Optimization Of The Impact Tube Shoes By Finite Element Method

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***Abstract*—Natural gas hydrate is an environmentally friendly and efficient new energy source. Drilling core is the most direct way to identify gas hydrates. The impact tube shoe is located at the lowermost end of the drilling coring device, and works together with the impact tube. In the coring process, the impact tube shoe is a key part to ensure that the coring work can be carried out smoothly. This paper uses ANSYS Workbench18.0 finite element analysis software to optimize the size of the impact tube shoes. The optimization content includes: The length of the cutting surface along the axial direction l, angle of front angle α, combination optimization of axial length l_1 and angle of front angle α, and the thickness δ of the end face. This paper explores the variation of the maximum stress and penetration resistance of the impact tube shoes when the shoes of different sizes penetrate into the mudstone layer. According to the calculation results, the optimized shoe size: l=35mm, α=20°, l_1=13mm, and δ=1.5mm. The optimized shoe model not only has the sufficient strength, but also exhibits good penetration performance, and smaller penetration resistance reduces drag during coring. And the impact tube shoe could work under the load of 254.17kN, which is the load under the seabed with the water depth of 1300m.**

Keywords-Impact Tube Shoe; Finite Element; Size Optimization; Gas Hydrate;Coring; Penetration Resistance

I. INTRODUCTION

Gas hydrate is considered to be one of the most ideal alternative energy sources in the future. Because of its high resource value, it has become a hot spot for long-term research in the petroleum industry. Drilling core is an indispensable way to study gas hydrates. At present, the developed heat preservation and pressure coring device has been developed for extracting deep buried diffusion hydrates. The extracted core is used to study the reserves of hydrates and the possibility of landslides on the seabed. However, tool-driven mode disturbs the formation, and the hydrate acquisition rate is low [1]. Now, there are few studies on the seepage hydrate concentrating tools with high hydrate content and shallow burial [2-3].

The impact tube shoe is one of the most important parts of the coring device. The coring process of the coring device actually uses the impact tube shoe to cut the mudstone layer, and finally the process of extracting the sample containing the natural gas hydrate mudstone. In this paper, the finite element software is used to optimize and improve the dimensions of the impact tube shoes to ensure the optimized model has sufficient strength and penetration performance.

II. METHOD AND MODELING

The coring is mainly in the mudstone layer where the seepage hydrate reservoir is located. In order for the extracted core to accurately reflect its composition, the working process must reduce the disturbance. The device uses a constant flow pump to press the impact tube shoe into the coring layer with a uniform motion. During the optimization, the following parameters are considered to remain unchanged: (1) Mudstone layer confining pressure is 13MPa. (2) The impact tube shoe inner diameter d_0=72mm, outer diameter d=88mm.

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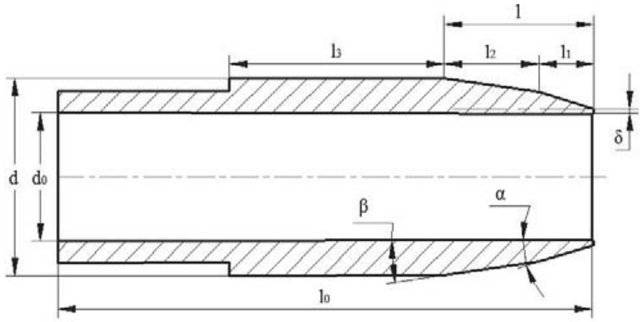
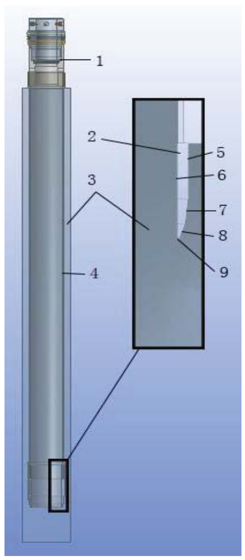


Figure 1. The structure of the impact tube shoe

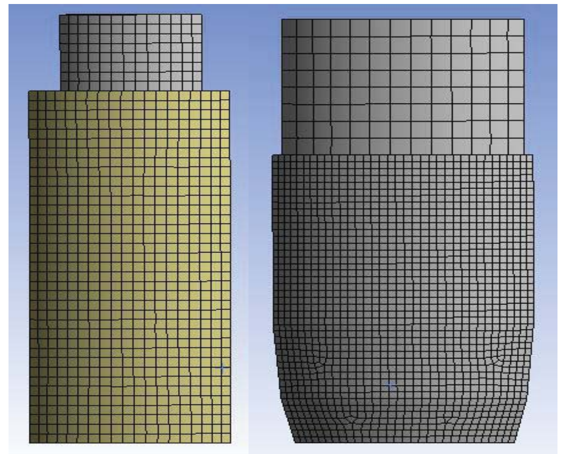


1-Impact tube joint, sealing devices, etc. 2-Impact tube shoe 3- Mudstone layer 4-Impact tube 5-Tube outer side 6-Tube internal surface 7-Tube rear surface 8-Tube front surface 9-Tube end face

Figure 2. Coring devices and the finite element model (only the impact tube shoes and mudstone layers are modeled)

- Model and material settings. The finite element software ANSYS Workbench18.0 was used to establish the model [4]. As shown in Figure 2, the impact tube shoe and mudstone layer are symmetric structures, thus one quarter of the model with symmetric boundary conditions is calculated. The impact tube shoes use Ti-6Al-4V titanium alloy material with excellent mechanical properties [5]. The impact tube shoe density is 4510kg/m^3, the elastic modulus E_{shoe}=110GPa, the Poisson's ratio λ_{shoe}=0.34, the safety factor n_{shoe}=1.3[6], and the allowable stress $[\sigma_{shoe}]$=825/1.3=634MPa. Soft mudstone layer elastic modulus E_{layer} = 680MPa, Poisson's ratio λ_{layer} = 0.3 [7].

- Meshing. The impact tube shoe and mudstone with a hexahedral mesh, and element size is 5mm. The contact part adopts the local mesh refinement function to improve the mesh quality, and the element size is 2 mm. The quality of meshing is concentrated at 0.85~0.95, and the quality is up to standard. The contact relationship between the impact tube shoe and the mudstone layer is frictional contact, and the coefficient of friction is 0.3 which comes from experimental data.



（a）Overall meshing （b）Impact tube meshing

Figure 3. Meshing

- Boundary conditions. As shown in Figure 4, a fixed constraint is added at the bottom position “A” of the mudstone layer, and a compressive load is applied at B~F which direction is directed to the impact tube shoe. In Figure 5, the impact tube shoe is applied directional downward displacement pointing to mudstone.

- Method. The optimized impact tube shoes should have less penetration resistance and sufficient strength during the coring process. The static analysis of the impact tube shoes with different sizes and angles is carried out employing the finite element method. The impact tube shoes will suffer yield damage under the action of high working load, so the Von-Mises following the fourth strength theory is used to study the stress state of the impact tube shoes.

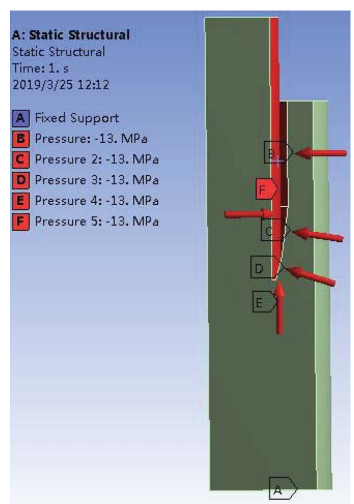


Figure 4. Mudstone layer constraint and loading

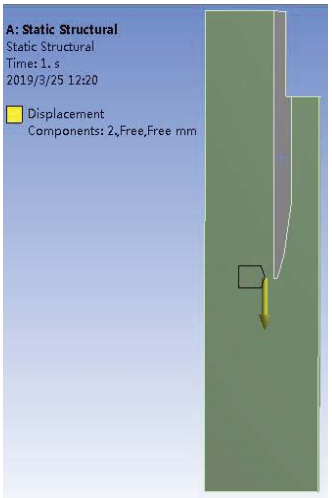


Figure 5. Displacement boundary condition of the impact tube shoe along the direction of mudstone layer

A. Optimization of the length l of the cutting surface in the axial direction

As shown in Figure 1, the length l of the cutting surface in the axial direction is the sum of the length l_1 of the front along the axis and the length l_2 of the back along the axis of the shoes. For simplicity, assuming α is equal to β. According to the size of the shoe, l varies from 5mm to 75mm. The inner diameter and outer diameter of impact tube shoes are unchanged, and the thickness of the initial end face δ is set to 1mm. In the simulated penetrating process, the set motion is a 2 mm displacement of the impact tube shoe model. The simulation calculation results are shown in Table I.

TABLE I. OPTIMIZATION OF THE LENGTH OF THE CUTTING SURFACE L ALONG THE AXIAL DIRECTION

l (mm)	σ_{max} (MPa)	F_1 (kN)	F_2 (kN)	F (kN)
5	551.27	8.4	32.2	40.6
15	650.29	11.1	26.0	38.1
25	691.51	13.1	24.2	37.3
35	621.76	14.3	23.6	37.9
45	729.06	15.6	26.9	42.5
55	688.52	15.9	26.7	42.6
65	662.02	16.2	26.5	42.7
75	640.27	16.2	26.4	42.6

As shown in the above table, the penetration resistance F is equal to the sum of the frictional resistance F_1 and the end reaction force F_2. When 5mm $\leqslant l \leqslant$ 25mm, the penetration resistance is reducing obviously with the increasing l. When 45mm $\leqslant l \leqslant$ 75mm, the penetration resistance of the impact tube shoe remains almost unchanged. Considering the strength of the impact tube shoes and the penetration performance of the tube shoes, taking l=35mm as the best.

B. Optimization of the front angle α

The front length l_1 and the rear length l_2 of the tube shoe have $l_1<l_2$ under normal circumstances [8], and take l_1=12mm, l_2=23mm. Keep the inner diameter, outer diameter and end face of the impact tube unchanged. When the front angle α of the impact tube changes in the range of 0°~30.25°, the corresponding back angle β changes in the range of 16.93°~0°, and the model is established every 1° interval of the front angle. The simulated motion is the same as part A. The results are as follows.

1) Strength analysis

With the increase of the front angle α (or the decrease of the back angle β), the maximum stress of the impact tube shoe first decreases and then increases, and the maximum Von-Mises stress is within the allowable range, as shown in Figure 6.

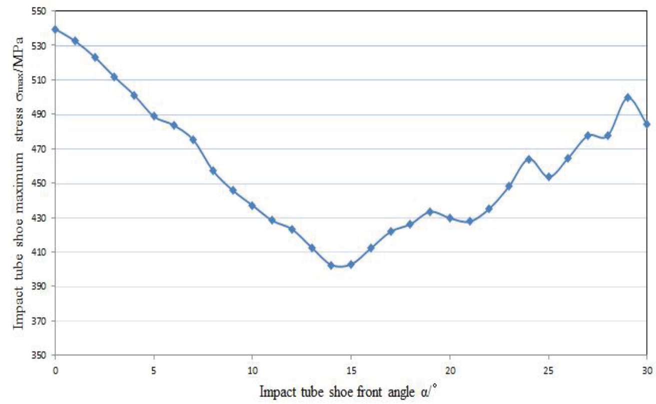


Figure 6. The maximum stress of the impact tube shoe changes with the front angle of the tube

2) Analysis of penetration resistance

As the front angle of the tube increases, the penetration resistance decreases, as shown in Figure 7.

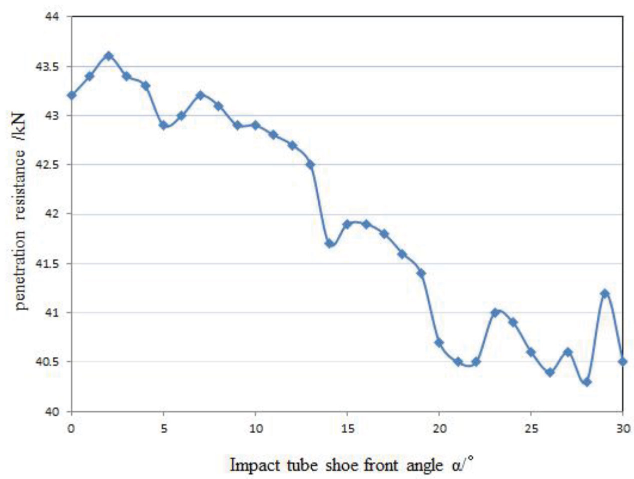


Figure 7. Penetration resistance changes with the front angle of the shoe

3) Determination of the optimal angle range

As shown in Figure 6, the maximum stress of the tube shoe varies from 402.5MPa to 539.55MPa. The maximum stress of the model is less than 450MPa and the variation is small when 11°≤α≤23°. As shown in Figure 7, the penetration resistance of the shoe is less than 42kN when 14°≤α≤30°, which indicates that the penetration performance of the large angle front angle model is better than the small angle front angle model. Combined with the calculation results of the strength and penetration resistance of the impact tube shoe, it is preliminarily determined that the impact tube shoe with the front angle α in the range of 14°~23° has better strength and penetration performance.

C. *Combination optimization of axial length l_1 and angle of front angle α of impact tube*

Change the length l_1 of the front in the axial direction, the front angle of the impact tube shoes changes in the range of α=14°~23°, l=35mm, and all other parameters remain unchanged. The results are as follows.

1) Strength analysis

It can be seen from Figure 8 that during the process of changing the front angle from 14° to 23°, the maximum stress of all model decreases with the increase of the front angle.

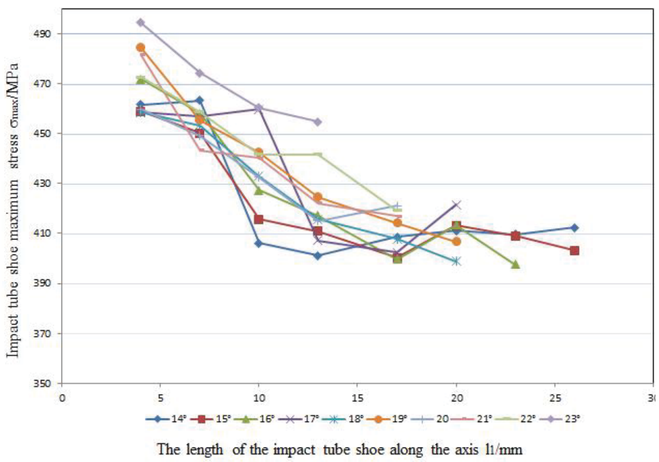


Figure 8. Curve of the maximum stress of the tube shoe along the length of the front of the tube shoe along the axis

2)Analysis of penetration resistance

It is found from Figure 9 that the impact tube shoes with an angle of 14° ≤ α ≤ 19° are subjected to greater resistance.

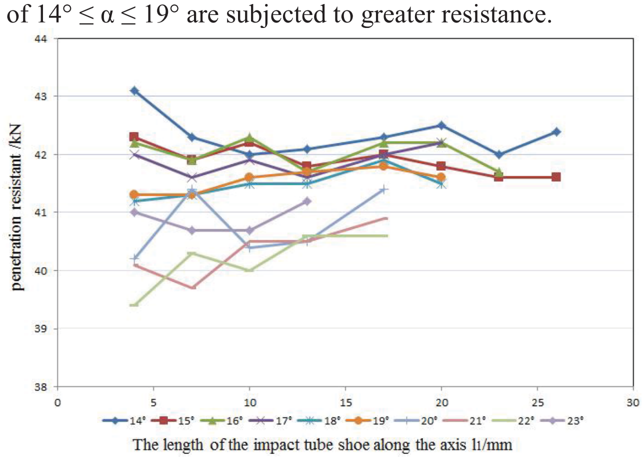


Figure 9. The variation of the penetration resistance of the impact tube shoe along the axial length of the front

3)Determination of the optimal impact tube shoe model

The penetration resistance of impact tube shoes of different models varies from 39.4 to 43.1 kN. The maximum stress of the shoe does not exceed 420 MPa when α is between 20 ° and 22 °, and the penetration resistance does not exceed 41 kN and the fluctuation is not large, as shown in Table II.

TABLE II. OPTIMIZED IMPACT TUBE SIZE PARAMETERS

α (°)	l_1 (mm)	σ_{max} (MPa)	F (kN)
20	13	415.09	40.5
21	17	417.04	40.9
22	17	419.26	40.6

The impact tube shoe model has better strength and less penetration resistance than the other models when α=20°, l_1=13mm, so it is determined that the impact tube shoe α=20°, l_1=13mm is optimal.

D. *Optimization of the end face ring thickness δ*

Reasonable end face size has an extremely important impact on the service life of the shoe. This example applies the optimized shoe model parameters l, α and l_1 above. Parameters such as outer diameter and inner diameter remain unchanged. The thickness of the end face δ is from 1mm to 4mm, and every model is established at intervals of 0.5mm. The simulated motion same as above, the results are as Table III.

TABLE III. COMPARISON OF CALCULATION RESULTS OF RING THICKNESS OF DIFFERENT IMPACT TUBE SHOES

δ (mm)	σ_{max} (MPa)	F (kN)
1.0	415.09	40.5
1.5	286.56	40.9
2.0	216.73	41.4
2.5	203.24	41.5
3.0	179.24	42.8
3.5	157.20	43.7
4.0	155.70	43.4

It can be seen from Table III that the smaller the thickness δ of the shoe end face is, the more "sharp" the end face will be, and the penetration resistance will be smaller, while the stress will increase. So it is considered that δ=1.5mm is optimal.

III. CALCULATION OF THE IMPACT TUBE SHOE STRENGTH UNDER THE ACTION OF MAXIMUM DRIVING FORCE

Simulation analysis of the impact tube shoes under the action of maximum driving force. The constant flow pump in the coring device can provide a maximum pressure of 70 MPa. As the end face area of the joint is 3631.68 mm^2, the maximum driving force of the coring device is calculated to be 254.17 kN. Apply 254.17kN load on the contact surface of the impact tube shoe and the impact tube (as shown in Figure 10 at position A). The size parameters of the impact tube shoe is the l, α, l_1 and δ which have been optimized above, and the other parameters remain unchanged. The stress is calculated when the impact tube shoes are completely penetrated into the mudstone layer.

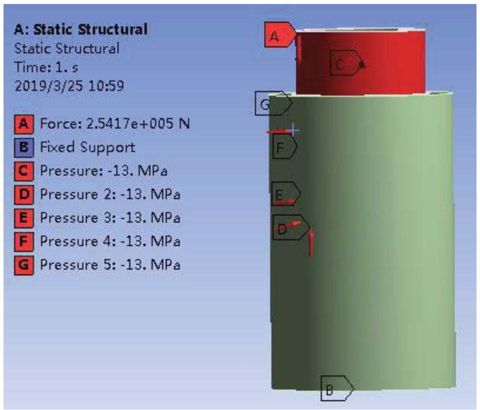
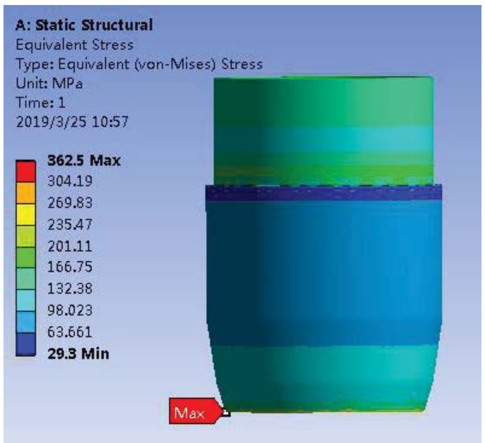
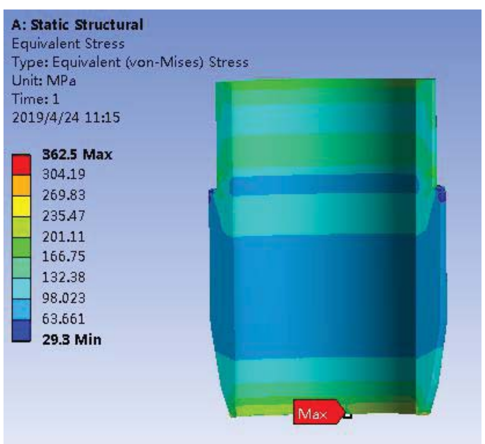


Figure 10. Restraints and loads



(a)Overall contour



(b)Sectional contour

Figure 11. Impact tube shoes von-Mises stress contour

The maximum Von-Mises stress of the impact tube shoe under the maximum driving force appears at the lower end position of the tube shoe as shown in Figure 11. In this state, the stress value of 362.5 MPa does not exceed its allowable stress value, which indicates that the optimization result is suitable for the coring work of the seepage gas hydrate.

IV. CONCLUSION

The ANSYS Workbench finite element software was used to optimize the geometrical structure of the impact tube shoes. The following conclusions were obtained:

a) The dimensional parameters of the optimized impact tube shoes are: l=35mm, α=20°, l_1=13mm, δ=1.5mm. The optimized impact tube shoe has higher strength and less penetration resistance.

b) Under the driving force of 254.17kN, the optimized model does not exceed its allowable stress value. The impact tube shoe could work under the load of 254.17kN, which is the load under the seabed with the water depth of 1300m.

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