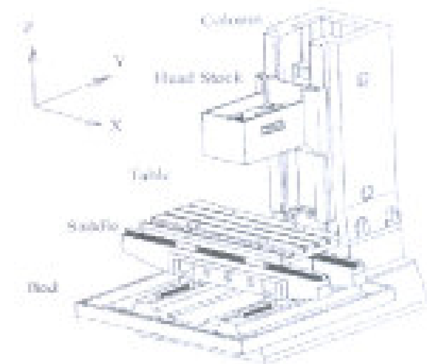

Fig:2 Basic structure of column.

1. Weight of headstock, w_1= 2959.6 N (-Z direction) at a distance l_1 = 635.17 mm from C.G. of column.

2. Weight of motor, w_2 = 960.4 N (-Z direction) at a distance l_2 = 606.17 mm from C.G. of column.

3. Weight of spindle, w_3 = 480.2 N (-Z direction) at a distance l_3 = 850.17 mm from C.G. of column.

4. Cutting force (Drilling thrust), w_4 = 8176.9 N (+Z direction) at a distance l_4 = 850.17 mm from C.G. of column

$$W L + w_1 l_1 + w_2 l_2 + w_3 l_3 = w_4 l_4$$

W= 2904.43 N

W= Force at the top end of column.

L= 1665 mm, Height of column.

So, above loads causes bending of column in x-z plane. The column will behave as a vertical cantilever beam. The bottom face of the column is mounted on the base of the machine tool. We can assume that the bottom face of the column is the fixed face.

COLUMN

Topology optimization is a mathematical approach which optimizes the material layout within a given design space, under given set of loading and boundary condition. As observed from the FE result of the existing design of the column, some of the material within the design space is participating the least for bearing the existing static (i.e. the region shown in blue colour or the least value), there is possibility to optimize the mass distribution within the prescribed design space boundaries.

For the purpose of optimization, material is taken homogenous, iso-tropic, linear and temperature independent.

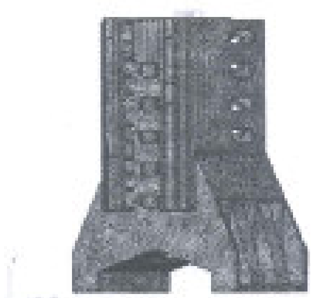

Fig.5 Mesh model of column

The solid model is meshed using Altair Hyper Mesh with second order solid element 10 node tetras, Altair OptiStruct solver is used to obtain the optimal material distribution. Meshed model of column is shown in figure 5.

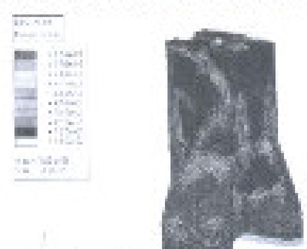

Fig.6 Density distribution in column (after 10th iteration)

After performing the iteration for optimization, the final element density plot was obtained as shown in figure 6. The material in blue colour shows the material participating least in taking the static load, hence the possibility of reducing the weight of the column. Fig. 7 shows the iso-surface plots with element density threshold as 0.26 in order to have the material connectivity.

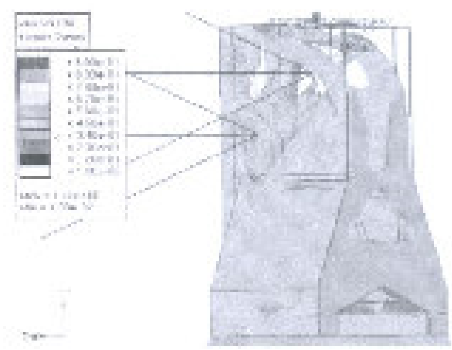

Fig.7 Density distribution in column (Density threshold 0.26)

5.0 MODIFICATION BEASED ON OPTIMIZATION RESULT

The topology optimization shows the possibility for altering the exiting design of the column for reducing the weight. So, the result of topology optimization has been implemented in the existing design one by one as suggested by the result. The material at the rear side of the column (opposite face to guide ways) can be removed without affecting the static behavior of the column under given loading conditions. Hence a taper has been provided in order to reduce the weight of column. Also the pockets suggested by the optimization results were created considering the manufacturing aspects the modification is shown in figure 8(a) & 8(b). Considering the various manufacturing aspects for the column the final topology is prepared in the PRO-E software is shown in fig. 8(a) & (b).

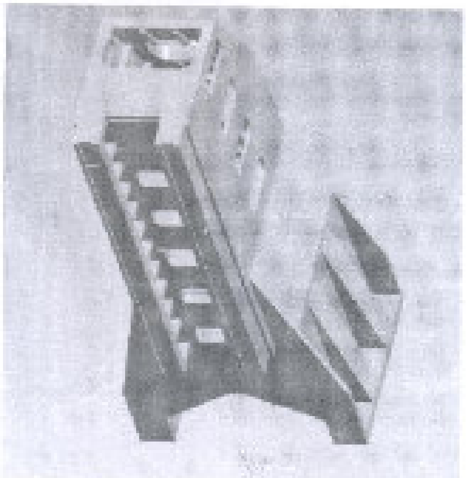

Fig.8(a) Modified topology of column (Front view)

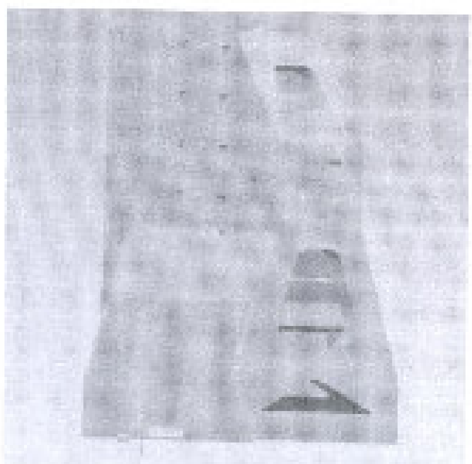

Fig.(b) Modified topology of column (Rear view)

The modified design is evaluated using FE analysis. The boundary conditions applied to the modified design is same as that to the original model. The FE Results are obtained for natural frequency and displacement patterns. (Refer Fig. 9 & 10).

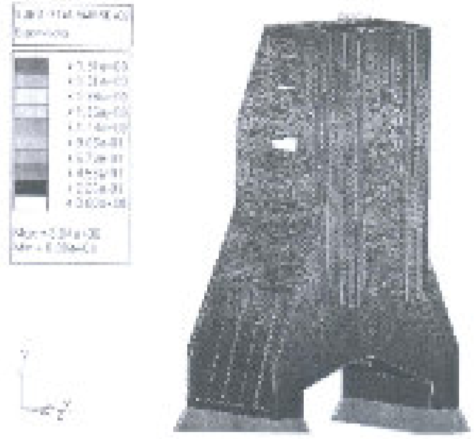

Fig.9 natural frequency profile Modified Design

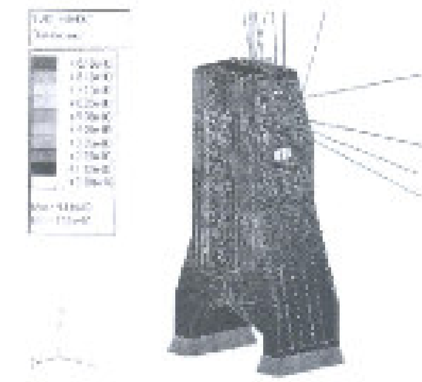

Fig.10 Displacement profile Modified Design

From the plots of the natural frequency and deformation for the modified design of column, it can be seen that Fundamental Natural frequency: 154.22 Hz Maximum deflection of column: 0.0082 mm

Table 2: Fundamental natural frequency of modified column

Modes	1	2	3	4	5
Natural frequency Hz	154	268	331	343	380

6.0. RESULT AND DISCUSSION

Comparison of the FE analysis results of the original design and the modified design of the column is shown in the table 3 .

Table 3 - Deformation and natural frequency for original geometry and modified geometry

Component (Column)	Deformation (mm)	Fundamental Natural frequency (Hz)
Original Design	[illegible]	[illegible]
Modified Design	[illegible]	[illegible]
% change	-2.74	52.33

From the comparison, it can be seen that after modifying the topology of the column the total deflection of the upper end of the column remains within the permissible limits, but substantial reduction of the material hence weight have been obtained Along with the increase in natural frequency.

7.0. CONCLUSION

Topology optimization of column is carried out with limiting deflection as constraint which gives reduction in weight by 2%.the FE analysis shows the reduction in deflection by 7.74%. The modal analysis has been carried out which shows 52.33 % increase in natural frequency.

8.0. REFERENCES

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