Structural Analysis and Optimization of Cylindrical Drum of Horizontal Scree-bowl Centrifuge

LIU Ji, SHEN Yi, XU Hai-bin, YUAN Ming-xin, WU Xin-hua, FAN Chun-yang

***Abstract*—To improve the intensity and performance of cylindrical drum of horizontal scree-bowl centrifuge, cylindrical drum is analyzed and optimized with Workbench in this paper. Firstly, the three-dimensional modeling for cylindrical drum of the horizontal n scree-bowl centrifuge is built. Then, the aspect ratio and wall thickness are optimized and analyzed based on Workbench. Finally, the optimization program of the cylindrical drum is determined and the intensity, deformation and vibration are verified. The results show that the stress intensity and deformation achieve the best optimizations with aspect ratio of 1.5 and wall thickness of 15mm.The model which is optimized satisfy the request under static effect.**

***Index Terms*—Horizontal scree-bowl centrifuge, Cylindrical drum, Aspect ratio, Wall thickness**

I. INTRODUCTION

Centrifuge is the equipment used to continuously separate solid and liquid phase of the material which has excellence such as low energy intensive, preferable separated effect and high yield. Drum is an important part of the centrifuge. Drum is affected by centrifugal force for its high speed (work speed could reach several hundred to several tens of thousands rpm), which will result in big stress of working order in the drum barrel. The centrifuge drum's stability and reliability directly affect the centrifuge's capacity. To avoid accidents during the routine production, stress and stress concentration should be reduced. As centrifuge technology matures and develops, drum intensity and drum vibration performance have become direct influences on the safety and reliability of centrifuges. As a result, design and optimization for centrifuge drums have realistic engineering significance. WANG Jun-shan [1] analyzed the stress of centrifuge drums with finite element analysis software like VisualNastran4D2002, which could easily find the dangerous point; TAO Jie *et al.* [2] analyzed the stress of cone drum junction, and they put forward that drum stresses and drum strains are affected by rotational speed, half cone angle and material density; LI Zi-guang *et al.* [3] got the distribution of the drum's maximum stresses and radial displacement by analyzing the simulation of stresses and strains. Besides, we know that cylindrical drum's axial length is an important parameter which affects the centrifuge's performance. The longer the axial length of the drum, the longer the spiral cyclic period will be if the diameter of the drum is fixed. The time of solid precipitation will be longer, and the dewatering efficiency will be better. Because the drum usually operates with high speed, the longer the axial length, the bigger the pressure which is caused by solid liquid mixtures when impacting the inner wall duo to centrifugal force will be. So the ratio of axial length and radial length (the aspect ration) need to get a balance. The drum wall thickness is neither too much or neither too little. Too great thickness would increase the energy consumption and reduce the operation life, which will cause economic losses. Too small thickness would bring hidden danger because of the torque caused by the high operating speed of the centrifuge. As a result, to improve the dehydrating effects of the centrifuge, the aspect ration and wall thickness are optimized and analyzed based on Workbench and the results verifies the effectiveness.

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II. FINITE ELEMENT MODEL OF DRUM

A. Structure of Drum and Its Modeling

Horizontal applied situation scree-bowl centrifuge combines two ways of dehydration mainly for fine materials such as coal flotation concentrate, waste coal and so on. The drum's first part still uses the conical and cylindrical structure. Solid particle suspension liquid deposited in the cylindrical and dehydrated in the cone section; The last part is used to improve the dehydration rate further with the screen mesh and the solid residue will be filtrated and dehydrated again, and the last residue will exit under centrifugal force. The two parts are connected by shaft-hole match and welded to reinforce. Drum model is shown in Fig.1. Because the model is complicated and multi-curved, we model the drum with Pro/E and import it to the Workbench directly.

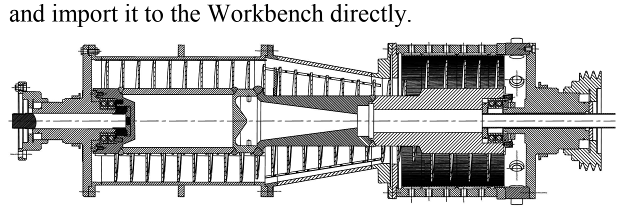


Fig.1. Schematic diagram of the drum of horizontal applied situation scree-bowl centrifuge

B. Basic Parameters of the Drum

Here are the basic parameters of the drum: the inner diameter of cylindrical part: R_1=630*mm*; the external diameter of screen mesh: R_3=780*mm*; the speed discrepancy of the spiral and the drum: Δn=20*r*/*min*; rotating speed of the drum: n_1=1500*r*/*min*; the speed ratio of planetary gear differential: 59:1; the maximum capacity of remove sediment: V=2.5m^3/h.

In this paper the aspect ration is incremented by 0.05 and we analyze the static case while the ratio is from 1.30 to 1.60; the wall thickness of the drum is incremented by 1mm and we analyze the static case while the wall thickness is from 10*mm* to 15*mm*.

C. Mesh Generation of the Drum

The model is made by cemented carbide 0Cr18Ni9. The elastic modulus is E=8.26E+11. The density is ρ=7900kg/m^3. The Poisson's ratio is ε=0.3.

At room temperature, the allowable stress of the material S_m=205*Mpa*. We do mesh generation with three steps which are preliminary generation, global generation and local generation. We divided the drum with refined hexahedral element. The final divided result is shown in the Fig.2. The number of all the nodes is 31692 and the number of all the elements is 13458.

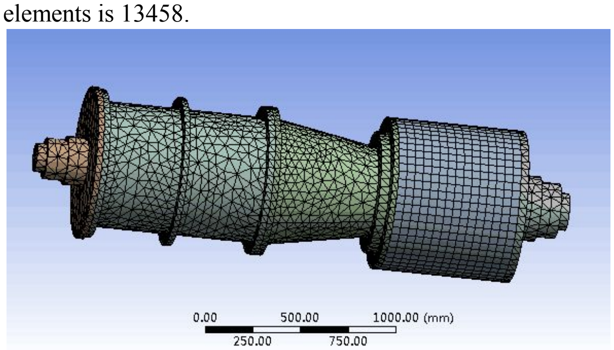


Fig.2. Result of mesh generation

D. Boundary conditions

The whole drum is installed on the bearing block and the drum's axial movement is limited. The drum can't work unless it rotates and therefore we should guarantee the tangential DOF. According to the fact, fixed constraint is exerted at one end and cylindrical constraint is exerted at another end, which will limit the circumferential and axial DOF and guarantee the tangential DOF.

E. Load

The drum is affected by centrifugal force and hydraulic pressure under normal operation, the following is the specific calculation:

(1) Centrifugal force: When the drum rotates with high speed, its mental body exerts centrifugal force to the finite element model in the form of angle velocity. The computational equation is shown:

$$\omega = \frac{\pi n}{30} = \frac{\pi 1500}{30} = 157.1 \quad rad/s \tag{1}$$

where, n is the rotating speed of the drum, and n=1500*r*/*min*.

(2) Centrifugal hydraulic force:

$$F = \frac{1}{2}\rho_w \omega^2 \left(R_1^2 - R'^2\right) \tag{2}$$

where, ρ_w is the sludge mixture density, and ρ_w=1085 kg/m^3.

ω is the angle velocity, and ω = 157.1 *rad*/*s*;

R_1 is the inner diameter of the drum, and R_1=315*mm*;

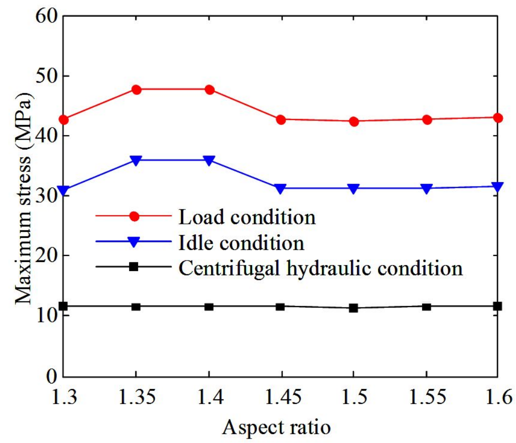
R' is the diameter of the liquid level in the drum, and R'=300*mm*.

After calculating, the hydraulic pressure F=0.494*MPa*.

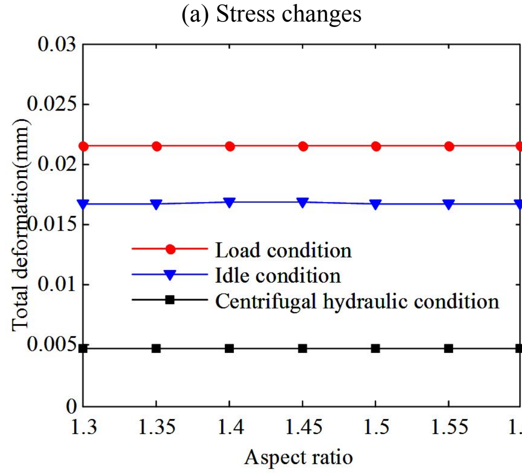
III. Determination of the Optimized Program

A. Effects on the Static Force Resulted from the Aspect Ration

In the analysis, other parameters are fixed and the aspect ration is incremented by 0.05 and the maximum is 1.60 while the minimum is 1.30. We observe the drum's relations of stresses-aspect ration and total deformation-aspect ration. The results are shown in Fig.3.



(a) Stress changes



(b) Total deformation changes

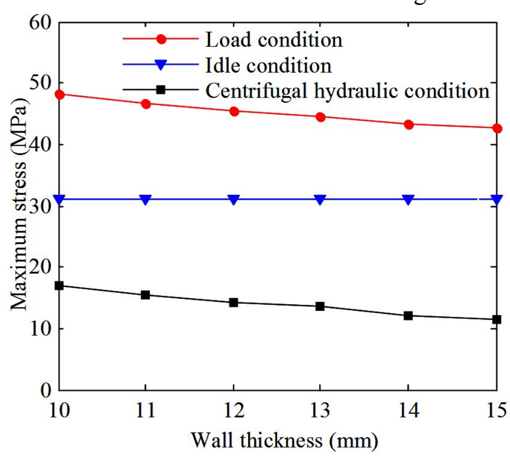
Fig.3. Effects on the total stresses and total deformation from the aspect ration

As shown in Fig. 3(a), it can be seen that the aspect ration is from 1.3 to 1.6, and the max stress exhibits quadratic curve relationship under normal working condition or centrifugal force. As a whole, the image exhibits rise in the first stage, and then decrease. The curve reaches the lowest between 1.45 and 1.55 where the stresses get the smallest. As we can see from the Fig. 3(b), the total deformation exhibits rise in the first stage, then decrease and finally rise again. The total deformation is small when the aspect ration is 1.3 and 1.5.

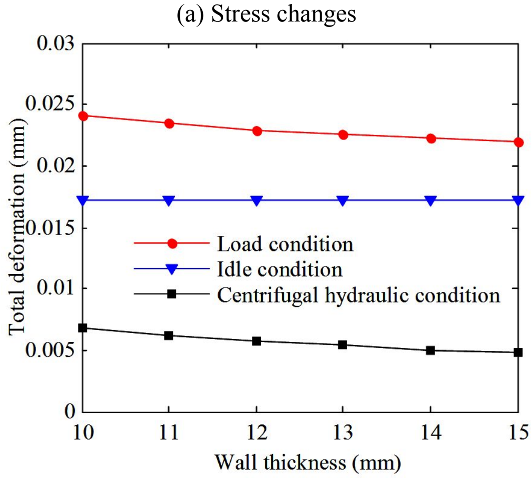
After analyzing the two combined figures, we can know that the stresses and total deformation could reach the smallest when the aspect ration is 1.5. Under normal working condition, the aspect ration is 1.5 while the stress is 42.562Mpa which is far less than the allowable stress on the end cover part of the drum. The total deformation is 0.021mm, which occurs on the external surface of the cylindrical drum. Therefore, the aspect ration could be optimized to 1.5 to make the drum operate safer and more reliable.

B. Effects on Static Force Resulted from the Wall Thickness of the Drum

When the aspect ration of the cylindrical drum is optimized, the wall thickness is incremented by 1mm. The maximal wall thickness is 15mm while the minimum is 10mm. We observe the relations of stresses-wall thickness and total deformation-wall thickness. The results are shown in the Fig.4.



(a) Stress changes



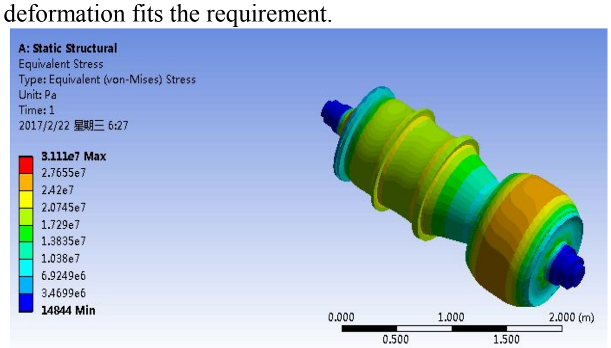
(b) Total deformation changes

Fig.4. Effects on the total stress and deformation resulted from wall thickness of the drum

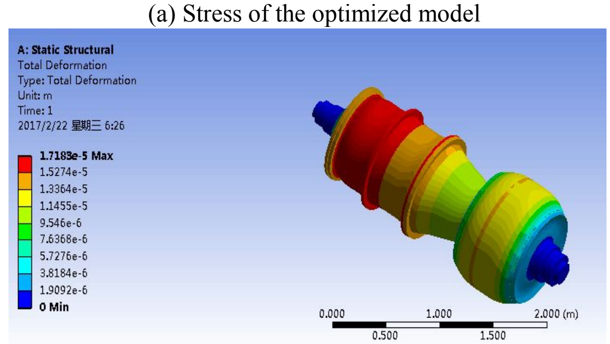
As shown in Fig. 4(a), we can see that the maximal stress intensity remains about the same under centrifugal force when the wall thickness is from 10 to 15*mm*. However, the maximal stress intensity exhibits about a curve and the whole image exhibits to decrease under normal working conditions and hydraulic and centrifugal working conditions. The curve reaches the lowest point when the wall thickness is 15mm where it is the smallest stress. What we can see from the Fig. 4(b) is that the total deformation exhibits little rise under centrifugal force, but the total still exhibits conspicuous decrease under hydraulic and centrifugal force and normal working conditions. The total deformation reaches the smallest when the wall thickness is 15mm. The stress is 42.563Mpa which is far less than allowable stress under normal working conditions when the wall thickness is 15mm, which occurs on the big end cover of the drum. On the external surface of the cylindrical drum, the total deformation is 0.02195mm. Therefore, we could optimize the wall thickness to 15mm to make the drum operate safer and more reliable.

C. Verification for the Optimized Model

Based on the analyses above, the draw ratio is elected as 1.5 while the wall thickness is designed as 15mm. To improve the safety of the whole drum, we still need to verify the static stress of the optimized drum. Fig. 5 is the results of the static analysis on the whole drum based on the workbench. As we can see from Fig. 5(a), the max stress of the optimized drum is 31.11Mpa which is far less than the material allowable stress which is 205Mpa. From the figure, we can obviously see that the color of the big end cover is darker, which indicates that stress value near the big end cover is generally big and the maximum occurs on the junction of the big end cover and coupling. Therefore, plastic deformation and abrasion are easy to occur on the junction. To guarantee the safety, we could reinforce the fixation of the big end cover and the coupling in order to avoid the stress concentration. We can see from the Fig. 5(b) that the max deformation is 0.0172mm and it occurs on the external surface of the cylindrical drum. Because the deformation is extremely small, the max total deformation fits the requirement.



(a) Stress of the optimized model



(b) Deformation of the optimized model

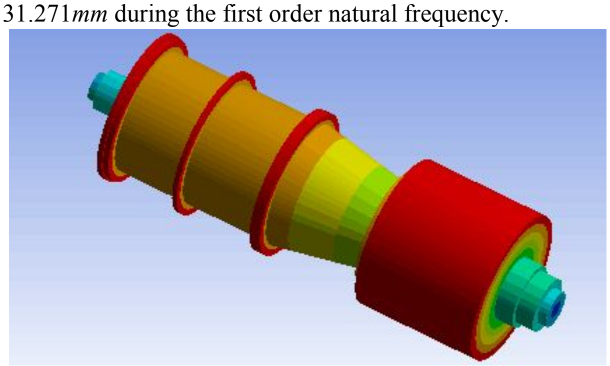
Fig.5. Static analysis of the optimized model

Drum of the centrifuge rotates and works at high speed, which will easily lead to greater dynamic stress which can result in fracture and fatigue failure. Model analysis is done on the drum of the centrifuge and we need to try to avoid the natural frequency to guarantee the safety. From Table 1, we can see that the first order natural frequency of the optimized model is 104.39Hz, and the corresponding critical speed is 6263.17*r*/*min* which is far more than the working speed of 1500*r*/*min* of the drum, which means that a normal working drum should stay away from the resonant region so that the resonance phenomenon will not happen.

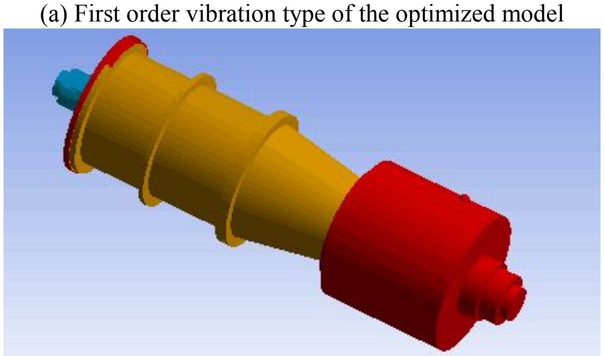
Table 1 First 6-order natural frequency of the optimized model

Order	1	2	3	4	5	6
Frequency *f*/*Hz*	104.39	112.31	289.69	290	651.8	731.11
Critical speed $n/(r.min^{-1})$	6263.17	6738.84	17381.4	17400	39108	43866.6

As we can see from the Fig. 6, the first order and second order natural frequency of the model have deformation on the big end cover and screen mesh and the biggest deformation occurs on the big end cover. The biggest deformation is 31.271*mm* during the first order natural frequency.



(a) First order vibration type of the optimized model



(b) Second order vibration type of the optimized model

Fig.6. First 2-order vibration types of the optimized model

IV. Conclusions

To improve the performance of the drum of the horizontal applied situation scree-bowl centrifuge, the paper models the drum with Pro/E at first. Then, the draw ratio of the cylindrical drum is optimized based on the analysis of the model with Workbench and the optimized project is chosen. Finally, static analysis is made on the optimized model and the safety is checked under the project. The research shows that when the draw ratio is selected as 1.5 and the wall thickness is 15*mm*, the stress and deformation are the smallest and the model could meet the requirements.

Acknowledgment

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