Mechanical properties analysis of sealing disc for straight plate pig during pigging

Nan Li¹, Liqiong Chen¹, Jie Zhang², Anlin Hu³, Xiangyu He¹, Qi Liu¹

¹School of Petroleum Engineering, Southwest Petroleum University, Chengdu, 610500, China ²School of Mechatronic Engineering, Southwest Petroleum University, Chengdu, 610500, China ³Province Key Laboratory of Oil and Gas Fire Protection, Chengdu, 611731, China

Abstract: In recent years, as the quantity demand of natural gas increases rapidly, a large number of natural gas pipeline has been increased. The stress and deformation of straight plate pig in the natural gas pipeline are obtained by the finite element software. The influences of the thickness of the sealing disc, the wring and the inner diameter of the sealing disc are studied too. Research results show that the effective stress on the pig increased by 2.5 times, the deformation also increased and there is stress concentration after the pig run in the pipeline than when they only realize interference. When the sealing disc is thinner than 42mm, the effective stress decreases with the thickness becomes larger. In contrast, when the sealing disc is thicker than 42mm, the effective stress increases with the thick becomes larger. With the increase of the wring, the effective stress on the pig will be larger, and the relationship between them is linear. The influence of the inner diameter of the sealing disc to the pig is little, with the inner diameter increase, the effective stress on the pig increases.

Keyword: Pig; Sealing disc; Effective stress; Shrink range; Thickness; Inner diameter; Numerical simulation.

1. INTRODUCTION

The project of pigging has become an essential process in gas transmission, and the application is becoming more and more widely. Many scholars have committed to the regular pattern when pigging. McDonald AE and Ovid Baker made McDonald and Baker pigging model, Barua modified their model, and made Barua pigging model, Minami and his workmates also modified their model, and made Minami pigging model, Zhipeng Liang made the pigging model coupled with the transient model, then modified Minami pigging model, and proposed a preliminary model of transient pigging, Peiyu Shi made McDonald and Baker pigging model and drift flow model coupled, simulated the motion of the pig in pipeline, got the variation of the pressure in pigging. Yuting Chen researched on internal flow field of straight plate pig in the natural gas pipeline based on CFD, Hong Zhao also worked on numerical simulation and optimization on internal flow field of the pig based on CFD, and studied the influence of ratio of length to diameter on the flow of the pig field. However, they rarely do the analysis of the stress on the pig. At present, Xiaoming Liu studied on the contact performance of the cup on the mandrel pig. Hang Zhang did the finite-element analysis on mechanical properties of sealing disc for pig. Thus, the paper uses straight plate pig for example, the stress and deformation of straight plate pig in the natural gas pipeline are obtained by the finite element software, and the influences of the thickness of the sealing disc, the wring and the inner diameter of the sealing disc are studied too.

2. FINITE ELEMENT MODEL

The writer established pigging model according to the situation of the pig moving in the pipeline, and analyzed the mechanical status, the physical model is shown in figure 1.
The pig is shown in figure 2, the major parts on it include 4 supporting discs, 6 sealing discs, 10 spacing discs and one cylinder. The size of the pipe is Φ813×5.5 mm, it is made of L485 (16MnR). The size of the pig is shown in Table 1.

<table>
<thead>
<tr>
<th>Disc</th>
<th>Inner diameter(mm)</th>
<th>Sealing disc(mm)</th>
<th>Supporting disc(mm)</th>
<th>Spacing disc(mm)</th>
<th>Cylinder</th>
<th>Length(mm)</th>
<th>Middle part(mm)</th>
<th>Forepart part(mm)</th>
<th>Rear part(mm)</th>
<th>Outer diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>470</td>
<td>822*30</td>
<td>790*40</td>
<td>600*40</td>
<td></td>
<td>1308</td>
<td>528</td>
<td>380</td>
<td>380</td>
<td>470*4</td>
</tr>
</tbody>
</table>

The material physical parameters of the pipe and pig are shown in table 2, the coefficient of friction between them is 0.1. There are two steps to apply load, firstly apply radial displacement load, making the pig and pipe realize interference. Secondly apply speed load is 2 meters every second. Then make mesh, lastly calculate for solution.

<table>
<thead>
<tr>
<th></th>
<th>Density (kg·m⁻³)</th>
<th>Elastic Modulus (GPa)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe</td>
<td>7.85×10³</td>
<td>209</td>
<td>0.280</td>
</tr>
<tr>
<td>Disc</td>
<td>1.32×10³</td>
<td>0.1</td>
<td>0.47</td>
</tr>
</tbody>
</table>

3. SIMULATION RESULTS

3.1 Effective stress analysis

Figure 3 and 4 are effective stress cloud pictures of the disc when the pig is still and moving forward, the effective stress is a value obeys yield criterion, it follows the fourth strength theory in mechanics of materials.
It’s obvious that the effective stress on the disc is much larger after the pig moving forward than before from figures 3 and 4. When the pig and pipe only realize interference, only 6 sealing discs are in force, and the force on each piece is equal, the values on the top and bottom are substantially equal, and the max effective stress is 25.2MPa. However, when the pig is moving forward, the force on the pig is no longer equal, the max effective stress is at the bottom of the edge for the sealing disc, and the force is relatively large at the connection of the sealing disc and the spacing disc, the largest of max effective stress around 63 MPa, it’s about 2.5 times than before the pig get move. Due to the influence of gravity, stress concentration occurs, and the pig moves forward by the pressure, the force is greater on the forepart of the pig.

### 3.2 Max-shear stress analysis

It's obvious that the effective stress on the disc is much larger after the pig moving forward than before from figures 3 and 4. When the pig and pipe only realize interference, only 6 sealing discs are in force, and the force on each piece is equal, the values on the top and bottom are substantially equal, and the max effective stress is 25.2MPa. However, when the pig is moving forward, the force on the pig is no longer equal, the max effective stress is at the bottom of the edge for the sealing disc, and the force is relatively large at the connection of the sealing disc and the spacing disc, the largest of max effective stress around 63 MPa, it’s about 2.5 times than before the pig get move. Due to the influence of gravity, stress concentration occurs, and the pig moves forward by the pressure, the force is greater on the forepart of the pig.
Fig. 6 Max-shear stress on the disc when the pig is moving forward

Figure 5 and figure 6 shows the max-shear stress when the pig is still and moving forward, respectively. The shear stress of the pig is small because there is no axial movement while the pig and pipe only realize interference. In the process of movement, in addition to the contact force, the pig also bears with the frictional force and the differential pressure of pushing the ball (including the pressure of gas, dirt resistance and pressure of pushing ball). The max-shear stress is at the bottom of the edge for the sealing disc, and the shear force is relatively large at the connection of the sealing disc and the spacing disc, the largest of max-shear stress around 35 MPa, and the disc’s breaking strength is 35 MPa in the experimental test. It also explains the reason why some pigs get broken after they moving in the pipeline forward a distance.

Clearly, the shear force is bigger in the front of the pig than in the back-end, and the biggest max-shear stress is at the bottom of the edge for the sealing disc. The max-shear stress is also large at the connection of the sealing disc and spacing disc, relatively. So it is easy make the pig broken in the above place. Figure 7 shows the picture of some broken pig, and the figure 6 vividly explained the reason why this phenomenon appears in this figure.

Fig. 7 Picture of some broken pig
3.3 Displacement analysis

As shown in figure 3 and 5, the deformations are all on the sealing discs before the pig moves forward, the max deformation is the difference between the outer diameter of the sealing disc and the inner diameter of the pipe. Figure 8 shows the displacement on the disc when the pig is moving forward. We can see that the max deformation is at the bottom of the front three sealing discs. As the pig moving forward, the sealing cup formed a certain amount of bending angle, the bending angle at the bottom of the front three sealing cups are bigger, so it’s more likely to be tore and broken. Thus it reduces the pigging efficiency, even makes the pig out of work.

4. SENSITIVITY PARAMETERS ANALYSIS

4.1 Thickness of the sealing disc

When the pressure on the pig is not equal, the force on the pig is different. Thus, as shown in figure 9, the equivalent stress is studied when the thickness of the sealing disc is different under different pressure.

When other parameters remain the same, we only change the thickness of the sealing discs, the cloud pictures of equivalent stress, max-shear stress and deformation are almost same with and the pictures shown above. So the cloud pictures won’t be shown.
As can be seen, the changing trends of the four curves are basically same. When the thickness is between 30 and 33mm, the changing range is large. When the thickness is about 34-41mm, the stress on the pig is relatively stable, and the max equivalent stress is about 61MPa. When the thickness is greater than 42mm, the force on the pig becomes larger, and it is not advantage for the operation of pigging. The reason for the above phenomenon is that when the thickness of the sealing disc increases, the contact area will become more, it also will be hard to bend the discs. So, before the thick increases to 42mm, the equivalent stress value is relatively stable, when the thickness is more than 42mm, the difficulty of bending the sealing disc greatly increased, the equivalent stress on the pig increased.

4.2 Interference quantity

From the above conclusion, the best thickness of sealing disc is 34-41mm. Therefore, when altering the outer diameter of the sealing disc, the thickness of the sealing disc at 34, 36, 38 and 40mm are simulated, respectively, and the other parameters remain unchanged, and assumed that the pig is operated under the same normal pressure. According to the specification in the Standard of SYT5922-2012, the wring of the straight plate pig should be in 1%-4%. Therefore the size of the sealing disc can’t be reduced or increased infinitely when simulating. In this paper, the variation law of the stress on the sealing disc when its outer diameter range from 405 to 412mm is studied, the curves are shown in Figure 10.

![Fig. 10 Graph of the equivalent stress when the outer diameter of the sealing disc is different under different thickness](image)

Fig. 10 Graph of the equivalent stress when the outer diameter of the sealing disc is different under different thickness

As can be seen from the above figure, in the above 4 kinds of sealing disc thickness, with the outer diameter increasing, the force on the pig increases, and the relationship of them is basically linear. Because the outer diameter of the sealing disc increases would lead it become more difficult when the pig and pipe realize interference, and the bending angle would also increase in the operation. The force on the pig will increase dramatically.

4.3 Inner diameter of leather bowl

From the above conclusion, the best thickness of sealing disc is 34-41mm. Therefore, when changing the inner diameter of the sealing disc, the thickness of the sealing disc at 34, 36, 38 and 40mm are simulated respectively, and the other parameters remain unchanged. The graph is shown in Figure 11.
It can be seen from figure 11, in the above 4 kinds of sealing disc thickness, with the inner diameter increasing, the force on the pig increases, when the inner diameter is between 235mm and 238mm, the force increases very slow, when the inner diameter is between 239mm and 248mm, the force increases relatively fast. At the same time, the writer tried to decrease the inner diameter of the sealing disc, the result is not ideal, it won’t be present here. It explains that although the stress increases as the disc diameter getting larger, the inner diameter of the sealing disc is disadvantage for pigging if it’s too small. The reason is that the values are almost equal between the inner diameter of the sealing disc and the outer diameter of the cylinder, if the size of the cylinder is too small, it can’t ensure the pig is stable in the pipe.

5 CONCLUSIONS

(1) The effective stress on the pig increased by 2.5 times, the deformation also increased and there is stress concentration after the pig run in the pipeline than when they only realize interference. The max effective stress, max-shear stress and deformation all concentrate on the bottom of the edge for the first three sealing discs and the connection of the sealing disc and the spacing disc.

(2) Because only the sealing discs and the pipe have the relation of interference, when they achieve sealing with the pipe and cleaning the dirt, the sealing discs played a key role. The value of equivalent stress is relatively stable when the thickness of the sealing disc is not greater than 42mm. When the thickness is thicker than 42mm, the difficulty of bending the sealing disc greatly increased, the equivalent stress on the pig increased.

(3) When the other parameters remain unchanged, the force on the pig is enlarged with the increase of the outer diameter of the sealing disc. The relationship of them is basically linear. Therefore, it’s better to make the outer diameter of the sealing disc less than 411mm. According to the specification in the Standard of SYT5922-2012, the spring of the straight plate pig should be in 1%-4%. In order to ensure the cleaning effect, from the two aspects above, the outer radius of the sealing disc 410mm can be chosen.

(4) When other parameters are kept constant, only size of the inner diameter of the sealing disc is changed. With the inner diameter increasing, the force on the pig increases, the values are almost equal between the inner diameter of the sealing disc and the outer diameter of the cylinder, the size should not be changed to ensure the pig moving stable in the pipe.
References


McDonald AE, and Baker O. “Multiphase Flow in Pipelines”. Oil and Gas Journal. 6(1964).


Zhao Hong, Ma Ming, and Su Xin. “Numerical simulation and optimization on internal flow field of the pig based on CFD”. Oil &gas storage and transportation. 05(2015).