The Screw Drill New Cardan Shaft Design and Strength Calculation on the Universal Joint

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Abstract. A large number of ultra-deep wells, extended wells and horizontal wells are springing up with the exploration and development of oil and gas fields to the deep part of the land and sea. The down-hole guiding drilling tools is normal screw drill, which consists of down-hole motor, cardan shaft and transmission shaft. How to improve screw drill life, avoid fatigue is an urgent problem to be solved. The cardan shaft is important component part of the screw drill and its major function is to convey the rotation rate, torque of the motor and to guide direction. The cardan shaft is easily damaged because of its complex stress. Which often leading to drill down and unnecessary tripping accident. Therefore, the cardan shaft working life directly determines the stability and the working life of the screw drill. The new cardan shaft structure was designed based on the analysis of the cardan shaft movement characteristic, and the universal joint strength checking calculation model was established. The 197 mm cardan shaft main damaged parts (universal joint) strength checking values was calculated and analyzed by using finite element analysis software based on the model. The analysis results show that the stress and the strain of the new type cardan shaft are more uniform, which reduces the damage caused by stress concentration. The new cardan shaft spherical gear structure load optimal value range is 57.6~81.7MPa, withstanding the torque value range is 1423~2018N.m, which enhances the high torque under working condition. The application in deep wells verified life of the new cardan shaft has increased more than 40% compared with that of normal cardan shaft. The results show that the new type cardan shafts has broad application prospects in down-hole dynamic drilling tools.

Introduction

A large number of ultra-deep wells, extended wells and horizontal wells are springing up with the exploration and development of oil and gas fields to the deep part of the land and sea [1]. The down-hole dynamic drilling tools must be used to increase penetration rate and guide purposes in deep section of wells. The down-hole guiding drilling tools is normal screw drill. The screw drill consists of down-hole motor, cardan shaft and transmission shaft, which has hard characteristics of low speed and high torque, overload capability [2, 3]. How to improve screw drill life, avoid fatigue is an urgent problem to be solved. The cardan shaft is important component part of the screw drill and its major function is to convey the rotation rate, torque of the motor and to guide direction. The cardan shaft is easily damaged because of its complex stress. Which often leading to drill down and unnecessary tripping accident [4-7]. Therefore, the cardan shaft working life directly determines the stability and the working life of the screw drill.

Based on the cardan shaft movement analysis, the authors design the new cardan shaft structure and carry out strength checking of the cardan shaft easily damaged parts by using numerical simulation. At the same time, field application is used to verify the feasibility of the new designed cardan shaft.
The Cardan Shaft Movement Characteristic

Down-hole dynamic drilling tool cardan shaft movement is more complex [8, 9, 10]. The cardan shaft movement form was simplified for ease of analysis, simplified model is shown in Figure 1. The coordinate system is established with the universal shaft bending center point for the origin point (Figure 1a). Therefore, the universal shaft upper section bends along the origin point can be divided along the X axis and Y axis of rotation (Figure 1b, Figure 1c). The relative motion of two gear is easily analyzed with X axis through the spherical gear contact surface.

Figure 1b shows that the relative motion of two spherical gear sliding along the circumference with for the axis of rotation in the Y axis. Figure 1c shows that the relative motion of gear is the relative rotation with for the axis of rotation in the X axis. If the two spherical gear surface contact is flat or curved surface, two spherical gear contact surface will occur "shocking", "shocking" is increased with the increasing of contacting surface. Therefore, in order to avoid the “shocking” phenomenon, one surface of the spherical gear contacting surface should be designed into the arc surface.

Structure Design of the New Cardan Shaft

The cardan shaft mainly consists of upper connection, universal joint, central axis, down connection [11, 12]. Structure of the new cardan shaft structure is shown in Figure 2. The new universal joint consists of two groups of relative vertical spherical gear. The spherical gear structure is shown in Figure 3. A set of spherical gear and connection joint formed rotating in the direction, and another spherical gear with center shaft formed rotating in the other direction, which combined to form a bending the universal rotating in any direction. In order to improve the service life of the cardan shaft, spherical gear contact surfaces can be designed arc surface to enhance the load-carrying capacity and reduce the wearing rate of spherical gear. The cardan shaft seal is used a spherical rubber ring seal, in addition, the lubricant pressure compensation system is designed to ensure the sealed cavity higher pressure to improve seal performance.

![Figure 1. The cardan shaft motion.](image1)

![Figure 2. Schematic diagram of new cardan shaft.](image2)

The two mutual vertical spherical gear is made out on two hemisphere of the same sphere. Which can respectively achieve two mutual vertical of single direction bent turning, and combined with inner spherical gear structure can achieve any direction of bent turning. Therefore, the new cardan shaft adapt to adjustable bent shell body screw drill.

Establishment of Spherical Gear Strength Checking Model

Movement of the cardan shaft spherical gear is more complex, which result in the cardan shaft is easily damaged, so we mainly carried out the spherical gear strength checking to meet needs of ultra-deep wells drilling. The spherical gear pressure distribute along the radial direction, the greatest working face pressure formula [13, 14, 15] is as follows:
\[ \int_A P \times L \times S_A \times d_A = T_c \]  
(1)

Where, \( P \) - working loads (MPa), \( L \) - the distance of working noodles to central axis (mm), \( S_A \) - working surface area (mm\(^2\)), \( T_c \) - cardan shaft torque (N.m), \( d_A \) - spherical radius (mm).

Thus, spherical gear strength checking model is obtained:

\[ P = \frac{T_c}{\int_A P \times L \times S_A \times d_A} \leq [P] \]  
(2)

Where, \([P]\) - spherical gear contact surface permitting pressure (MPa).

**Establishment of the Finite Element Analysis Model**

The finite element analysis software [16] is used to analysis the 197mm screw dill new cardan shaft spherical gear strength distribution.

1. Simplified structure of the spherical gear
   
   The spherical gear structure geometry and force is more complex, and main bearing parts is four outside gear of spherical gear. Because four gear structure is the same, so we can carry out finite element analysis with half of the sphere.

2. Meshing of spherical gear
   
   Because 10-node tetrahedral elements (nodes) Solid92 surface boundary is very better approximate the surface boundaries, so when the structure is irregularly shaped, stress or deformation is more complex, this unit can be used, the meshing model diagram is shown in Figure 3.

![Meshing model](image)

Figure 3. The meshing model.

![Spherical gear stress and strain changes](image)

Figure 4. The spherical gear stress and strain changes at different loads.

According to the actual situation, constraints on the bottom surface of the hemisphere is imposed, displacement value is zero, the movement of the bottom surface of the hemisphere in 6 directions is restricted.

**Results Analysis**

The stress and strain changes of spherical gear at different loads are shown in Table 1 and Figure 4.

<table>
<thead>
<tr>
<th>Loading [MPa]</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
<th>80</th>
<th>85</th>
<th>90</th>
<th>95</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress Max[MPa]</td>
<td>289</td>
<td>315</td>
<td>342</td>
<td>368</td>
<td>394</td>
<td>420</td>
<td>447</td>
<td>473</td>
<td>499</td>
<td>525</td>
</tr>
<tr>
<td>Strain Max[%]</td>
<td>1.74</td>
<td>1.90</td>
<td>2.06</td>
<td>2.22</td>
<td>2.38</td>
<td>2.54</td>
<td>2.70</td>
<td>2.85</td>
<td>3.03</td>
<td>3.17</td>
</tr>
</tbody>
</table>

Figure 4 shows that the stress and strain of spherical gear increase with load increasing, and relation between stress and strain and load is linear relation. When the load increase 100MPa, the stress and strain keep linear increasing. The results show the new cardan shaft can bear higher loads.
According to the theory of the specific energy of the shape change and the analysis, the strength checking calculation formula ensured no failure of spherical gear is as follows.

\[
\sigma_{\text{max}} \leq \frac{\sigma}{N}
\]  

(3)

Where, N is allowable safety factor range is 1.5 ~ 2.5.

When the safety factor is from 1.5 to 2.5, the range of the load value is 57.6~ 81.7MPa, and its torque value range is 1423 ~ 2018N. The results show that the new cardan shaft can bear large torque, and its life is longer at high load working condition.

The spherical gear stress and strain distribution at different loads are shown in Figure 5(Since there are more picture data, this article only lists 60MPa, 80MPa stress and strain distribution images under the loads).

![Figure 5. The spherical gear stress and strain distribution at different loads.](image)

Figure 5 shows that the stress of the new cardan shaft is more uniform, which reduces the damage caused by stress concentration.

Field Application

The designed new cardan shaft with 197mm screw drill were carried out 2 wells testing in deep wells. The test and analysis results are shown in Table 2.

<table>
<thead>
<tr>
<th>Well n.</th>
<th>Section[m-m]</th>
<th>Cardan shaft type</th>
<th>Life[h]</th>
<th>Raised rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2517-4924</td>
<td>New cardan shaft</td>
<td>426</td>
<td>46%</td>
</tr>
<tr>
<td>2</td>
<td>2513-4973</td>
<td>New cardan shaft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3436-4963</td>
<td>Normal cardan shaft</td>
<td>291</td>
<td></td>
</tr>
</tbody>
</table>

The table 2 shows that the new universal shaft working life is more than 40% compared with that of normal universal shaft. The application results show that the new universal shaft can meet the requirement of deep and ultra-deep wells drilling.

Conclusion

(1) Based on analysis of Cardan shaft movement characteristics, the new cardan shaft cardan is designed. And cardan interface is designed as surface contact to bear high load capacity and to avoid wearing. In addition, the lubricant pressure compensation system is designed to ensure the sealed cavity higher pressure to improve sealing performance.

(2) The finite element analysis results of the new cardan shaft stress and the stain show that its stress is uniform, which can reduce damage at stress concentration.

(3)The cardan shaft structure torque value is 1423 to 2018N.m within the range of the safety factor according to the function relation between load and torque. The transmission shaft can bear large torque, and increases the life of at working conditions with larger torque.

(4) Field application results show that the new universal shaft working life is more than 40% compared with that of conventional universal. Which can meet the requirement of deep and ultra-deep wells drilling.
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Reference