Mechanical Chuck Design and Slip Strength Analysis

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Abstract. Chuck is one of the key parts of coal mine tunnel drill, its performance directly affects the performance of the machine. In view of the existing problems of the hydraulic chuck, the structure of the new hydraulic chuck is designed and its working principle is briefly described. The strength of slips is analyzed by finite element method. The calculation results show that the initial design of slips meets the requirements of tunnel drilling rigs.

1 Introduction

The hydraulic chuck is the key component of the drill in coal mine tunnel. The drilling rig's lifting, drilling and twisting and unloading of drill pipe must be completed by the powerful clamping of the drill pipe by the hydraulic chuck. In the process of drilling, chuck should bear not only circumferential torsion force along the outer wall of drill pipe, but also extrusion pressure along the axial direction of drill pipe, and the opening and clamping action is frequent, so the parts need to have certain strength and wear resistance. The working environment of coal mine is bad, mud water and coal powder carried by the outer wall of drill pipe may enter into the chuck, increasing the damage probability of chuck. Therefore, chucks must have high reliability to meet the requirements of mine tunnel drilling.

There are two kinds of hydraulic chucks used by domestic pit drilling rig: regular closed hydraulic chucks and normally open hydraulic chucks[1]. The working principle of the normally closed hydraulic chuck is the disc spring clamping and hydraulic loosening. The working principle of the normally open hydraulic chuck is the loosening of the hydraulic clamping spring, which is usually called the capsule hydraulic chuck. Normally closed hydraulic chucks adopt inclined plane force transmission structure, three slips are arranged inside, and the T shaped inclined groove of the slip seat drives the slips to do radial movement to clamp or loosen the drill pipe. The structure of three slips can not be effectively clamped for non-circular sections such as three-edge drill pipe. There are three T-shaped beveled grooves in uniform distribution design of slip base, which is difficult to manufacture[2].The capsule type hydraulic chuck has the advantages of large clamping force, rapid response and small inertia, which is widely used in coal mine tunnel drill. But the capsule type hydraulic chuck has strict requirements on the size of the internal parts, and the size clearance is not ideal, which easily leads to the phenomenon of "being

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gnawed"[3]. In the installation process, it is also easy to cause the edge of the backing plate to cut the rubber cylinder. The service life of the rubber cylinder affects the service performance of the capsule hydraulic chuck to a certain extent. In view of the above situation, a new type of mechanical chuck is designed by selecting the advantages of two types of hydraulic chuck.

2 Scheme design

In this scheme, a new type of hydraulic chuck is designed, and the drill pipe is clamped by the slips. The principle is to change the axial displacement of the slip sleeve into the radial displacement of the slip through the interaction between the inclined plane set on the slip sleeve and the inclined plane set on the slip sleeve, and clamp the drill pipe. In order to enhance the reliability and versatility of the new type of hydraulic chuck, four slips are arranged on the chuck seat to install four slips. The return of the slip sleeve is accomplished by a set of return springs arranged inside the chuck. The return of the slips is achieved by threading a leaf spring fixed at one end in the wedge-shaped groove of the slips.

The new type hydraulic chuck is composed of center tube, slip sleeve, slip, sheet spring, front and rear end cover, chuck body and other parts. This is shown in Figure 1. The center tube is arranged in the center of the chuck, which can transfer torque and push force to the slips, guide the slips and fix the spring. It is the core part of the hydraulic chuck. One end of the sheet spring is fixed on the center pipe through a screw, and the other end is inserted in the sliver hole of the slip. The rear end cover is connected with the chuck body by a double-headed stud and a nut. The front end cover is connected with the chuck body by screws. The front end cover is connected with the chuck body by screws. The limit ring is installed in the annular space between the slip sleeve and the front end cover to prevent the sheet spring from being damaged due to excessive travel of the slip sleeve when there is no drill pipe in the chuck.

The working process of the new hydraulic chuck is as follows: The chuck body, slip sleeve and Yx seal ring constitute the oil cylinder cavity. When the high pressure oil enters the cylinder chamber and pushes the slip sleeve to move while pressing the return spring, the slip moves along the chuck body radially and clamps the drill pipe. The sheet spring produces elastic deformation. When the high pressure oil is relieved, the return elasticity of the return spring causes the slip sleeve to move in reverse, and the return elasticity of the sheet spring causes the slip to move away from the center of the chuck, loosening the drill pipe.

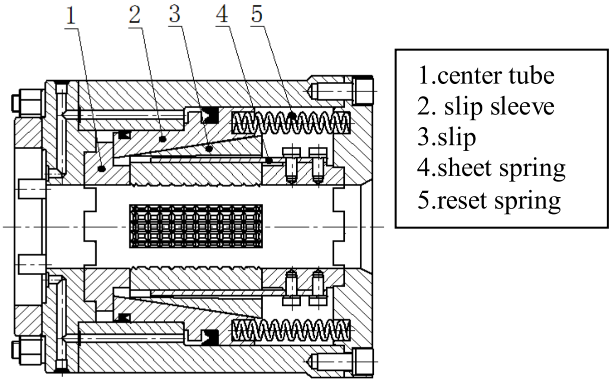

Fig. 1. Chuck structure

3 Determination of main parameters

The new type of hydraulic chuck needs to meet the design requirements of maximum torque of 4300NM and maximum pulling force of 120KN. The diameter of the supporting drill pipe is 73mm.

3.1 Maximum working load of chuck

The clamping capacity of chuck should be determined according to the maximum value of normal drilling condition and strong pulling condition.

(1) Clamping force of chuck under strong pulling condition:

$$P_q = kP_{s\max}$$

Where, k is the safety factor, k =1.6. $P_{s\max}$ is the maximum pulling force, $P_{s\max}$ =120kN.It is calculated that the clamping force of chuck is 192kN under strong pulling condition.

(2) Clamping force required for chuck under normal drilling conditions:

$$P_z = k \bullet \sqrt{P_y^2 + P_x^2}$$

Where, P_x is the maximum feed force acting on the drill pipe, P_x =90 kN. P_y is the maximum circumferential force acting on the drill pipe; $P_y = 2M_n/d$. M_n is the maximum torque output of the power head, M_n =4300NM. d is the diameter of drill pipe, d =73mm.

After calculation, P_y is 118kN, and the clamping force of chuck is 237kN under normal drilling conditions.

(3) Compare the two loads and choose the larger one as the maximum working load $P_{\max} = P_z = 237kN$.

3.2 Thrust required for clamping drill pipe

According to the structural principle of the new type of mechanical chuck, it can be seen that the high-pressure hydraulic oil pushes the slip sleeve to move in the axial direction, and the slip sleeve and the slip act on each other to push the slip toward the center of the chuck and clamp the drill pipe. During the movement, the return force of the return spring and the sheet spring should be overcome. Figure 2 is a schematic diagram of the force exerted on the slip sleeve and the slip. In order to calculate the thrust force generated by the high pressure oil pushing the slip sleeve, the force analysis of the slip sleeve and the slip sleeve was carried out.

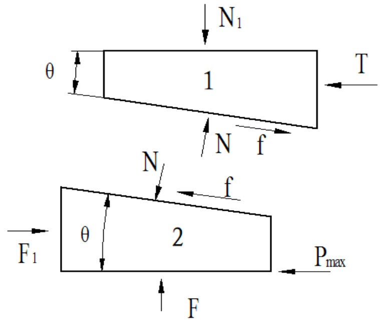

Fig. 2. Force analysis of slip and slip sleeve

(1) The equation of mechanical equilibrium in the X-coordinate direction of slips is established.

$$T = N\mu\cos\theta + N\sin\theta$$

Where, μ is the friction coefficient between slip sleeve and slip, μ =0.2. N is the force between slip sleeve and slip. f is the friction between slip sleeve and slip. θ is the slant Angle of slip, θ =9°. N_1 is the internal binding force of slip sleeve.

(2) The equation of mechanical equilibrium in the Y-coordinate direction of slips is established.

$$N\cos\theta - N\mu\sin\theta = F = P_{\max} / \mu_1$$

Where, F_1 is the force exerted by the rectangular slot of the center tube on slips. F is the force exerted by drill pipe on slips. μ_1 is the friction coefficient between slips and drill pipe, μ_1 =0.4.

It is calculated that the thrust force produced by the high-pressure oil pushing the slip sleeve is 219kN. When designing the hydraulic cylinder of slip sleeve, it is necessary to consider the reaction force of return spring and sheet spring as well as the pressure value of high pressure hydraulic oil. The hydraulic cylinder of the new type mechanical chuck is 225/180mm.

4 Slip strength analysis

The slips contact the drill pipe directly in the process of using and the design of the slips tooth shape directly affects the friction coefficient between the slips and the drill pipe. The tooth shape design is too sharp, which will increase the friction between slips and drill pipe, but also easy to damage the surface of the drill pipe and cause premature wear and failure of slips. The tooth shape of the chuck slip used is usually designed as a rectangular tooth shape formed after processing V-groove on the slip body, and the length-width ratio of the rectangular tooth is in the range of 3:1 ~6:1 [4,5].

4.1 Establish finite element model and divide mesh

The interaction between slips and slip sleeves is the main process of slips clamping drill pipe. The chuck is axisymmetric structure. In strength analysis, only the models of slip and slip sleeve are established. The Solid95 unit is used in the simulation calculation. The unit is a three-dimensional 20-node solid unit. While ensuring accuracy, the Solid95 unit can allow irregular shape degradation and has the ability of plasticity, large deformation and large strain.The slip material is 20CrMnTi. The material of the slip sleeve is 45 steel. Parameters of materials involved in calculation are shown in Table 1.

Table 1. Parameters involved in analysis.

name	elasticity modulus(MPa)	Poisson's ratio	Yield stress (MPa)	Ultimate strength (MPa)	density (kg/m^3)
slip	2.07e5	0.25	835	1080	7800
Slip sleeve	2.09e5	0.27	355	600	7890

4.2 Apply constraints and loads

According to the actual working process of slips, the following constraints are imposed. The X direction constraints are applied to the front and rear end faces of slips.A contact surface is provided between the slip and the slip sleeve and a symmetric constraint is provided.An axial load of 10 MPa is applied on the right end face of the slip sleeve.

4.3 The calculation results

According to the calculation, when the axial load is 10 MPa, plastic deformation occurs to the local teeth of slips, and the overall rigidity is stable. The results meet the design requirements. This is shown in Figure 3.

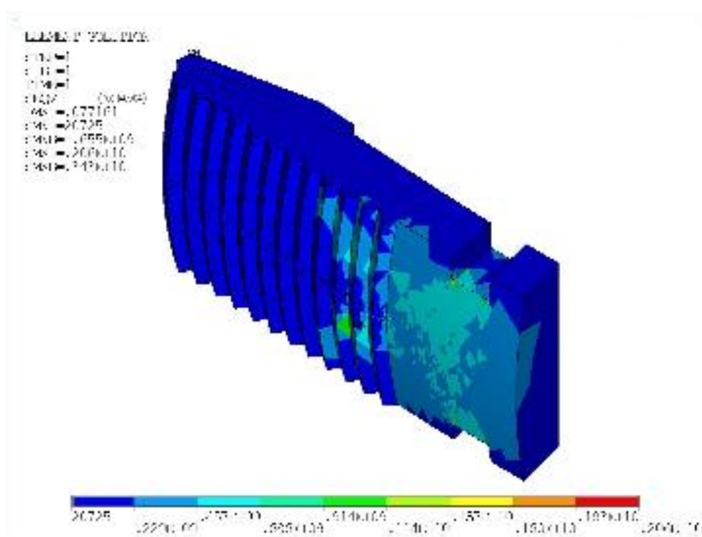

Fig. 3. The slip stress diagram

5 Conclusions

The new type hydraulic chuck has simple structure and convenient processing and installation. The center pipe smoothly transfers the torque generated by the drill power head to the chuck, and the torque transfer is uniform. The four slips with uniform distribution make the parts with uniform force after the chuck is clamped. The new chuck can hold the drill pipe of different cross-sectional shapes.Finite element simulation analysis of slips meets the design requirements. The mechanical chucks can be widely used in construction of various types of coal mine gas extraction drilling, which has a certain value of popularization and use.

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