

# Structural Strength and Fatigue Strength Analysis of Roller Arm

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**Abstract:** The cone reamer is used for underhole reaming, mainly through the impact crushing and cutting of teeth to complete rock breaking, easy to produce vibration. At the same time, the underground topography is complex and rock materials are changing. Therefore, the force of the cone reamer is complex and easy to damage. According to the statistics of the field use, the main failure form is the failure of the roller arm. The reaming arm consists of two parts: a cone arm and a bearing. As for the reaming arm, it is subjected to the reaction force of rock on teeth and the support force of piston when working. When the teeth eat into the rock alternately, longitudinal vibration will be generated, so that the force of the cone arm is random impact load. Due to the instability of bit weight, additional dynamic load is caused, resulting in the piston support force is also random impact load. Thus causing the fracture of the cone arm. For bearings, reamers are used to drill stepped holes and rely on the outer teeth of the cone as opposed to the cone bit. When the teeth eat into the rock alternately, the longitudinal vibration is generated, and the rock is broken through the impact and cutting of the teeth. And the axial acceleration of the cone reamer is greater than the longitudinal acceleration, so the axial vibration is severe and the bearing bears the impact load. At the same time, the wall morphology and rock material are changing, so the bearing is subjected to random contact fatigue load. The piston cracks under the repeated action of random load, leading to fatigue failure. It can be seen from the structure characteristics and working principle of the cone reamer that the cone arm is the core functional component of the cone reamer. Therefore, abnormal failure of the above components should be avoided as far as possible. Therefore, this paper completed the simulation analysis of the cone arm, obtained the stress and strain distribution of the cone arm, and established the finite element analysis specification and safety evaluation index of the cone arm.

**Keywords:** Cone reamer, Structural strength analysis, Fatigue strength analysis.

## 1. Introduction

The structure of the cone reamer is shown in the figure, which is mainly composed of three parts: upper joint, lower joint and body sub, and the three parts are connected by threads[1]. Body sub consists of body, expansion mechanism and cutting mechanism. Expansion mechanism includes: piston, spring, pin shaft. The piston and spring are arranged in the body, and the piston can move along the axial direction of the body. The pin sleeve is arranged in the rectangular slot of the body to limit its axial and radial movement. The cutting mechanism includes: reaming arm, cone and tooth. The roller arm is connected to the body through a pin shaft, and the body is provided with a rectangular slot for installing and accommodating the roller arm. The cone is mounted on the reaming arm journal, and the teeth are mounted on the cone. The teeth are cutting parts that are directly in contact with the rock [1].

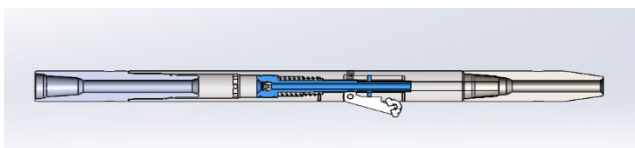


Figure 1. Schematic diagram of structure characteristics of cone reamer

The cone reamer is used for underhole reaming, mainly through the impact crushing and cutting of teeth to complete rock breaking, easy to produce vibration. At the same time,

the underground topography is complex and rock materials are changing. Therefore, the force of the cone reamer is complex and easy to damage. According to the statistics of field use, the main failure mode is reaming arm failure. The reaming arm consists of two parts: a cone arm and a bearing. As for the reaming arm, it is subjected to the reaction force of rock on teeth and the support force of piston when working. When the teeth eat into the rock alternately, longitudinal vibration will be generated, so that the force of the cone arm is random impact load. Due to the instability of bit weight, additional dynamic load is caused, resulting in the piston support force is also random impact load. Thus causing the fracture of the cone arm. For bearings, reamers are used to drill stepped holes and rely on the outer teeth of the cone as opposed to the cone bit. When the teeth eat into the rock alternately, the longitudinal vibration is generated, and the rock is broken through the impact and cutting of the teeth. And the axial acceleration of the cone reamer is greater than the longitudinal acceleration, so the axial vibration is severe and the bearing bears the impact load. At the same time, the wall morphology and rock material are changing, so the bearing is subjected to random contact fatigue load. The piston cracks under the repeated action of random load, leading to fatigue failure.



Figure 2. Failure diagram of the cone arm

## 2. Structural Strength Simulation Analysis of Roller Arm

When the reamer is working, the upper end face of the piston is in contact with the drilling fluid. The sealing structure is used to isolate the drilling fluid on the upper and lower end faces of the piston, so as to ensure the pressure difference between the upper and lower end faces, so as to realize the axial downward movement of the piston. The sealing between the piston and the body will have a direct effect on the expansion quality of the reamer and affect the subsequent reamer quality. At the same time, the sealing ring may be squeezed into the gap between the body and the piston during the dynamic sealing process, resulting in. Therefore, this section carries on the simulation analysis to the sealing structure, discusses the sealing performance and carries on the structure optimization.

### 2.1. Establish finite element model

The expansion structure is composed of piston, cone arm, pin shaft and cone, and the three reaming arms are evenly distributed at 120 degrees. No. 2 roller has the most force, about 41% of the total load. Therefore, No. 2 roller arm is used to complete the mechanical analysis. The assembly model of piston, pin shaft and reaming arm was established with Solidworks in a ratio of 1:1. The model was saved in Step format and then imported into ABAQUS software. The assembly model is shown in the figure.

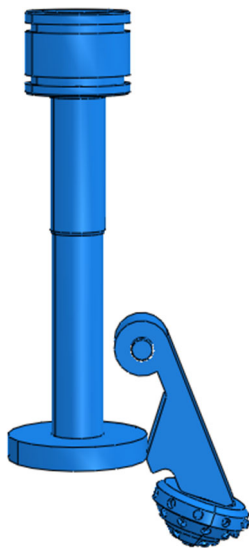


Figure 3. Schematic diagram of finite element model of cone arm

### 2.2. Material setting and meshing

The global size of the pin meshing is 1. The structure of reaming arm, cone and piston is complex, so it is difficult to divide by hexahedral mesh, so tetrahedral element is used. In this analysis, the C3D10M element is used. This element has accurate calculation results and improves some of the behavior of conventional second order tetrahedral elements. It exhibits minimal shear and volume locking in contact, so it can be calculated accurately and get better results. The geometry of the pin shaft is a regular cylinder, so the element type is hexahedral element C3D8R, and structured mesh partitioning technology is adopted to complete the division. The whole assembly is divided into 652817 grids.

### 2.3. Boundary conditions and loading modes

In the cone reamer, there are contact pairs between the pin shaft and the reamer arm, the piston and the reamer arm, the bearing large journal cylinder and the cone, and the bearing small journal cylinder and the cone. In the process of reaming, when the piston pushes the reaming arm outward, there is contact between them, so the tangential contact property is defined as penalty, and the friction coefficient is 0.5. The normal direction is hard contact, allowing separation after contact. During the outer tensioning process of the reaming arm around the pin shaft, there is contact between the reaming arm and the pin shaft, so the contact attribute is defined as penalty and the friction coefficient is 0.1. The cylindrical surface of the bearing large journal and the cone, and the cylindrical surface of the bearing small journal and the cone are in contact with each other. The contact is set as: penalty function is adopted for tangential behavior, and the friction coefficient is 0.1; The normal behavior is set to pressure interference contact, allowing post-contact separation.

During the operation of the reamer, the upper face of the piston is thrust, so the thrust load is applied to the upper face of the piston, and the direction is axial downward. Two RP points were created at the axis of the cone arm, and the two sides of the cone arm were coupled respectively. The load of 54.4KN was applied respectively, and the torque of 4760N·m was applied to the two sides of the rectangular groove.

In the reaming process, the piston only moves along the axial direction of the body, so its movement and rotation in the X and Y directions are limited. The position of the pin is fixed relative to the body, and the axial displacement of the pin is limited by the screw, so the axial displacement of the pin is limited. When the cone teeth cut the rock at the bottom of the hole, the force direction and size of different cutters have complicated nonlinear changes with the rock breaking. However, in extreme conditions, the second row of tooth rings and the third row of tooth rings are the main cutting rings. In extreme conditions, one or two teeth of each main tooth ring are in contact with rocks. In addition, the stress status of teeth in this paper is not the main research content, so only the stress status of one or two teeth of each tooth ring under extreme conditions is considered. Therefore, assuming that only one tooth of each ring eats the rock, the bearing stress can be accurately reflected. After reasonable assembly of the cone, tooth claw and tooth, the two lowest teeth were selected as fixed constraints to simulate the tooth eating into the rock. There is no relative movement between the tooth and the cone, so binding constraints are set between the tooth and the cone.

### 2.4. Finite element analysis

Mises stress was used as the evaluation index for the roller

arm. The following figure shows the results of the finite element analysis for each component of the reamer assembly model.

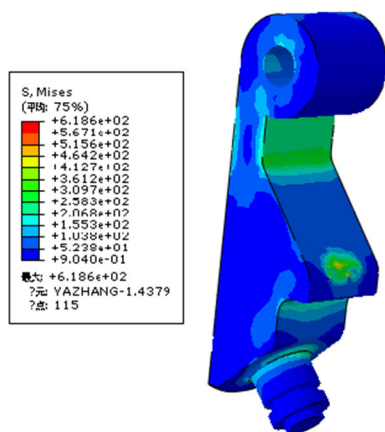


Figure 4. Schematic diagram of the analysis results of the cone arm

It can be seen from the figure that the stress was mainly distributed at the contact point between the cone arm and the piston, the lower arm of the cone arm and the bearing. The maximum Mises stress of the cone arm was 618.6MPa, which was less than the yield limit of the material and in line with the use requirements.

### 3. Fatigue Strength Simulation Analysis of Roller Arm

#### 3.1. Fatigue analysis method

By applying constant amplitude variable stress with a certain stress ratio to the standard specimen of the material and recording the number of cycles required for fatigue failure under different maximum stresses, the anti-fatigue performance of the standard specimen can be obtained. The test results are shown as S-N curves, and the curves are shown in the figure below:

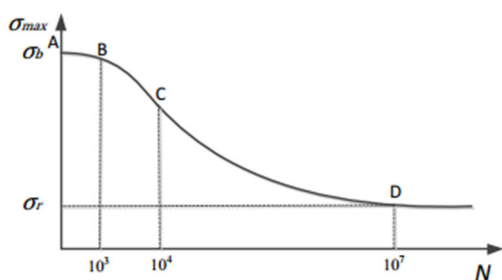


Figure 5. S-N curve diagram of material

When the number of cycles is less than, the maximum stress value resulting in failure of the specimen is basically unchanged. Therefore, the variable pressure strength at this stage is regarded as the static stress strength. When the number of cycles is  $\sim$ , the fatigue failure of the material is dominated by strain fatigue. Because the number of cycles is low, the maximum stress is high, so it is also called low cycle fatigue. At this stage, the maximum stress value of fatigue failure decreases continuously, but it is still greater than the yield stress. When the number of cycles is  $\sim$ , the fatigue failure of the material is dominated by the elastic strain.

Because the number of cycles is high and the maximum stress is low, it is also called high cycle fatigue. At this stage, the maximum stress of the material is less than the yield stress. For high cycle fatigue, S-N method is suitable for simulation. When the material is subjected to stress above the fatigue limit, each cycle will cause cumulative damage, when the damage accumulates to a critical value. Fatigue failure occurs. As for the roller arm, it belongs to high cycle fatigue, so S-N method is adopted to simulate.

#### 3.2. Determination of S-N curves of materials

The fatigue life curve of cone arm represents the relationship between fatigue strength and fatigue life of standard fatigue specimen of cone arm material under certain cyclic characteristics. The fatigue life of the material of the cone arm can be obtained by the rotary bending test of the standard fatigue specimen, and then the fatigue life curve can be obtained by taking the fatigue life pair value as the horizontal coordinate and the fatigue strength of the material as the vertical coordinate. In this paper, the S-N curve of the roller arm material is obtained by approximate processing according to the material parameters and the characteristics of S-N curve. The material of the cone arm is 20CrNiMo, and the S-N curve is approximately represented by four points. Through the above method, the four points coordinates on the approximate S-N curve of the cone arm material are obtained and the S-N curve is made as shown in the figure below.

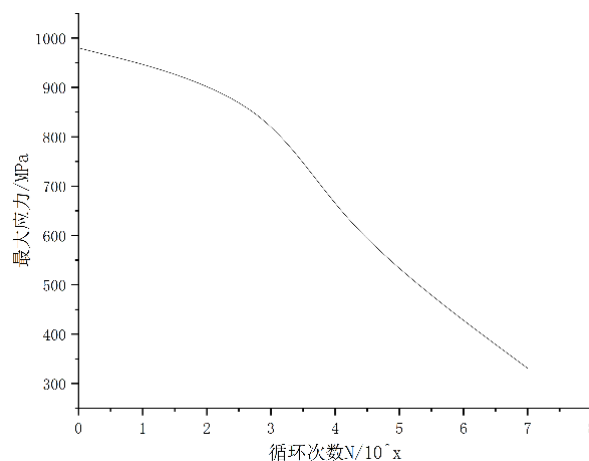


Figure 6. S-N curve of roller arm material

#### 3.3. Select stress correction methods

The fatigue life of the roller arm is predicted by the nominal stress method based on S-N curve. The S-N curve of the material is the life of the material under symmetric cyclic variable stress. For the load spectrum of the roller arm, the average stress is not equal to 0, so the actual pulsating cyclic stress needs to be converted into symmetrical cyclic variable stress. Therefore, the effect of average stress needs to be considered. At the same time, the rotating bending test shows that the load period and the stress ratio of the average load stress affect the propagation velocity of the crack. Considering the above two points, the average stress is corrected. There are two methods of average stress correction, Goodman and Gerber. Among them, Goodman theory is applicable to high-cycle fatigue, so in this analysis, Goodman theory is adopted to correct the average stress.

#### 3.4. Finite element analysis

The fatigue life of the cone arm refers to the number or time

of cyclic load exerted by the cone arm from the beginning of working to the occurrence of fatigue failure. In fatigue analysis, LOGLife refers to the logarithm of the number of cycles of components from the start of work to fatigue failure, so LOGLife is taken as the evaluation index.

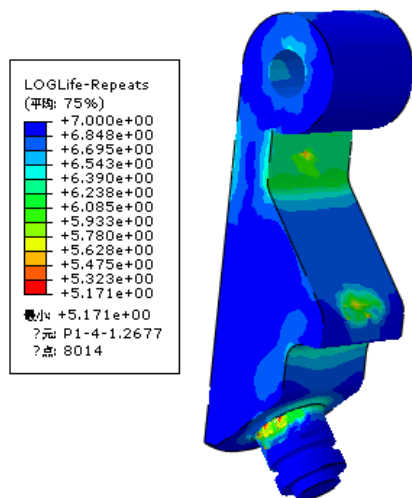


Figure 7. Fatigue life diagram of the roller arm

#### 4. Summary

The static strength of the cone arm was analyzed by the finite element method. The results showed that the stress was mainly distributed at the contact point between the cone arm and the piston, the lower diameter of the forearm of the cone arm and the bearing. The maximum Mises stress of the cone arm was 618.6 MPa, which was less than the yield limit of the

material and in line with the use requirements.

The roller arm is subjected to alternating load. Based on the static strength analysis results, Fe-Safe software is used to simulate the fatigue strength of the roller arm. Using LOGLife value as the evaluation index, the results show that the smaller LOGLife value is concentrated at the contact point between the roller arm and the piston, the lower diameter of the roller arm and the bearing. The minimum value 5.171 is located at the bearing large journal.

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