Finite element analysis and optimization of oil packer

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Abstract

A compression type of packer is modeled using ANSYS software, with the sealing process being the main concentration. After the simulation, appropriate sealing pressure is computed, and also the contact pressure between packer rubber and tube is presented. In addition, the changing process of compression distance of packer rubber is given in this article, which shows that 30 mm is the stable distance. Second, chamfer angle of packer rubber is optimized, which shows that the angle of 40°–45° achieve the maximal contact stress. Third, the length and coefficient of rubber is analyzed.

Keywords: finite element analysis, optimization, oil packer.

1 Introduction

In the oil field, packer is an important tool mainly used in well completion [1–3], isolation of different layers, and so on. The action principle of packer is as follows: First, pressure of oil acts on rubber that is the outside layer of the packer, then the rubber begins to be compressed along the axial direction, at the same time, the rubber extends in the radial direction. With the packer rubber compression increasing, the contact occurs between rubber and inside layer of tube, which completes the sealing process [4, 5].

As the most important factor in sealing, the performance of rubber has a significant effect on the result of sealing [6]. The behavior of rubber is the main focus in the process of sealing. It is necessary to give a research and optimization of packer rubber to achieve a better effect.
2 Model of packer rubber

In order to simulate the behavior of packer rubber, Mooney–Rivlin model is used to compute the stress–strain behavior of packer rubber. In the first place, we assume that the rubber is completely incompressible. In the second place, two parameters determined by material have to be confirmed.

The equation of Mooney–Rivlin is as follows:

\[ W = (I_1, I_2, I_3), \]
\[ I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2, \]
\[ I_2 = \lambda_1^2\lambda_2^2 + \lambda_1^2\lambda_3^2 + \lambda_2^2\lambda_3^2, \]
\[ I_3 = \lambda_1^2\lambda_2^2\lambda_3^2, \]

where \( \lambda_1, \lambda_2, \lambda_3 \) are the three principal stretch ratios. According to the incompressible behavior of rubber,

\[ I_3 = \lambda_1^2\lambda_2^2\lambda_3^2 = 1 \]

Mooney–Rivlin model can be described as

\[ W = C_1(I_1 - 3) + C_2(I_2 - 3) \]

According to the stress tensor of Piola–Kirchhoff \( (t_{ij}) \) and strain tensor of Cauchy–Green \( (\gamma_{ij}) \),

\[ t_{ij} = \frac{\partial W}{\partial I_1} \frac{\partial I_1}{\partial \gamma_{ij}} + \frac{\partial W}{\partial I_2} \frac{\partial I_2}{\partial \gamma_{ij}} + \frac{\partial W}{\partial I_3} \frac{\partial I_3}{\partial \gamma_{ij}} \]

The relationship between main stress \( (t_i) \) and main strain \( (\lambda_i) \) can be described as follows:

\[ \begin{cases} 
  t_1 = 2\lambda_1 \left[ \frac{\partial W}{\partial I_1} + (\lambda_1^2 + \lambda_3^2) \frac{\partial W}{\partial I_2} + \lambda_2^2\lambda_3^2 \frac{\partial W}{\partial I_3} \right] \\
  t_2 = 2\lambda_2 \left[ \frac{\partial W}{\partial I_1} + (\lambda_1^2 + \lambda_3^2) \frac{\partial W}{\partial I_2} + \lambda_1^2\lambda_3^2 \frac{\partial W}{\partial I_3} \right] \\
  t_3 = 2\lambda_3 \left[ \frac{\partial W}{\partial I_1} + (\lambda_1^2 + \lambda_2^2) \frac{\partial W}{\partial I_2} + \lambda_1^2\lambda_2^2 \frac{\partial W}{\partial I_3} \right] 
\end{cases} \]

Under the uniaxial tensile test, \( t_3 = t_2 = 0 \)

\[ \lambda_2^2 = \lambda_3^2 = \frac{1}{\lambda_1} \]
As for the totally incompressible material, \( I_3 = \lambda_1^2 \lambda_2^2 \lambda_3^2 = 1 \), according to eqns (8) and (9),

\[
t_1 = \frac{2}{\lambda_1} \left( \lambda_1^2 - \frac{1}{\lambda_1^2 \lambda_2^2} \right) \left( \frac{\partial W}{\partial I_1} + \lambda_2^2 \frac{\partial W}{\partial I_2} \right),
\]

(10)

\[
I_1 = \lambda_1^2 + \frac{2}{\lambda_1^2}
\]

(11)

According to eqns (7)–(10), Mooney–Rivlin model can be described as

\[
\frac{t_1}{2 \left( \lambda_1 - \frac{1}{\lambda_1^2} \right)} = C_{10} + \frac{1}{\lambda_1} C_{01}
\]

(12)

\( C_1, C_2 \) are the parameters determined by the material, and we use \( C_1 = 0.5889 \), \( C_2 = 0.2944 \) to analyze the performance of packer rubber. Geometry and mechanical parameters are set as shown in Table 1.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Parameter</th>
<th>Geometry</th>
<th>Mechanical</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inner diameter (mm)</td>
<td>Outer diameter (mm)</td>
</tr>
<tr>
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<td>80</td>
<td>–</td>
</tr>
<tr>
<td>Rubber</td>
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<td>114</td>
<td>60</td>
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<td>114</td>
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<tr>
<td>Press block</td>
<td>80</td>
<td>114</td>
<td>15</td>
</tr>
<tr>
<td>Outer tube</td>
<td>121.4</td>
<td>139.7</td>
<td>–</td>
</tr>
</tbody>
</table>

In order to simplify the process of computing, the cross-section of the rubber is modeled. The computation result is shown in Fig. 1.

3 Analysis of the performance of packer rubber

Under the pressure of 2 MPa, the packer rubber began to compress in axial direction, and in the radial direction packer rubber contacted the inside of the tube, but there are huge gaps between rubber and central tube, which indicates that the packer rubber is in the initial state of compression. With the pressure increasing to 4 MPa, the contact stress between packer rubber and tube is 0.75619 MPa, and the compression distance is 17.382 mm, but there are still some gap between central tube and rubber.

Under a pressure of 8 MPa, the contact stress increase to 1.6132 MPa, and also the compression distance increases to 24.023 mm. The contact stress and distance have reached the goal of sealing, but in order to ensure a better and more stable state, 12 MPa is employed on the packer, and the final contact stress is 3.4743 MPa, which is shown in Fig. 2.
Contact stress between packer rubber and tube is shown in Fig. 2, which indicates that with the increase of pressure, two peak values occur in the curve. This is because under the lower pressure, the middle part of the rubber contacts the tube first and then with increase of pressure, the middle part begins to stretch to central direction, the stress of upper and lower part of the rubber begins to increase and exceeds the value of the middle part. As a result, the peak value comes up.

The final compression distance is around 30 mm, which is shown in Fig. 3. When the pressure continues to increase, the distance only increases very slightly after reaching the value of 30 mm.

The chamfer of rubber is simulated in the process, and the effect of different chamfer angle on contact stress is shown in Fig. 4. According to the figure, we can conclude that the optimized angle is between $40^\circ$ and $45^\circ$. 

Figure 1: The simulation of sealing process of packer rubber.

Figure 2: The distribution of contact stress between rubber and tube.
As shown in Fig. 5, when the rubber length is 40 mm, the peak value of contact stress is over 2.5 MPa and the sealing length is about 20 mm. When the length increases to 60 mm, the peak value of contact stress is below 2.5 MPa, but the sealing region expands to 30 mm. When the length of rubber increases to 80 mm, the peak value of contact stress continues to decrease, and the contact region expands to more than 40 mm.

With the increase in rubber length, the summit value of contact region decrease, but the sealing area expands. This is because longer rubber covers more regions, so the sealing area expands. But the pressure keeps the same value, which can’t give the longer rubber enough compression, so the longer rubber gets less contact stress.

In order to increase the value of contact stress under the condition of longer rubber, the pressure must be increased. According to Fig. 6, the peak value over pass 3.5 MPa, when the pressure is loaded at 16 MPa, which ensures that the contact stress keeps the high value when using longer rubber.

The condition of different oil well may have an effect on the sealing ability of the packer, and the different condition of well mainly reflect on the coefficient between well and packer.
In order to research the different condition of oil well, this article applies different coefficients ranging from 0.2 to 0.6, and other parameters of the packer keep the same. Figure 7 shows the result of simulation. We can find that with the coefficient of 0.2, the maximal contact stress is about 4 MPa. After we increase the coefficient to 0.4, the result of maximal contact stress between the rubber and packer reaches 6 MPa. When applying the coefficient of 0.6, the peak contact stress reaches 8 MPa. According to the result of different coefficient, we can make a conclusion that within an appropriate range of coefficient, with the increase of coefficient, the contact stress rises and the sealing ability of the packer enhances. However, the larger the coefficient gets, the more likely the rubber gets ripped, the worst case is that the rubber of the packer may get destroyed totally by the
large friction. So, in order to get the larger contact stress and also ensure a good condition of the packer, the coefficient must be reasonable.

![Figure 7: The effect of coefficient on contact stress.](image)

4 Conclusions

After analysis of the sealing process of packer rubber, a conclusion is made as follows: The appropriate setting pressure is 12 MPa; there are two peak values in the curve of contact stress distribution. The stable compression distance is around 30 mm. Optimized chamfer angle is between 40° and 45°, which helps the packer achieve higher contact stress. With the increase of rubber length, the sealing region becomes larger, but the contact stress decreases, which can be solved by increasing the setting pressure. Different well conditions may affect the sealing ability of the packer; within a reasonable range of coefficient, the larger coefficient can increase the contact stress between packer and tube of well.

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References


