Design and analysis of a new type and normally open hydraulic chuck

Yanfu Li[1,2,3,i]

[1] State Key Laboratory of Coal Mine Safety Technology, Fushun, Liaoning Province 113122, China;
lief_lee@outlook.com

[2] Coal Technology and Engineering Group Shenyang Research Institute, Fushun, Liaoning Province 113122, China

[3] Shenyang Coal Science Research Institute Co., Ltd., Shenyang, Liaoning Province 110016, China

Abstract: To solve the problem that large torque drilling rig requires high performance of the chuck, this paper introduces the composition and working principle of a normally open hydraulic chuck, as well as the design and calculation method of its bearing capacity and clamping force. Through the use of creo2.0/simulate finite element analysis module, finite element analysis is made on the main structure parts of the chuck. The results show that the parameter selection and structure design of the chuck mechanism meet the requirements of use, which provides a guarantee for improving the reliability of the chuck mechanism and the overall performance of the drilling rig.

Keywords: Drilling rig; normally open; hydraulic chuck; design; finite element

1. Introduction

China is a major energy consumption country with coal as the main energy, which approximately makes up 67% in primary energy consumption composition of the whole country. Along with the coal mining depth and intensity increase, it is necessary to take the effective measures to reduce the gas emission quantity in the mining process, to avoid the gas exceeding the limit and accumulation, and to prevent occurrence of gas explosion and the coal and the gas prominent accidents. Adhering to the policy of "Draining gas before coal mining" reduces the gas content in the coal bed, guarantees that the gas is not out of gauge when it is stoped and achieves the goal of the safety in production[1]. At present,the drainage technology of large and long borehole which is gradually popularizing in China has raised the higher requirements for the drilling capability of hydraulic drilling rig.

2. Composition and working principle of the chuck

The hydraulic chuck is the central component of the hydraulic drilling rig, whose function is to clamp the drill rod, to transmit the rotary motion from the decelerator and the feed force from feed mechanism to the drill rod, to make the drill bit to break the coal and to move along the axial position[2]. The working condition of the chuck often is very bad, and the chuck must bear great axial load and great rotation torque and open and close frequently.

The paper introduces the hydraulic chuck of EDG-300 large-long borehole drainage drilling rig. Its composition is shown in **Figure 1.**

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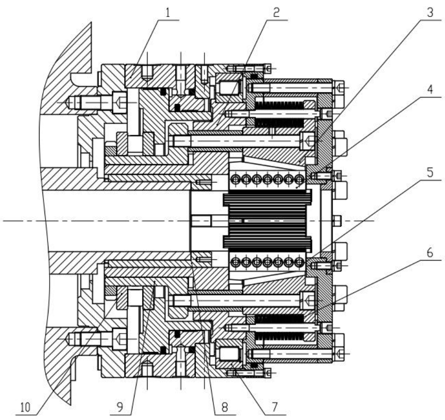


Figure 1. The composition of the hydraulic chuck of EDG-300 drilling rig. 1-Clamping; hydro-cylinder; 2-Revolved Body; 3-Ferrule; 4-Slips; 5-Reset spring; 6-Disc spring; 7-Bearing; 8-Flat key; 9-Sliding sleeve; 10-Bearing.

The hydraulic chuck of EDG-300 drilling rig is a normally open hydraulic chuck with hydraulic clamping and disc spring loosening. Its working principle is that when the drilling rig isn't working, the chuck is opening; when the high-pressure oil enters the clamping hydro-cylinder, the piston of the clamping hydro-cylinder pushes the ferrule to move left. Because the left and right sides of the slips have mechanical limit, the ferrule makes the slips move along the radial direction and hold the drill rod tightly. When the system stops entering the high-pressure oil, the slips push the ferrule to move right under the effect of reset springs and disc springs and lossen the drill rod[3].

The advantage of the chuck is as follows: 1. because of the hydraulic clamping, the clamping force is large, and the abrasion of slips and drill rod will not affect the clamping force; 2. by adjusting the clamping hydro-cylinder, the clamping force can be adjusted, which is very beneficial to the protection of drill rod; 3. compared with the rubber hydraulic chuck, it overcomes the shortcomings of high precision requirement for floating-ring and principal axis and high reliability requirement for sealing; 4. compared with the rubber hydraulic chuck, the hydraulic clamping has long service life[4].

3. Design and calculation of main parameters of chuck mechanism

3.1 Determination of bearing capacity of hydraulic chuck

The bearing capacity of hydraulic chuck is generally determined by the maximum load (P_{max}) of normal drilling and strong pull-out conditions. Under the normal drilling condition, the chuck bears the feed force and circumferential force caused by torque, and its load is a combined force. Under the condition of strong pull-out, the load of chuck is only determined by the maximum pull-out force of the drilling rig[5].

1) Under normal drilling conditions, the load of the chuck is:

$$P_g = \alpha \cdot \sqrt{P_y^2 + P_z^2} \quad (1)$$

(1) In Formula 1:

P_g: the load of chuck under normal drilling condition, kN;

P_y: the circumferential force acting on drill rod, kN;

$P_y = 2M/d$ (M: maximum output torque of power head;d: the diameter of the drill rod), kN;

P_z: the axial force acting on drill rod, kN;

α: the safety coefficient, about $\alpha = 1.2 \sim 1.6$.

2) Under the condition of strong pull-out, the load of the chuck is:

$$P_b = \alpha \cdot P \quad (2)$$

In Formula 2:

P: the maximum pull force of feed hydro-cylinder (calculating according to the maximum working pressure of the system), kN;

α: the safety coefficient, about $\alpha = 1.2 \sim 1.6$.

To sum up, comparing P_g and P_b,

$$P_{\max} = \max\{P_g, P_b\} \tag{3}$$

3.2 Clamping force of slips on drill rod

Generally speaking, it refers to the necessary clamping force when the hydraulic chuck is bearing the maximum load (P_{max}).

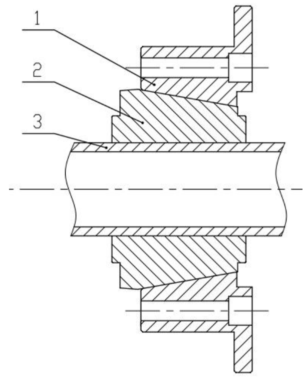
$$F = P_{\max} / \mu \tag{4}$$

In Formula 4:

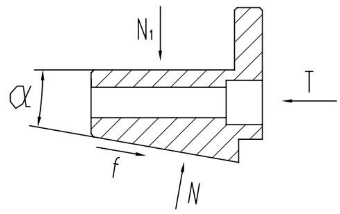
μ: the friction coefficient between slips and drill rod, $\mu = 0.4 \sim 0.6$.

3.3 Parameter design of the chuck

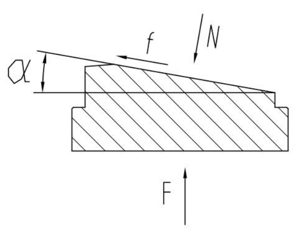
The structural parameters of hydraulic chuck are mainly determined by the diameter of drill rod and the maximum working load of the chuck.



(a) Clamping part structure of the chuck



(b) Force analysis diagram of ferrule



(c) Force analysis diagram of slips

Figure 2. Stress analysis of hydraulic chuck. 1-Ferrule; 2-Slips; 3-Drill rod.

In **Figure 2**(b),

$$T = f\cos\alpha + N\sin\alpha = N\mu_1\cos\alpha + \sin\alpha \tag{5}$$

In Formula 5:

μ_1: the friction coefficient between ferrule and slips.

In **Figure 2**(c),

$$N\cos\alpha + N\mu\sin\alpha = F = P_{\max} / \mu \tag{6}$$

To solve the equation (5) and (6)

$$T = \frac{\mu\cos\alpha + \sin\alpha}{\mu_1(\cos\alpha + \mu\sin\alpha)} P_{\max} \tag{7}$$

3.4 Number and specification of sleeve bolts

In the clamping process of the chuck, the cylinder rod drives the ferrule to move left, and the connecting bolts on the ferrule need to bear great pull, so it is necessary to check the strength of the connecting bolts.

The stretching strength conditions of dangerous section of the bolts are:

$$\sigma_{ca} = \frac{1.3 \times 4Q}{\pi \cdot d_1^2 \cdot k} \le [\sigma] \tag{8}$$

In Formula 8:

$[\sigma]$: allowable strength of bolt material, $[\sigma] = \sigma_s/S$;

σ_s: yielding limit of bolt material, MPa;

S: safety coefficient, about $S = 1.2 \sim 1.5$;

Q: total tensile force on bolts, N;

d_1: diameter of dangerous section of bolt, mm;

k: number of bolts[6].

4. Finite element analysis of hydraulic chuck

4.1 Model simplification

In the finite element analysis of hydraulic chuck, it is necessary to simplify the components and parts. In this paper, Creo 2.0/simulate finite element analysis module is used to analyze the chuck[7]. The simplified chuck consists of drill rod, slips and ferrule. There is no contact between slips. It sets face contact between slips and drill rod and between slips and ferrule. The simplified model is shown in **Figure 3.**

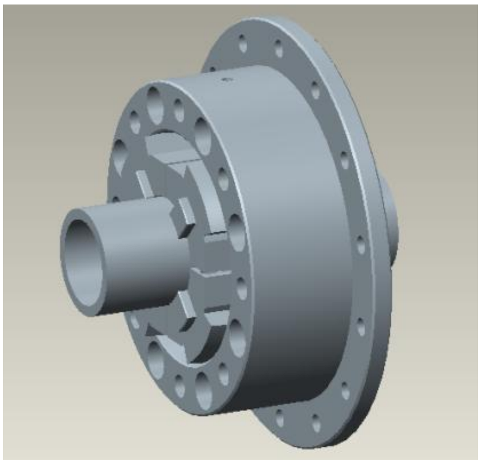


Figure 3. Simplified model of chuck

4.2 Distribution of materials, application of restraint and load

According to the actual situation, the material of slips is 20CrMnTi, which is a carburizing steel with good property and whose material property is as follows:

Elastic modulus: $E = 2.12 \times 10^{11}$Pa;

Poisson's ratio: $\mu = 0.289$.

The material property of drill rod and ferrule is as follows:

Elastic modulus: $E = 2.09 \times 10^{11} Pa$;

Poisson's ratio: $\mu = 0.269$[8].

After simplifying the model, it applies thrust of 300 kN to the ferrule. The model which has restraint is shown in **Figure 4.**

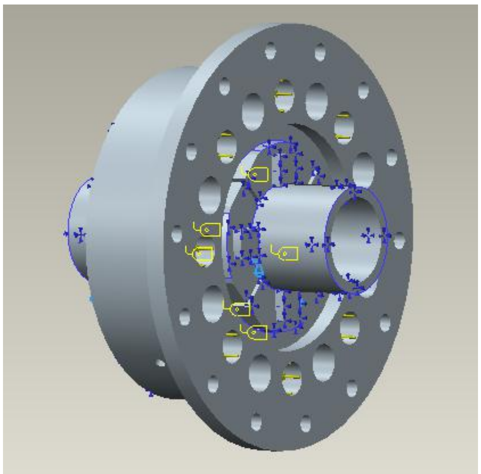


Figure 4. Chuck for restraint and load

4.3 Results and analysis

By creating a chuck model, defining constraint, applying loads and analyzing, the stress distribution of chuck under the maximum working pressure of clamping cylinder is obtained. It is shown in **Figure 5.**

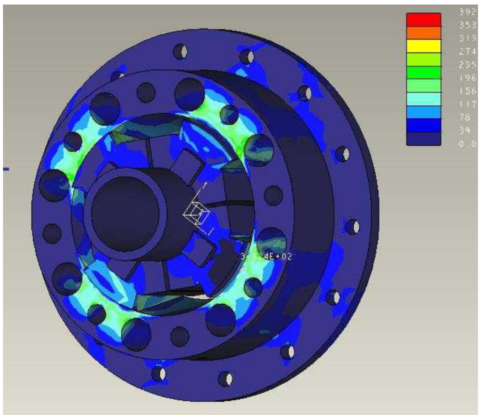


Figure 5. Result chart of chuck stress analysis

It can be seen from **Figure 5** that the maximum stress of the chuck is 392 MPa. It is at the front contact place of the ferrule and the slips, the safety coefficient is 2.13. The result can meet the usage requirement.

The maximum strain of chuck under the maximum working pressure of clamping cylinder is shown in **Figure 6.**

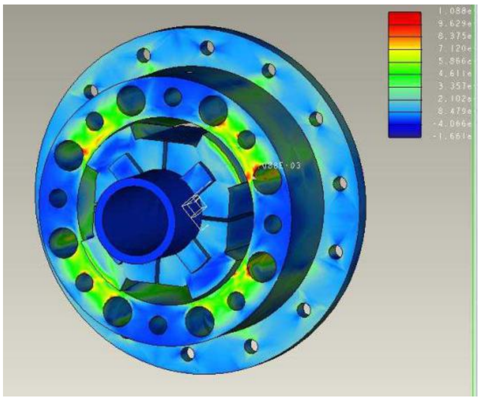


Figure 6. Result of chuck strain analysis

It can be seen from **Figure 6**, the maximum strain of chuck is about 0.00109 mm. The strain is very small, and the result can meet the usage requirement[9,10].

5. Conclusion

EDG-300 drilling rig is a newly developed mining drilling rig. The torque transmitted by the chuck of the power head is 18000 Nm. Through the analysis and research of the chuck, combined with the characteristics of the powerful drilling rig which has large torque, the design of the chuck of the drill adopts the normally open structure and improves the clamping force through hydraulic clamping. Through the simulation of the actual working condition of the chuck by Creo 2.0/simulate finite element analysis module, the rationality of chuck structure parameter design is verified. It provides reference for the structure design and optimization of the chuck. At the same time, it also provides a guarantee for the overall design of the drilling rig.

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10. Xu S. Finite element method in mechanical design. Beijing: Higher Education Press; 1992: 122-138.

[i] Yanfu Li (1978-), male, is an engineering doctor graduated from Shenyang Institute of Automation, Chinese Academy of Sciences in 2009. He is mainly engaged in the research and development of drilling technology and equipment for coal mines.