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Finite-element Analysis and Optimization for the Column of Numerically Controlled Triaxial Deep Hole Drilling Machine

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Abstract

Solidworks is selected for modeling the 3D-solid structure of the deep-hole drilling machine. Based on parametric modeling and structural optimization theory, the parametric model of column is established. The equivalent stress and maximum principal stress on the column are solved by FEA. The two parameters (column thickness and inner rib thickness) are included. According to the design variables, the main target method is applied for the purpose of optimizing the weight of the column (Chen, Ding, & Guo, 2010). Topology optimization is used to determine the location of the sand holes by ansys software with density method.

Keywords: Deep Hole Drilling Machine column, topology optimization, finite element method, multi-objective

1. Introduction

CNC three-axis drilling machine is a multi-axis deep hole drilling equipment which processes steam generator tube sheet. In the nuclear steam generator tube sheet processing, 1.5 tons of high pressure hydraulic tights jig. The column bears the reaction force of 1.5 tons of high-pressure oil and about 0.5 tons of the axial drilling force. The drilling assembly weight is 11 tons and the center-balance counterpart is 11 tons.Intensity and stiffness affect the accuracy of drilling directly (Li & Shen, 2011). In order to ensure the accuracy of parallel in the processing deep hole, the importance of the column structure is obvious.

2. Mathematical Modeling

The basic structure of the column includes the column wall, roof, floor, rail and internal ribs.It owns rectangular hollow and nearly symmetrical structure, and internal cross stiffener board. The column material is gray cast iron HT250. The parameters are as follows: Total height of: 5700mm, Length: 1920mm, Width: 2100mm, Wall thickness: 40mm, Roof thickness: 60mm, Rottom plate thickness: 154mm. The geometrical model is shown in Figure 1.

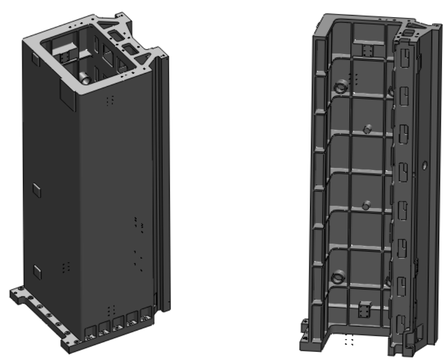


Figure 1. Geometrical model of the column

3. Finite Element Analysis

This is Static analysis. We choose the SOLID95 units, the material properties of gray cast iron HT250: E = $1.2X10^{11}N/m^2$, Poisson's ratio is 0.25. The bottom of column constraints and the forces is shown as following. Mesh cell size is 150mm.

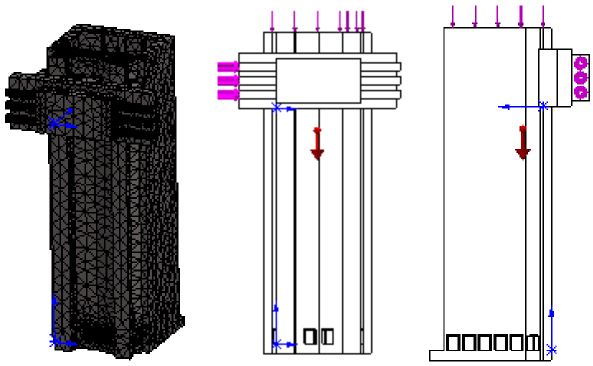


Figure 2. Constraints, forces and mesh

Solidworks simulation software provides the result of FEA, shown in Figure 2. The first principal stress is 12.3Mpa and the most of the column on the first principal stress are lower than 9.8Mpa. Tensile strength of the iron HT250 is 250Mpa. The ultimate stress of the column is much lower than the ultimate stress of casting material HT250 structural strength. On the condition of not affecting the stiffness of the case, the quality of the column can be reduced (Ni, Yi, & Tong, 2005). Summary of the initial design of the column statics, modal analysis is shown in Table 1.

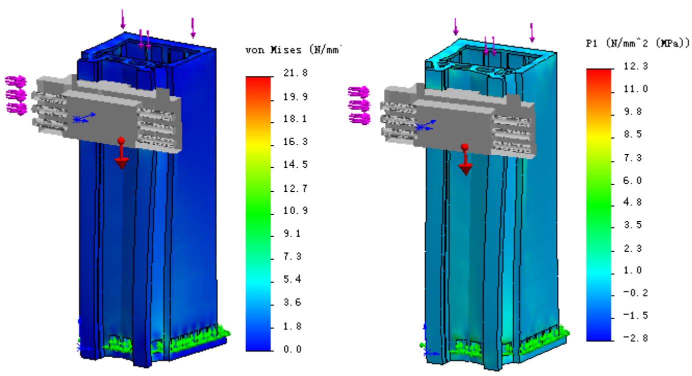


Figure 3. The FEA of the column

Table 1. Statics and the modal analysis for the initial design of the column

stress/Mpa		displacement/mm		fundamental frequency/Hz	quality/T
Mises	P1	Co-displacement	X-direction displacement	31.84	21.522
21.8	12.3	0.25	0.20		

4. Optimization

4.1 Size Optimization

4.1.1 Design Variables

Wall thickness (X1), the internal board (X2), the guide support ribs (X3, X4, X5), the tendons (X6, X10), the longitudinal reinforcement (X7, X8, X9), the layer of reinforcement (the X11, X12, X13, X14, X15, X16, X17).

Study their impact on the performance of column structure (shown in Figure 3). Due to the characteristics of gray cast iron, the strength and stiffness is not with the casting wall thickness increased in proportion to increase. With the casting wall thickness increases, the relative intensity of the gray cast iron has continued to reduce. Delimitations for the parameters of Column are listed in Table 2.

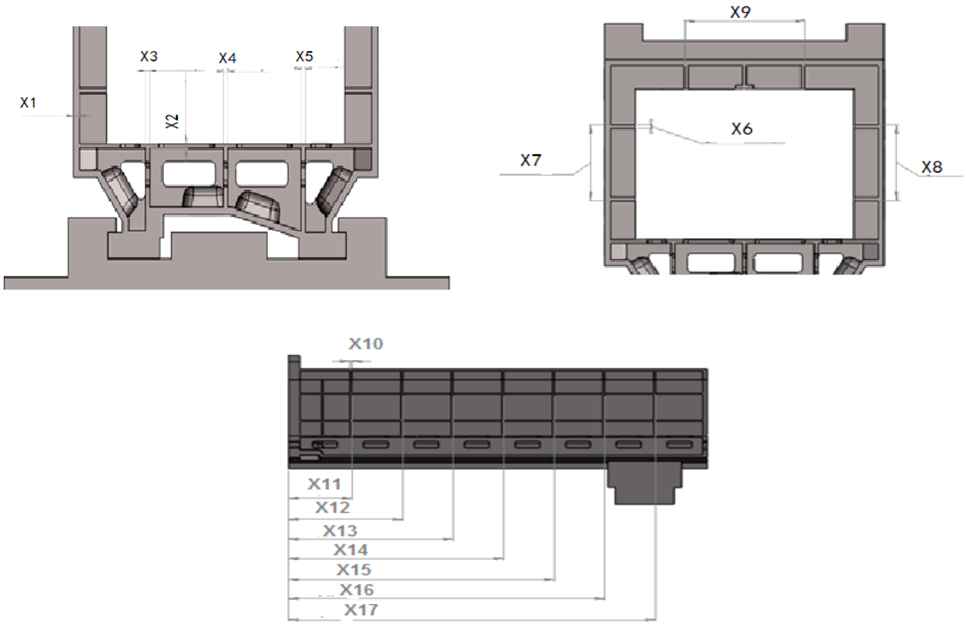


Figure 4. Design variables

Table 2. Delimitation for the parameters of Column structure

Serial number	Part	Initial value /mm	Lower limit /mm	Upperlimit /mm
X1	Wall thickness	40	30	50
X2	Internal board	25	18	30
X3	guide support ribs 1	25	18	30
X4	guide support ribs 2	25	18	30
X5	guide support ribs 3	25	18	30
X6	longitudinal reinforcement 1	25	18	30
X7	Left longitudinal reinforcement	250	50	450
X8	right longitudinal reinforcement	250	50	450
X9	top longitudinalreinforcement	400	100	700
X10	longitudinal reinforcement 2	25	18	30
X11	Layer of reinforcement 1	690	690	2070
X12	Layer of reinforcement 2	1380	690	2070
X13	Layer of reinforcement 3	2070	690	2070
X14	Layer of reinforcement 4	2760	2070	3450
X15	Layer of reinforcement 5	3450	2070	3450
X16	Layer of reinforcement 6	4140	3450	4830
X17	Layer of reinforcement 7	4830	3450	4830

4.1.2 Optimization Results

The main target method is introduced，In order to save material costs ，the optimization model is expressed as:

$$\text{Min M (x)} \tag{1}$$

$$\text{S.t.}\delta \le [\delta]$$

Where

M: the quality of the column structure;

δ: the maximum displacement on the column;

[δ]: structure allows displacement.

The optimization results are shown in Table 3.

Table 3. The size of column

Serial number	Part	Initial value/mm	Optimal value/mm	Initial mass/T	Optimized quality/T
X1	Wall thickness	40	37.9		
X2	Internal board	25	18.4		
X3	guide support ribs 1	25	18.2	32.585	31.575
X4	guide support ribs 2	25	21.9		
X5	guide support ribs 3	25	25.6		
X6	longitudinal reinforcement 1	25	18.0		
X7	Left longitudinal reinforcement	250	442.2	31.575	31.248
X8	right longitudinal reinforcement	250	239.4		
X9	top longitudinal reinforcement	400	637.6		
X10	longitudinal reinforcement 2	25	18.0		
X11	Layer of reinforcement 1	690	2070		
X12	Layer of reinforcement 2	1380	2070		
X13	Layer of reinforcement 3	2070	2070	31.248	30.698
X14	Layer of reinforcement 4	2760	3450		
X15	Layer of reinforcement 5	3450	3450		
X16	Layer of reinforcement 6	4140	4830		
X17	Layer of reinforcement 7	4830	4830		

4.2 Topology Optimization

Sand holes are set in an appropriate location.They facilitate the casting process and they can reduce the column quality. Location of sand holes ensure that the stiffness of the structure and the fundamental frequency meet the requirement.

Topology optimization of the mathematical model (Sui, Yang, & Sun, 2000) can be expressed as:

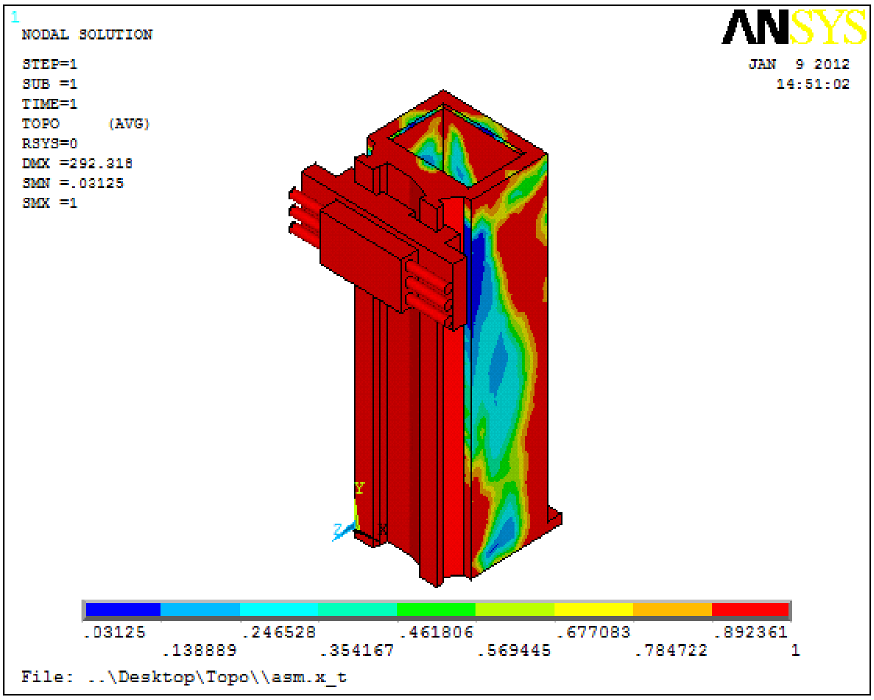
$$Min\ F(X) \tag{2}$$

$$S.t.\ g_j(x) - g_j^*(x) \le 0，j = 1，2，3 \dots m \tag{3}$$

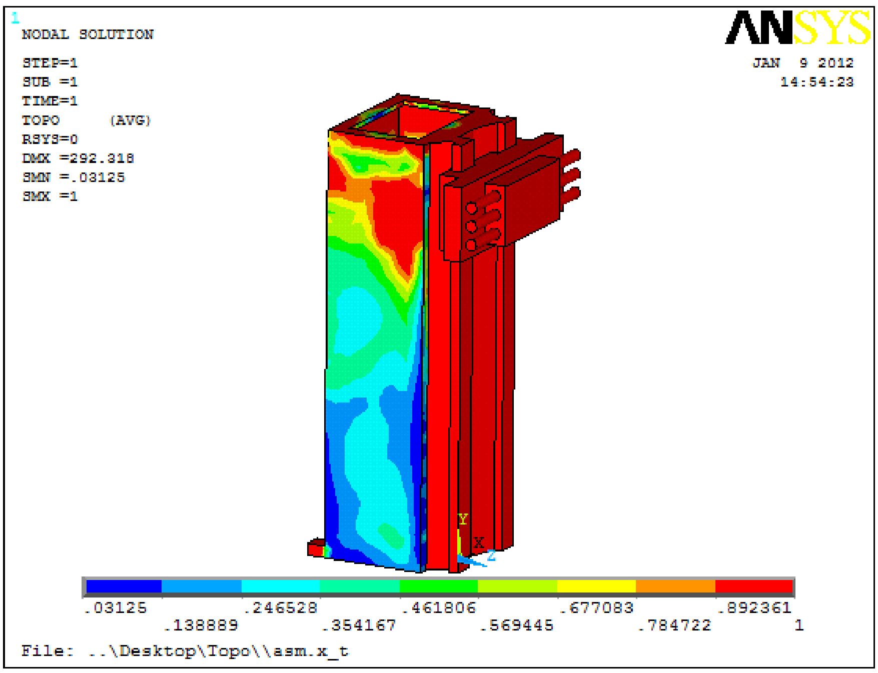
$$x_{min} \le x_i \le 1，i = 1，2，3 \dots n$$

x_i: the cell density, x_{min}: lower limit, take a very small amount of non-zero, *F(x)*: the objective function, $g_j(x)$: constraint (also known as state variables), $g_j^*(x)$: the constraint the upper limit of the condition.

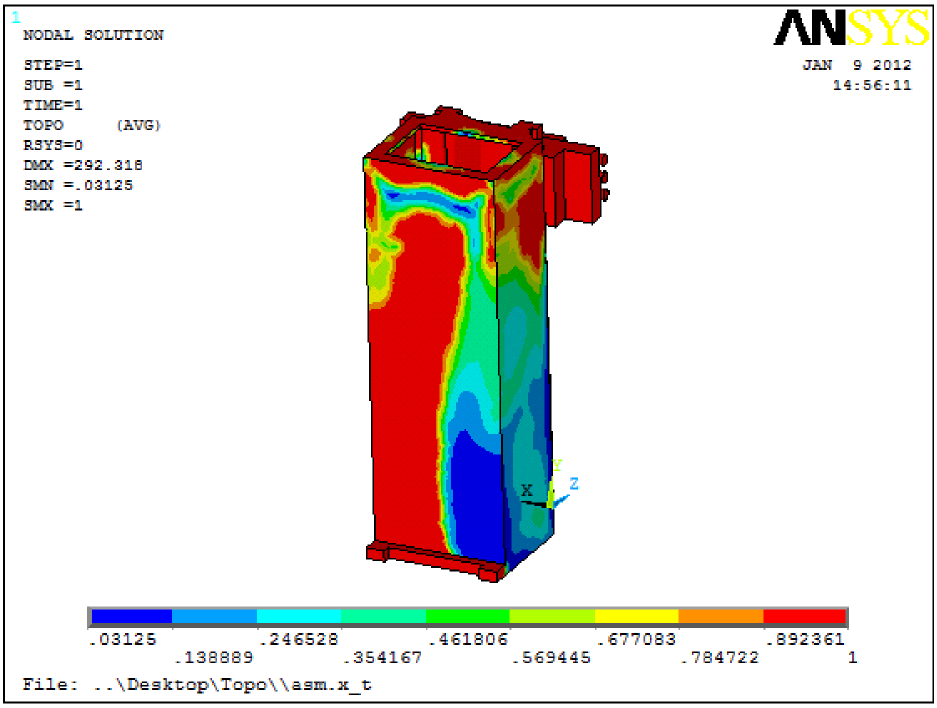
By virtue of experience and intuitive judgment, the column structure is difficult to draw the location of the sand hole. The column structure topology optimization determine the sand holes on the position of the column performance (Cui, Sang, & Wen, 2004). This paper uses Ansys for structural topology optimization; Ansys uses the method of density as a topology optimization algorithm.



(a) The right panel topology cloud images



(b) The left panel topology cloud images



(c) Guide opposition panel topology cloud images

Figure 5. Topological structure of column

There are eight sand holes in the cross position of the layer ribs and longitudinal reinforcement. The optimized structure is shown in Figure 5. Comparison of structure and properties before and after the topology optimization is listed as Table 3.

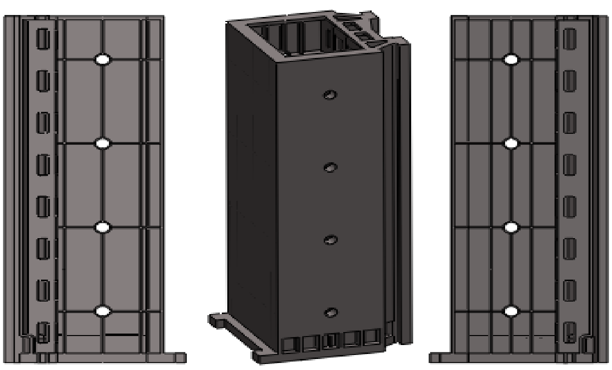


Figure 6. Optimized structure of the column

Table 4. Comparison of structure and properties before and after the topology optimization

	Casting process	Maximum displacement /mm	Fundamental frequency/Hz	Quality/T	Reduction rate of quality
initial design	ordinary	0.25	31.84	21.522	7.36%
optimization	better	0.25	31.79	19.938	

5. Discussion

According to parametric model of FEA, we get that strength margin of the column structure is big. So we can propose the column size optimization and topology optimization. The size optimization adjust the location of strengthen the ribs and the location of the layer of ribs.The topology optimization determine the location of the sand holes, reducing the column weight while improving the process of the column (Ding & Lin, 2008). After optimization, the fundamental frequency did not change greatly. Column 7.36% mass reduction, improve material utilization.

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