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Design and Optimization of Rubber Tube of Orifice BoP

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Abstract. The rubber tube is made of rubber material. It is the important part of the orifice boP. The rubber tube is squeezed and deformed to contact with the drill pipe to achieve the sealing function. There are large deformation and contact problems in the sealing process of rubber, which is difficult to calculate theoretically. In this paper, finite element analysis software is used to analyze the contact stress between the designed rubber cylinder and the drill pipe under different loads and the influence of friction factor on the contact stress. The influence rules are summarized, the structure of the rubber cylinder is optimized, and the contact stress of the optimized rubber cylinder is analyzed. The results meet the design requirements.

1 Introduction

The function of the orifice boP is to seal the annulus gap between the drill pipe and the casing to prevent the high-pressure fluid from gushing out of the hole. The rubber tube is the core component of the orifice boP[1]. During the working process, the piston extrudes the rubber tube and comes into contact with the drill pipe. The rubber tube is made of rubber material. Rubber is a kind of composite material with high nonlinearity. Rubber is affected by material nonlinearity and geometric nonlinearity at the same time. In the process of rubber preparation, the rubber components are characterized by inhomogeneity, discontinuity and anisotropy[2]. Because of the small elastic modulus of the base material of rubber, the rubber material can also be simplified in the study, which is considered to be uniform, continuous and isotropic. After the occurrence of large deformation, the rubber tube will interact with the sleeve and drill pipe, etc. Therefore, such problems are nonlinear, large deformation and contact problems, which are difficult points in finite element mechanical simulation.

2 Mechanical analysis of rubber tube

The performance parameters of the rubber material must be experimentally determined for the specific rubber. Uniaxial tension, biaxial tension and plane shear tests were performed on the rubber. The finite element software was used to fit the experimental data, and the rubber model of Mooney-Rivlin was used for calculation. The model parameters

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C01=4.33899 and C10=0.17599 were obtained through fitting analysis. The deformation of the rubber cylinder under force is very large, so the accuracy of theoretical calculation is difficult to determine. In this paper, finite element analysis method is used to simulate the sealing process of the rubber tube of orifice boP[3].

2.1 Structural dimensions of rubber tube

The rubber tube is used to seal the annular space between the orifice boP and the drill pipe with the outside diameter of 89mm. The preliminary design structure size of the rubber tube is shown in figure 1. In order to ensure that the rubber tube is not scratched by the drill pipe in the sealing process, the inner diameter of the rubber tube is 95mm in the design.

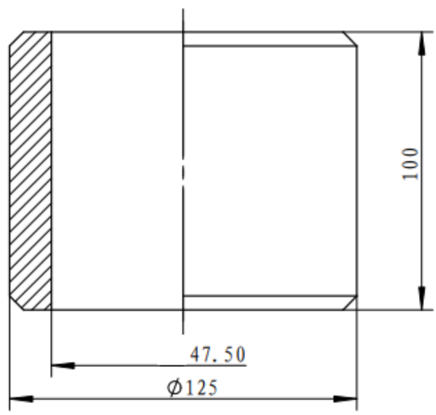


Fig. 1. Initial design schematic of rubber tube

2.2 Finite element model and meshing

In the working process of orifice boP, the load of sleeve, upper and lower pressure ring, rubber tube and drill pipe is distributed axisymmetric. Take the section of the axis to establish the finite element calculation model. The sleeve, the upper and lower pressure ring, the rubber tube, the drill pipe all adopts the PLANE 182 structure unit. PLANE182 is defined by four nodes, each of which has two degrees of freedom: translational motion in the X and Y directions of the node coordinate system. The unit has the functions of plasticity, superelasticity, stress rigidization, large deformation and large deformation. Friction contact between rubber and rigid body exists in the working process of orifice boP[4], and the friction coefficient between rubber and rigid body is set as 0.5. Rubber and rigid body contact pairs were selected for CONTA 172 contact unit and TARGE 169 target unit[5]. A relative distance is always maintained between the pressure ring and the rotating sleeve, so contact is not used. The figure after grid division of the rubber tube model of orifice BOP is shown in figure 2.

2.3 Finite element model constraints

Apply boundary conditions:The upper and lower ends of the sleeve and drill pipe are fixed in Y direction, and the lateral side of the sleeve is fixed in X direction.The pressure ring of the rubber tube is fixed vertically and an axial load is applied on the pressure ring.

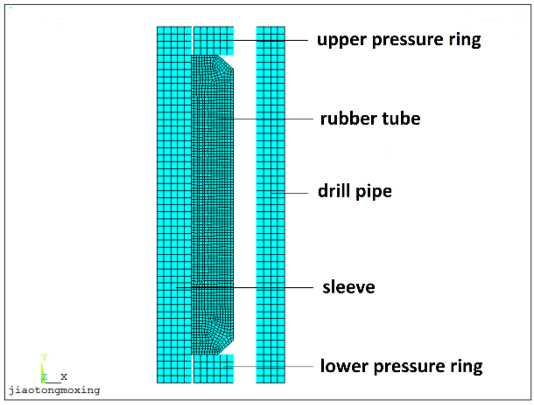


Fig. 2. The drawing of rubber tube after being meshed

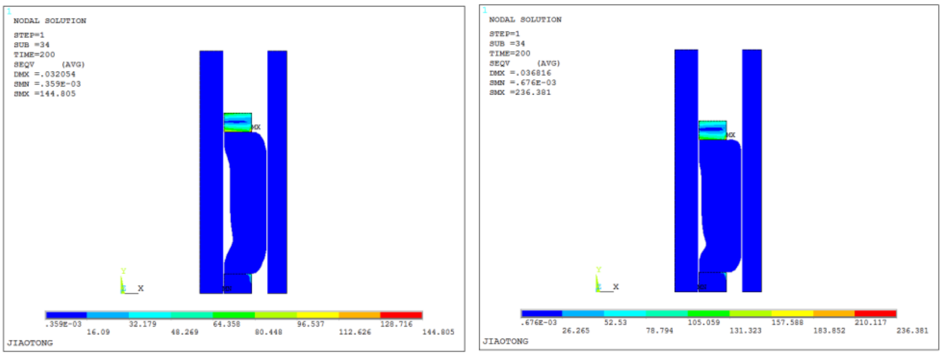
2.4 The results of finite element model calculation

Suppose that the pressure of the high-pressure liquid acting on the piston is 10 MPa and 15 MPa respectively, The acting on the upper pressure ring of the rubber tube through force transfer is 8.21 MPa and 12.32 MPa respectively. Apply the above two loads respectively, The stress nephogram of the finite element model is obtained through nonlinear contact analysis, as shown in figure 3. Table 1 shows the parameter values of each material.

Table 1. Parameters involved in analysis.

name	elasticity modulus(MPa)	Poisson's ratio	Yield stress (MPa)	Ultimate strength (MPa)	density (kg/m^3)
Rubber tube	9.16	0.49			2200
Pressure ring	2.05e5	0.26	800	1000	7800
Drill pipe	2.05e5	0.26	457	527	7800
sleeve	1.76e5	0.27	480	800	7200

As can be seen from figure 3, Firstly, the compressive stress of the lower pressure ring is obviously less than that of the upper pressure ring because of the friction force. Secondly, in the process of compression deformation, the degree of extrusion deformation on the upper pressure ring side of the rubber tube is obviously stronger than that on the lower pressure ring side. Thirdly, when the setting load is large, the lower part of the rubber tube has a large triangular "sag". This triangular "sag" will affect the distribution of contact stress between the cylinder and the casing. There are two reasons for this phenomenon, one is the effect of friction, the second is the thickness of the rubber tube is not enough, the rubber tube inner diameter and drill pipe wall clearance is too large.

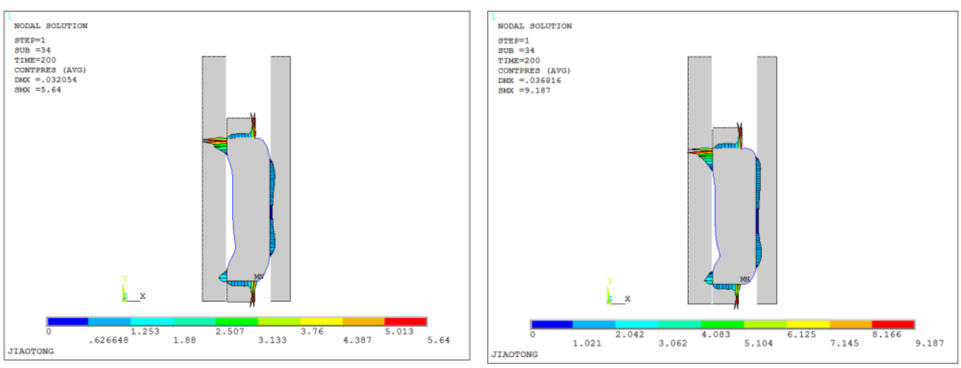


a. p=8.21MPa b. p=12.32MPa

Fig. 3. Von -Mises stress of different load-fashion on rubber tube

2.5 The contact stress between rubber tube and casing

The sealing performance of orifice boP depends on the contact pressure between rubber tube and drill pipe. If the contact stress is greater than the pressure of the sealing medium, the sealing effect is good; otherwise, the sealing fails.Figure 4 shows the distribution of contact stress between the rubber tube and the sleeve, the drill pipe, and the upper and lower pressure rings.



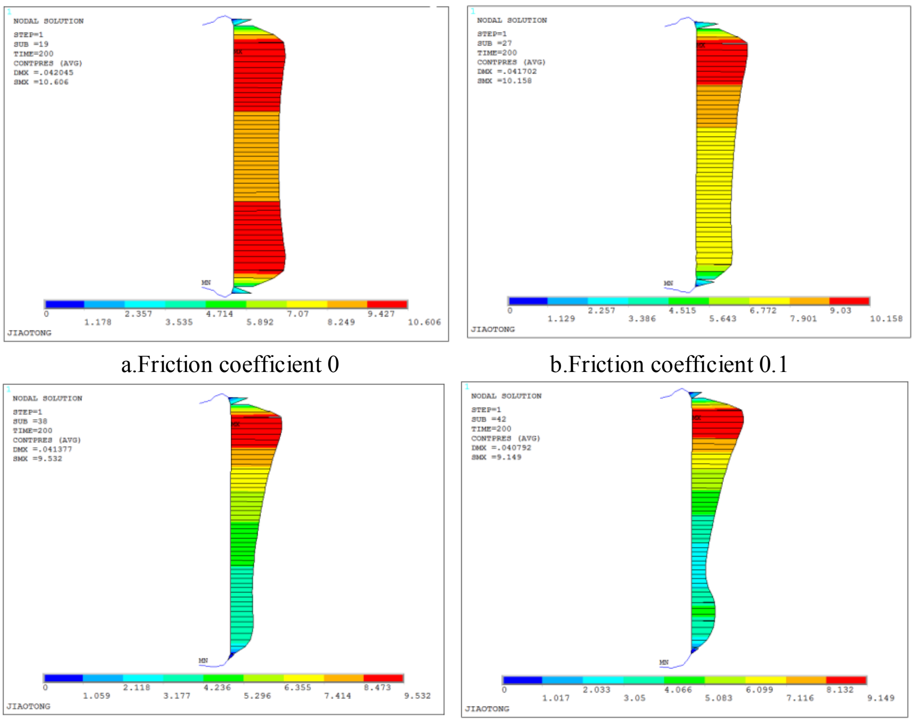
a. p=8.21MPa b. p=12.32MPa

Fig. 4. Contact stress of different load-fashion on rubber tube

It can be seen from figure 4 that the maximum contact stress between the rubber tube and the casing under the setting load of 12.32MPa is 9.19MPa. This contact stress obviously did not achieve the desired effect that we had designed. But from this figure, we can analyze the sealing form of the rubber cylinder and draw the following conclusions: Under different loads, the contact stress between the rubber tube and the casing presents two peak values. When the load is small, the two peaks are close to each other and the distribution of contact stress is uniform. When the load is large, the peak value of contact stress between the lower part of the rubber tube and the casing is obviously smaller than that between the upper part of the rubber tube and the casing. The upper part of the rubber tube plays a major sealing role.

3 The influence of friction coefficient

It is difficult to determine the friction coefficient between the rubber tube and the casing during the operation of the orifice boP. The friction coefficient between the rubber tube and the casing is different due to the different amount of liquid between the sealed fluid and the sealing surface of the rubber tube and the casing. Because the friction coefficient has a certain influence on the sealing performance, it is necessary to simulate the deformation of the rubber tube and the distribution of the contact pressure with the casing under different friction coefficient. It provides theoretical support to optimize the structure of rubber cylinder.



a.Friction coefficient 0 b.Friction coefficient 0.1

a. Friction coefficient 0.3 b. Friction coefficient 0.5

Fig. 5. The contact stress in different friction coefficient

Friction coefficients of rubber tube, drill pipe, sleeve and upper and lower pressure ring were set as 0, 0.1, 0.3 and 0.5 respectively. Taking the axial load of 12.32MPa as an example, The calculated contact stress is shown in figure 5. The friction coefficient has a great influence on the contact mode between the rubber tube and the casing. When the friction force is 0, the contact stress is distributed symmetrically and the contact is uniform. When the friction force is 0.5, the contact stress presents a double peak distribution, and there is a large gap between the peaks, with 0 contact stress appearing locally. With the increase of friction coefficient, the maximum contact stress between rubber tube and casing decreases continuously. When the friction coefficient is between 0 and 0.3, the contact stress decreases obviously. When the friction coefficient is between 0.3 and 0.6, the contact stress drops gently.

4 Mechanical analysis of optimized rubber cylinder

Figure 6 shows the axial distribution of the optimized rubber cylinder contact stress. It can be clearly seen from the figure that the maximum contact stress between the rubber barrel and the casing meets the design requirements. The inner diameter of the rubber barrel is less affected by friction, the contact stress is obviously increased under the same load, and the contact stress curve is relatively gentle, without triangular depression. The optimized structure of the rubber barrel can meet the requirements of the boP.

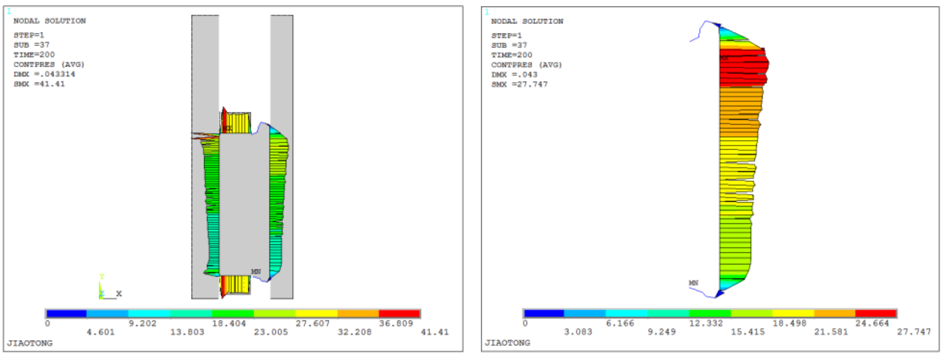


Fig.6. Contact stress of optimized packer rubber tube

5 Conclusions

The force analysis of the initial design of the rubber cylinder shows that the sealing performance cannot meet the design requirements. The reason is that the inner diameter of the rubber barrel is too small, the deformation is serious in the extrusion process, and the triangle "sag" appears due to the friction force, which affects the sealing effect.

The contact stress between the rubber barrel and the casing under the action of different friction coefficients is analyzed, and the rule that the contact stress between the rubber barrel and the casing decreases with the increase of friction coefficient is obtained, which provides a theoretical basis for the subsequent optimal design of the rubber barrel.

Increase the inner diameter of the rubber barrel and set the friction coefficient as 0.5. After optimization, the rubber barrel can meet the sealing performance requirements under the same load.

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