Analysis on the mechanical properties of crawler doubles - arm degree-dividing bar car bolt drill

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Abstract. In view of the low efficiency of roadway support in coal mine, a crawler double arm bolts drill with indexing function is proposed, in view of the low efficiency of roadway support in coal mines, a crawler double-arm bolt drill with indexing function is proposed. The mechanical characteristics of its key components in the telescopic action of the spindle arm are calculated and analyzed, and the binding force of the spindle arm and the variation rule of the telescopic acceleration and rotation Angle parameters are obtained. And the torque of the spindle arm decreases slightly with the decrease of the rotation Angle of the spindle arm, and increases greatly with the increase of the length of the spindle arm. The results show that the maximum torque is 6914Mpa when the length of the spindle arm is 2.4m and the rotation Angle is 45°, which lays a foundation for the subsequent design of the drill car and the improvement of the efficiency of anchor guard operation.

1. Introduction
In the mining process of coal mine roadway, tunneling and support complement each other. However, the low efficiency of coal mine roadway support seriously restricts the improvement of coal mining capacity [1]. Kang Hongpu et al. [2] put forward the development and prospect of bolt support technology in coal mine roadway in China, indicating that the support mode of coal mine roadway provides reliable technical guarantee for safe and efficient construction and production of coal mine; Li Xu [3] et al. carried out dynamic simulation on the working mechanism of the cantilever roadheader, and studied the force law of the key winch points of the mechanism; Wen Guochen [4] et al. studied and optimized the dynamic characteristics of the luffing mechanism of the bolt drill, and obtained the force change of the hydraulic cylinder in the luffing of the bolt drill, which laid the foundation for the analysis of the mechanical characteristics of the bolt drill. The above research provides ideas about the design and development of bolt drilling rigs. On this basis, a supporting auxiliary equipment with high degree of automation is proposed, which is a crawler dual-arm indexing bolt drilling rig. It has the characteristics of high-precision indexing anchor protection and high-efficiency double-joint anchor protection, which is used to improve the support efficiency.
2. Integral mechanism of bolt drill carrigae

The high precision anchors positioning greatly saves the anchor protection time, and the drilling truck indexing system can realize the precise control of anchor drilling truck support. The indexing system of this drilling rig is composed of an indexing plate and a gear racked oscillating hydraulic cylinder, in which the gear rack oscillating hydraulic cylinder is shown in Figure 2[5]. The gear rack swing cylinder converts the reciprocating motion of the hydraulic cylinder through the gear to the rotation and swing of the rack, and can realize the positive and negative two-way rotation. Since the motion length of the rack with input thrust is proportional to the swing angle of the gear with output torque, accurate and stable control of swing rotation can be achieved[6].

3. Study on mechanical properties of anchor drill rig arm expansion

The spindle arm is an important pillar part of the anchor drill truck, which bears a variety of complex internal forces. The qualified degree of its mechanical properties is directly related to the safe operation of the anchor drill truck[7]. Therefore, it is necessary to study the mechanical properties of the spindle arm.

The overall stress of the drill truck is shown in Figure 3, where \( G_1, G_2, G_3 \) is the gravity of each part of the right rig part, \( G_4 \) is the gravity of the right telescopic boom, \( G'_1, G'_2, G'_3 \) is the gravity of each part of the left rig part, \( G'_4 \) is the gravity of the left telescopic boom, \( G_5 \) is the gravity of the main shaft arm, \( B \) is the rotation center of the main shaft arm, and \( \gamma \) is the rotation angle of the main shaft arm. The value stipulates that the right turn is a positive value, and the left turn is a negative value. As a displacement compensation and attitude adjustment component, the spindle arm contains two actions of luffing and stretching. Now, the stress of the spindle arm is accurately analyzed and studied by combining the luffing action.
The telescopic main shaft arm is the extension or contraction action of the main shaft arm along the axis when the anchor rod rig needs to raise or lower the working height. The mechanical characteristics of the main shaft arm during extension are analyzed here. The contraction mechanical characteristics are the same, so I won’t repeat them. If the length of the spindle arm is $l_5$, the axial thrust of the spindle arm is $F_5$, and the top acceleration of the spindle arm is $a$, it can be written as:

$$a = \frac{F_5 - G}{G_1 + G_2 + G_3 + G_4 + G_5 + G_6 + G_7 + G_8 + G_9}$$ (1)

Since the spindle arm and the telescopic arm are fixedly connected and have the same acceleration, the acceleration of the spindle arm and the contraction arm in two directions can be:

$$\begin{cases} a_{x_5} = a_{x_4} = a_{x_6} = a \sin \gamma \\ a_{y_5} = a_{y_4} = a \cos \gamma \end{cases}$$ (2)

Figure 4 shows the force of the main shaft arm of the anchor rod drilling rig. According to the D’Alembert principle, the main force, the restraining force and the inertial force acting on the mass point system form a balanced force system in form. The spindle arm and telescopic arm are separated, and the mechanical analysis is carried out respectively, and the equilibrium equations of each rigid body are listed.

The force balance equation of the spindle arm is as follows:

$$\begin{cases} X_B - F_5 \sin \gamma = 0 \\ Y_B + F_5 \cos \gamma - (G_1 + G_2 + G_3 + G_4) - (G_1' + G_2' + G_3' + G_4') - G_5 = 0 \end{cases}$$ (3)

Where $X_B$ is the transverse component of the restraining force of the main shaft arm; $Y_B$ is the axial component of the restraining force of the main shaft arm; $G_1', G_2', G_3', G_4'$ is the gravity of the left and right telescopic arms and $G_5$ is the gravity of the main shaft arm.

Force balance equation of right telescopic arm:

$$\begin{cases} X_{45} - \frac{G_1 + G_2 + G_3 + G_4}{g} a_{x_5} = 0 \\ G_1 + G_2 + G_3 + G_4 - Y_{45} - \frac{G_1 + G_2 + G_3 + G_4}{g} a_{y_5} = 0 \end{cases}$$ (4)
Where $X_{45}$ is the transverse component of the force of the main shaft arm on the right telescopic arm; $Y_{45}$ is the axial component of the force of the main shaft arm on the right telescopic arm.

![Figure 4](image)

**Figure 4** The force diagram of each component when the main shaft arm is telescopic

The thrust $F_5$ of the main shaft arm passes through the center of rotation $B$, so the main shaft arm is subjected to torque when it is telescopic:

$$
T = (G_1 + G_2 + G_3)l_4 \cos \gamma + (G_1 + G_2 + G_3)l_5 \sin \gamma + \frac{1}{2} G_4 l_4 \cos \gamma + G_5 l_5 \sin \gamma - (G_1 + G_2 + G_3)l_4 \cos \gamma + (G_1 + G_2 + G_3)l_5 \sin \gamma - \frac{1}{2} G_4 l_4 \cos \gamma + G_5 l_5 \sin \gamma + \frac{1}{2} G_4 l_4 \sin \gamma + G_5 l_5 \sin \gamma
$$

(5)

Because the main shaft arm length $l_5$ is variable, the torque $T$ received when the main shaft arm is telescope is affected by the rotation angle $\gamma$ and the main shaft arm length $l_5$ together. The parameters such as gravity and length of each component are shown in Table 1. The combination of (1) and (3) can obtain the constraint force $X$, $Y$, rotation angle $\gamma$ and the top acceleration $a$ of the main shaft arm when the main shaft arm of the anchor drill rig is extended and retracted, as shown in Figure 5. From equation (5) combined with the data parameters in Table 1, the relationship between the torque $T$ of the spindle arm, the rotation angle $R$ of the spindle arm and the length $L$ of the spindle arm can be obtained as shown in Figure 6.

| Right telescopic boom | 300 | 1.2 |
| Telescopic arm left | 300 | 1.2 |
| Spindle arm | 550 | [1.6, 2.4] | [-45, 45] | [-3, 3] |

**Table 1. Spindle boom telescopic boom parameters**
The change of constraint force $X_B$, $Y_B$ of the main shaft arm with rotation angle $\gamma$ and expansion acceleration $a$ is shown in Figure 5. In the elongation stage, when the acceleration is positive, the $X_B$ constraint force on the spindle arm increases with the increase of rotation angle, while $Y_B$ decreases synchronously. In the contraction stage, the result is opposite. When the rotation angle of the main shaft arm is fixed, the $X$-direction restraint force increases with the acceleration when it is extended, and the $Y$-direction restraint force decreases simultaneously, and the result is the opposite in the contraction phase. After determining the rotation angle of the spindle arm, it is necessary to take into account the constraint load limit to improve the expansion acceleration, ensure safety and improve efficiency.

Figure 6 shows that the torque value of the spindle arm increases with the length of the spindle arm when the rotation angle is fixed, and when the length of the spindle arm is fixed, the torque of the spindle arm also increases with the increase of the rotation angle. The length of the spindle arm has a greater effect on the torque of the rack and pinion than the rotation Angle. The increase of spindle arm length and rotation angle will increase the torque of the spindle arm, that is, when the spindle arm is the longest and the rotation angle is the largest, the torque of the spindle arm reaches the maximum.
4. Conclusion

Through the research and analysis of the bolting rig, the following conclusions are drawn:

1) Crawler-type double-arm indexing anchor rod drilling rig is suitable for anchoring operations at different heights and different working conditions. The overall structure is compact, easy to disassemble, and can be used for anchoring operations at different angles.

2) The restraint force of the main shaft arm is affected by the rotation angle and the expansion acceleration. When the main shaft arm rotation angle is fixed, the X-direction restraint force increases with the increase of acceleration when the main shaft arm is extended, and the Y-direction restraint force decreases simultaneously, and the result is opposite in the contraction phase.

3) The length of the spindle arm has a greater influence on the torque of the gear rack than the rotation angle when the spindle arm of the anchor drill truck is telescopic. The increase in the length of the main shaft arm and the larger the rotation angle will increase the torque received by the main shaft arm, that is, when the main shaft arm is the longest and the maximum rotation angle, the torque of the main shaft arm rack and pinion cylinder achieves the maximum value. The main shaft arm length is 2.4 m, the maximum torque obtained when the rotation angle is 45° is 6914 Mpa.

Acknowledgement:
Project (GXXT-2020-061) supported by the University Synergy Innovation Program of Anhui Province; Project (GXXT-2019-048) supported by the University Synergy Innovation Program of Anhui Province; Project (gxbjZD11) supported by the Top-Notch Talent Program of University (Profession) in Anhui Province.

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