Comparison and analysis of the torque transmission structure indrilling jar

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Abstract

In order to solve the drill-jamming accidents, drilling jar is added to drill string assembly. Drilling jarmust transmit torque through torque transmission structure. In this paper, three kinds of torque transmission structures are designed and compared. A combination of mechanics study and finite element simulation is used in this paper to find out the stress state under practical working condition. The conclusion can be referred to help choose and design the torque transmission mechanism.

Keywords

Drilling jar, torque transmission mechanism, finite element simulation.

1. Introduction

In order to solve the drill-jamming accidents happen during going down, drilling or pilling out operations,drilling jar is added to drill string assembly. When encountering a drill-jamming accident, the driller can solve the problem in time with some simple operations,the time and economic costs compared with the traditional solution will be much cheaper, meanwhile the effect will be much better.

Drilling jar works as a part of drill string when there is no accident, which means it has to transmit torque. In general, the torque transmission structure includes a hydraulic cylinder and a splined mandrel, which works with mud scraper ring and sealing ring. The torque transmission structure is supposed to move axially, so that the drilling jar can complete operations like holding pressure, making shock and resetting;at the same time, there cannot be circumferentialrelative rotation between hydraulic cylinder and splined mandrel, so as to ensure the torque transmission.

Most of the torque transmission mechanism of traditional drilling jar is spline coupling, newly, pin connection and set screw coupled with ball have the same function. The three different kinds of transmission mechanism are modeled respectively in this paper, mechanics study along with simulation are used to study the stress state of the three structures under working conditions, and combined with actual situation to summarize the advantages and disadvantages of these structure, hoping to help relative design in future.

2. The Basic Size of DrillingJar and Working Condition

According to the industry standard of drilling jar *SY/T 5496-2010* and the size of a hydraulic jar, the structures of splined coupling, pin connection and set screw coupled with ball are designed separately. In this paper, the outside diameter of drilling jar is 165mm,so is the hydraulic cylinder, the diameter of water hole is 57mm.The object of this paper is torque transmission, so the main working parameter istorque, which, referring to the actual working condition, is 2.5×107KN ·mm.

3. The Torque Transmission Mechanism

3.1 Spline Coupling

At present, the spline can be divided into rectangular spine, involute spline and triangular spline according to the shape of the spline tooth. The rectangle spline is widely used in sliding connection for its high centering precision and good abrasion resistance. So this paper will use rectangle spline as object.

Refer to the mechanical design handbook, the number of rectangle spline's tooth, according to the high torque, is 10.And the rest size of the structure is designed basing on the size of drilling jar. The point is when choosing tolerance zone of size, the assembly method should be sliding so that it can meet the need of axial movement between hydraulic cylinder and splined mandrel.

3.2 Set Screw Coupled with Ball

The set screw coupled with ball is set nearly at the free end of hydraulic cylinder as Fig.1 shown below, the cooperation tightness between ball and the mandrel is able to be adjusted by the set screw, so that to prevent ensure relative circumferential rotation between hydraulic cylinder and splined mandrel, while the axial movement is promised. One more set is in need to raise the reliability of the mechanism if the it is under large load [1].

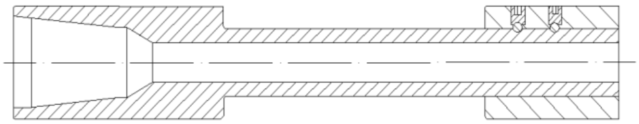


Fig. 1 The set screw coupled with ball

3.3 Pin Connection

Pins can be divided into cylindrical pin, conical pin and special shaped pin. What is discussed in this paper is cylindrical pin,the diameter of the pin is slightly smaller than that of the groove on the mandrel, so that to ensure the tight fit between hydraulic cylinder and splined mandrel. In practical application, 8 grooves are disposed symmetrically on the spline to bear large load. The pin can slide in the groove and transmit torque, the structure is shown in Fig.2 and Fig.3.One of pin's advantages is the manufacturing cost is low, and it's an economical and reliable torque transmission structure.

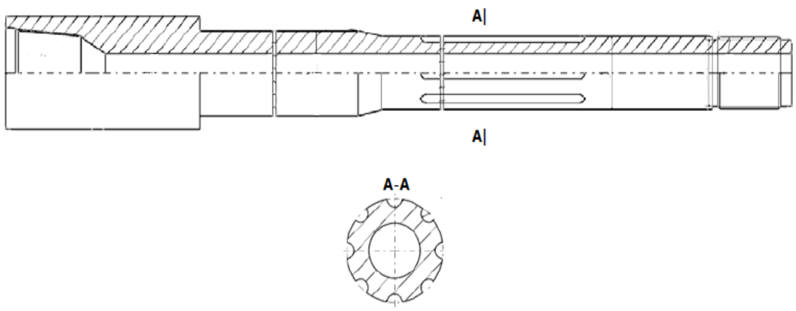


Fig. 2 The structure of pin connection

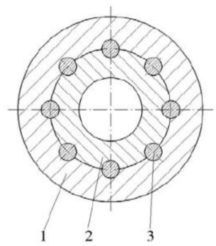


Fig. 3The cross section of pin connection
(1.Hydraulic cylinder 2.mandrel 3.pin)

4. Strength Check

In this paper, the main consideration of working condition is structure under torque, so mechanics of materials is used to check the strength of dangerous section in mandrel.

Wherein the mandrel structures of pin and set screw coupled with ball are similar, the only difference is the number of the groove. There is only 1 groove in the mandrel of set screw coupled with ball structure, so checking the strength of 8 grooves only can represent the other. Same method should be used to check the spline.

4.1 The Strength Check of Drill Mandrel

In the working condition, the situation of drill mandrel under torque is as shown in Fig.4 below. The dangerous section in the picture is slotted section A, the following is torsional strength checking [2].

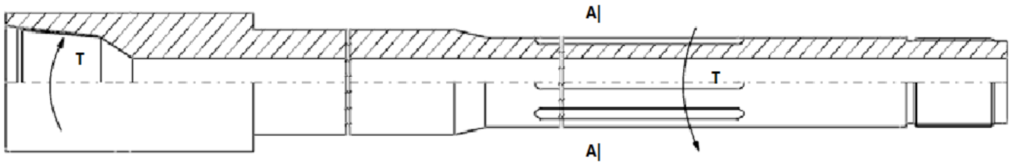


Fig.4 The drill mandrel under torque

$$\tau = \frac{T}{W_t} \le [\tau] \tag{1}$$

Where, τ is the torsional shear stress of drill mandrel; T is the torque loaded on the drill mandrel, during the working process ; $T \le [T] = 2.5 \times 10^7 KN \cdot mm$, $[T]$ is Allowable working torque, in the checking process $T = [T]$; W_t is the module of torsional section $W_t = \pi(D^4 - d^4)/(16D) = 1.803 \times 10^5 mm^3$; $[\tau]$ is the allowable torsional stress of materials, $[\tau] = 320 MPa$; τ_s is the maximum allowable shearing stress, $\tau_s = 0.5\sigma_s$.

So the torsional shear stress is $\tau = \frac{T}{W_t} = 138.7 MPa < [\tau]$

The factor of safety is $S = \frac{\tau_s}{\tau} = 3.46$.

After checking, it's obvious that the drill mandrel can meet the requirements.

4.2 The Strength Check of Splined coupling

The situation of splined coupling structure under torque is as shown in Fig.5below, the following is the checking process [3].

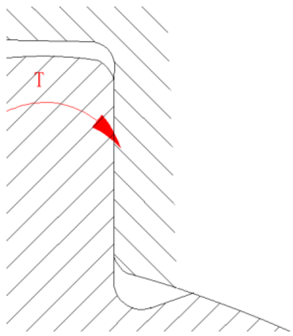


Fig.5The spline coupling structure under torque

$$\tau' = \frac{T}{W_t'} \le [\tau] \tag{2}$$

Where, τ' is the torsional shear stress of splined mandrel; T is the torque loaded on the drill mandrel, during the working process ; $T \le [T] = 2.5 \times 10^7 KN \cdot mm$, $[T]$ is Allowable working torque, in the checking process $T=[T]$; W_t is the module of torsional section $W_t=\pi\left(D^4-d^4\right)/(16D)=1.803\times10^5 mm^3$; $[\tau]$ is the allowable torsional stress of materials, $[\tau]=320MPa$; τ_s is the maximum allowable shearing stress, $\tau_s=0.5\sigma_s$.

So the torsional shear stress is, $\tau'=\frac{T}{W_t'}=110.9MPa<[\tau]$

The factor of safety is $S=\frac{\tau_s}{\tau'}=4.32$;

After checking, it's obvious that the splined mandrel can meet the requirements.

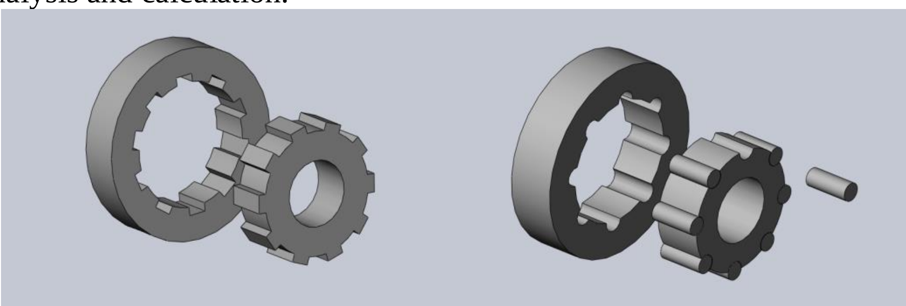
5. Finite Element Simulation

After the structure was determined, Solid Works is used to build the model which is going to be imported into ABAQUS for finite element analysis. The simulation of actual working condition is done in the analysis process. After analysis the stress distribution of the mechanism can be observed.

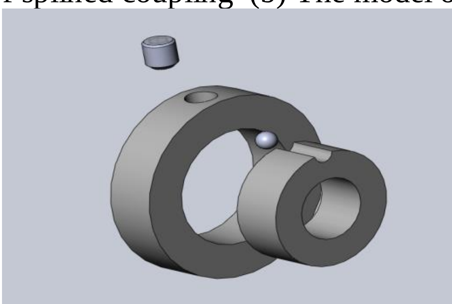
The torque mechanism is designed to make sure the jar can transmit torque in inoperation situation.The most serious test for the torque transmitting mechanism is at the moment when the drill assembly encounters obstacle and gets stuck.In that moment,the outside of hydraulic cylinder and the part below it is stuck and unable to rotate,but the mandrel is still capable of rotation because of the torque transmitted above.At this point,the torque mechanism of the jar is under the largest load,so the boundary condition is set based on this extreme situation.

5.1 Model Simplification

The model is simplified based on the reference value.The specific way is to remove the tiny structure like chamfer,stress relief groove etc.The effect of tiny structures reducing the maximum stress is not very considerable, though they do improve the stress concentration state; on the other hand,the cross section of the torque transmitting mechanism is the same,and the torque loaded on each cross section is also the same, so the model can be established by cutting out a certain length on the torque mechanism.After simplification, the result is valuable and calculation is remarkably reduced. The simplified model is shown in the following Fig.6.The next step is importing the model into finite software for analysis and calculation.



(a) The model of splined coupling (b) The model of pin connection



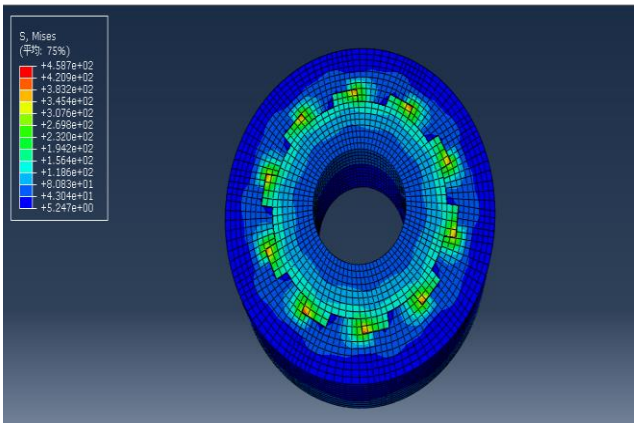
(c)The model of set screw coupled with ball

Fig.6. The simplified models of the three structures

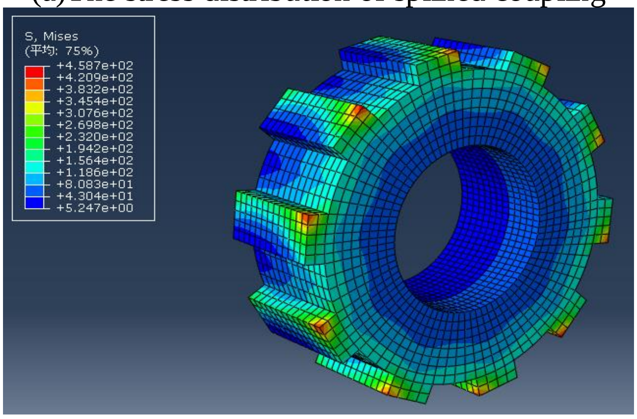
5.2 Simulation Results

Spline Coupling

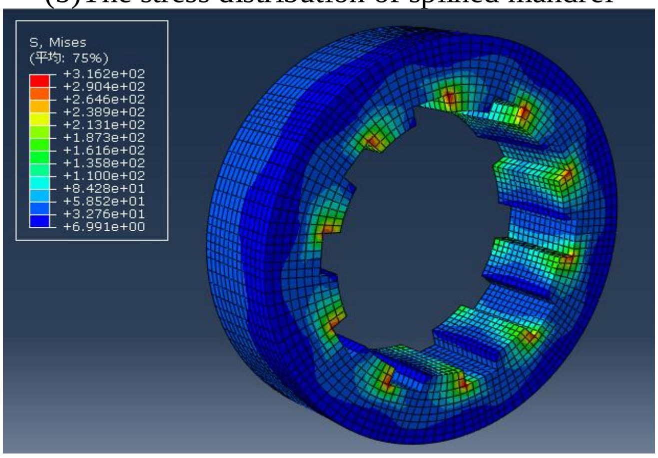
The simulation results are shown in Fig.7 below, the value of maximum stress is 458MPa,which locates at the corner which is near upper end surface of the splined mandrel's teeth. At the same time, the maximum stress value of the inner spline is 316MPa,which is only 1/3 of the yield stress. In order to improve the computational efficiency and reduce unnecessary computation, some structures like chamfer and stress relief groove that are designed to improving the stress distribution are removed. So it can be concluded that the stress concentration state can be improved greatly in the practical application.



(a)The stress distribution of splined coupling



(b)The stress distribution of splined mandrel



(c)The stress distribution of inner spline

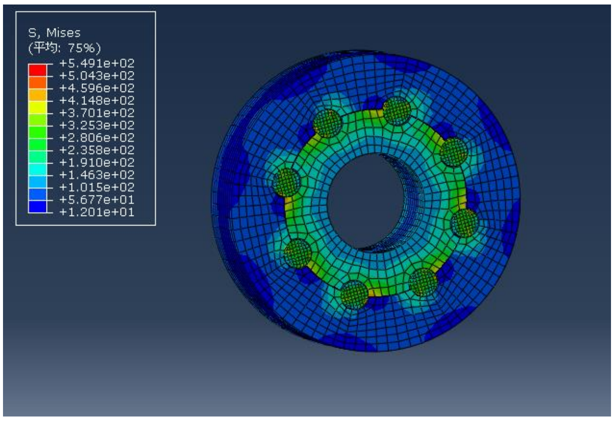
Fig.7 The finite element analysis results of spline coupling

Set Screw Coupled with Ball

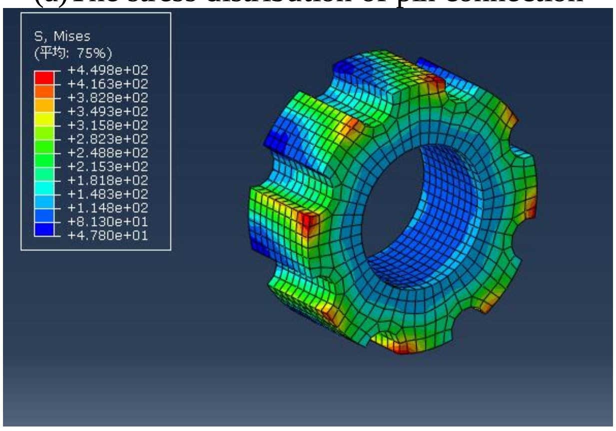
It shows errors during the analysis process, the structure is in serious damage. The specific performance is that the ball has irreversible deformation and is completely destroyed. The mandrel drives the deformed ball to rotate in the hydraulic cylinder and destroy the inner wall. The maximum value has reached the yield stress 960MPa, and the distribution of maximum stress point is extremely irregular. The reasons cause the high value at the contact point may be the large load and the small contacting area.

Pin Connection

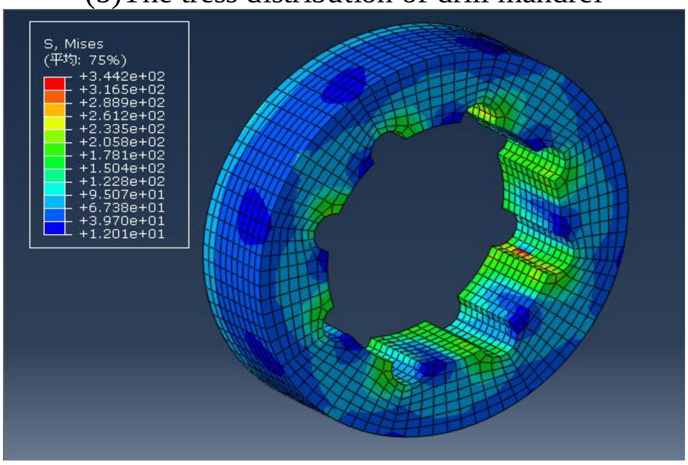
The results are shown in Fig.8 below, the maximum value of pin connection model is 549MPa,which is slightly larger than the splined coupling structure. The maximum stress point appears at the pin and the high stress area is small, which means the stress distribution is dispersive. The maximum stress value of mandrel is 449MPa, which appears in the vicinity of the upper end surface of the teeth's corner. The maximum stress value of hydraulic cylinder is 344MPa, which appears at the point in the middle of the groove.



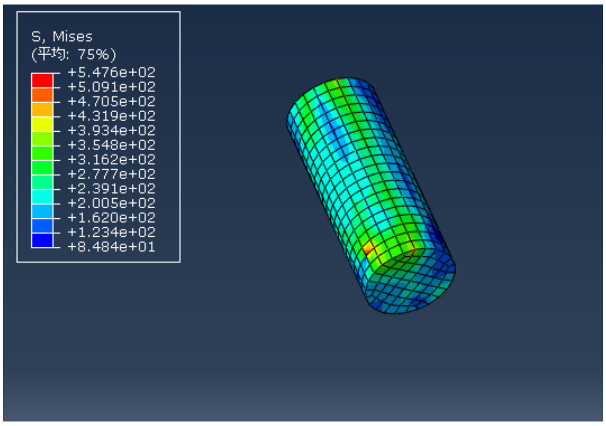
(a)The stress distribution of pin connection



(b)The tress distribution of drill mandrel



(c)The tress distribution of hydraulic cylinder



(d)The tress distribution of pin

Fig.8 The finite element analysis results of pin connection

6. Conclusion

Comparing three finite element analysis results, it can be concluded that spline coupling structure has the smallest maximum stress value, if chamfer and stress relief groove are added, the stress distribution state can be improved more; the advantage of pin connection is that the stress on the inner surface of hydraulic cylinder is well-distributed, and the value is also low; the structure of set screw coupled with ball is completely destroyed under the practical working load.

The following summaries are made Based on the finite element analysis results and the practical situation of the three kinds of torque transmission mechanisms.

Spline coupling structure is of high reliability, it can transmit torque stably and bear high load. Chamfer and stress relief groove are also able to improve the stress concentration state and prolong the service life of the tool.

The advantage of pin connection is that the stress on the inner surface of hydraulic cylinder is well-distributed, and the value is also low,the reliability of hydraulic cylinder is promised; secondly, the processing difficulty is much lower than that of spline coupling structure, it is a low-cost and reliable structure.

The advantage of set screw coupled with ball is the looseness between ball and groove is adjustable. When jar is working for a long time, the cooperation between the hydraulic cylinder and the mandrel will become less close, adjusting the set screw then to reduce the vibration between the two, thereby to prolong the service time of the tool; the disadvantage is the small effective contact area, so it cannot work under large load.

References

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