Design and Simulation of Wire Rope Recycling Device in Coal Mine

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Abstract. Aiming at the problem of low efficiency of artificial recycling rope in friction hoist, and the rope recycling device used in underground was proposed and designed. Then the working process of the device was analyzed. With the dynamics analysis software, the dynamic characteristics of the recycling device under the maximum load bearing 6.5t conditions was simulated. Finally, the impact force on the device, the contact force between the wire rope and the rope wheel and the force of the wire rope and the rope arranging device were obtained. The simulation results show that the continuous recycling device can run under the rated load, the impact force can reach to 7244N at the start of jog running, and the recycling process is relatively stable, which can meet the requirement of rope arranging. It is possible to recycle the entire replacement wire rope layer by layer without cutting the wire rope, which also can achieve the function of replacing artificially wire rope.

Introduction

Some problems will occur in the hoisting wire rope after multi-rope friction hoist used for a period of time, such as wire broken, worn or used longer than the specified requirements of the “Safety Regulations for Coal Mines”, so the wire rope of hoist must be replaced in time, recycling old wire ropes while replacing wire ropes, especially underground recycling\cite{1}. Nowadays, the construction process is simple, and it totally relies on man power dragging and pulling to recycle the rope, which will cause some problems, such as, heavy workload, the high staff cost and the low efficiency\cite{2}. The processes and equipment have been improved at some domestic mines. For example, the rope was retracted and released by using rope wheel shelves at the Hemei No. 6 Mine of Henan Coal Chemical Industry\cite{3}, the steel pipes was used to pass through the center hole of the rope wheel that is placed on the rope wheel shelves horizontally. Wang Dazhi\cite{4} and others used the tension winch to improve the flat-type winding rope vehicle, which solved the problem of time-consuming and laborious situation of manual winding wire ropes. However, in the process of rewinding, the vehicle still needs a certain number of people to assist the construction. Therefore, the improvement and design of a continuous recycling device that can be used underground is of great economic value for the recycling of hoisting wire rope in mine hoisting systems.

Overall Design of Continuous Recycling Device

The Structure and Function of Continuous Recycling Device

The continuous recycling device can replace manpower to drive the rope wheel to recycle the wire ropes. The speed of the recycling ropes underground should match the speed at which the pithead is fed into the wire rope. Therefore, the characteristics, such as running and stopping at anytime, strong controllability and flexibility to drive rope wheel, should be included in continuous recycling device. In order to ensure that the wire rope wind around the rope wheel orderly, a rope arranging mechanism has been designed to synchronize arranging wire rope. Combined with the current construction technology of underground wire rope recycling\cite{5,6}, a continuous wire rope recycling device has been proposed. The overall structure is shown in Figure1.
The function module of the continuous recycling device is divided into: driving module, supporting and clamping module, and arranging rope module. The driving module: the chain transmission is used to transmit the power of the winch to the driving shaft, let the driving lever drive the rope wheel to rotate, the supporting and clamping module: the parallel four-bar linkage mechanism is used to control the advance and retreat of the support shaft to finish the supporting and clamping of the rope wheel, the arranging rope module: The chain transmission is used to transfer the rotating movement of the rope wheel to the rope arranging mechanism, which ensure that the wheel is rotated one circle, and the distance of arranging rope can reach the diameter of one rope, thereby recycling the rope orderly.

Analysis of Working Process of Continuous Recycling Device

JD-1 winch, commonly used in mine, is chosen as driving winch, which has good control feature, and can adjust the speed of output, so that the load can move to a predetermined position and stop safely. The winch drives the drive shaft to rotate, and the driving lever that is installed on the driving shaft drives the rope wheel to rotate. At the same time, the driving shaft transmits the rotary motion of the rope wheel to the bi-directional screw of the rope arranging mechanism through the chain transmission, and drives the rope arranging mechanism to perform the rope arranging. By matching the screw's lead and the transmission ratio of the chain transmission of the rope arranging mechanism, the rope wheel is rotated one circle, and the rope arranging mechanism just moves a distance of the diameter of the wire rope. When the rope arranging mechanism reaches the left and right limit position and the screw rotates in the same direction after it contacted the position limiter, the moving direction of the rope arranging mechanism can be changed.

In this way, the jog running of the driving winch is coordinating with the entry speed of the wire rope of the pithead, the whole wire rope can be recycled orderly without cutting the wire rope step by step with the continuous recycling device.

The Building of Major Parameter and the Model of Continuous Recycling Device

The Major Parameter of Continuous Recycling Device

The maximum load of the recycling device is 6.5t, and the maximum diameter of recycling wire rope is 46.5mm. The main driving chain is double-row chain, The number of teeth of driving sprocket and driven sprocket is 32 and 45 respectively. The single-row chain is adopted in the rope arranging transmission chain, the transmission ratio is 1:1, and the pitch of the bi-directional screw is 46.5 mm.

Nowadays, the feeding rope speed that is commonly used in mine rope recycling is 4 m/min. When the feeding speed reaches 8 m/min, which is considered as rope slide. Therefore, the maximum recycling speed of the recycling device is 9 m/min, and the recycling device executes jog running, thus avoiding interference to the equipment of rope replacing at the pithead.

Simulation Model of Continuous Recycling Device

The dynamic simulation model of the continuous recycling device was established in the dynamic simulation platform.
software Recurdyn, as shown in Figure 2. The wire rope was modeled by many micro-segments to achieve flexibility and easy to achieve winding[7-9].

In the end of the wire rope, a tensile force along the axis of the wire rope was applied to replace the friction of the bottom plate of the road way to the wire rope. The axial tensile force was controlled by step function. According to the underground construction conditions, the tensile force was indicated by step (time, 0, 0, 0.5, -1000), -1000 indicated that the end of the wire rope subjected to a tensile force of 1000N.

The radius of the wheel which was covered with the rope fully is 0.9 m, so the rotating speed of rope wheel was about 0.17 rad/s at specified load. The rotating speed of the driving sprocket was calculated to be about 0.24 rad/s. The step function was used to add the driver, combined with the characteristics of jog start, the startup acceleration time was set to 0.5s, and the drive function was step (time, 0, 0, 0.5, -0.24). The negative sign indicated the direction of rotation and controlled rope wheel rotating to wind wire rope in the correct direction.

The simulation time was set to 50 s and the simulation steps was set to 600.

Results and Analysis of Recycling Process

The Interaction Force between the Shelves and the Rope Wheel

The rope wheel was driven by the driving lever to rotate the rewinding wire rope. The driving lever only bears the tangential force of the rotation of rope wheel. The weight of the rope wheel and the wire rope are borne by the driving shaft and the support shaft.

Figure 3 shows the force of the rope wheel and the driving lever. It can be seen that at the moment when the rope wheel starts to rotate, the force that lever pushes the rope wheel will change drastically, at 0.34s, the force reaches the maximum of 7244 N. As the rope reaches the predetermined speed, the force of the rope and the lever gradually stabilizes at around 3000N. Because the wire rope bears the friction of the bottom plate, the value is 1000N, and the radius of the wheel which is covered with the rope fully is 900 mm, and the eccentric distance of the lever is 300 mm, the driving force of the lever shaft in the steady state can be calculated to be 3000N. It shows that the simulated steady-state force can be consistent with the theoretically calculated force.

Figure 2. Dynamic model of continuous recycling device.

Figure 3. The force between the rope wheel and the lever shaft.

Figure 4. The force of rope wheel.
The Figure 4 shows the forces between the rope wheel and the driving shaft, and the force between the rope wheel and the support shaft. Because the lever and the rope wheel have a certain degree of impact with each other at the time of starting, the force of the driving shaft is shaken at the beginning. The overall trend is periodic fluctuations, the maximum value is 34895 N, the minimum value is 28887 N, and the extreme values are obtained at 9.35s, 28.04s and 46.38s, respectively, the difference between the maximum and minimum is 6000 N. This is because the driving force of the lever to the rope wheel at steady state is 3000 N, and as the lever rotates, the direction of the force of the shaft changes in the circumferential direction. The combined force of the gravity of the rope wheel and the force of the driving lever is the force of the driving shaft and the rope wheel, so that the force of the rope wheel and the driving shaft will periodically fluctuate with the rotation of the rope wheel between the maximum and the minimum values. The support shaft only bears the weight of the wire rope and the wheel, which is about 31885 N, which is equal to half the weight of 6.5t of the wheel which is covered with the rope fully.

Analysis of Displacement and Velocity of Rope Wheel and Rope Arranging Device

Figure 5 shows the rotational angular velocity and angular displacement of the driving sprocket and the driving shaft. The driving sprocket is stable at 0.24 rad/s under the control of the step function. From the angular displacement of the driving shaft, it can be seen that the angular displacement within 50s is -486° (the negative sign indicates the direction of rotation), and the angular displacement slope that is the angular velocity is 0.17 rad/s. Because the unstability of the chain transmission, the angular velocity of the driving shaft is dynamically changing. From Figure 5, it can be seen that the angular velocity fluctuates around 0.17 rad/s.

The rotating speed of rope wheel is 0.17 rad/s, and it takes 36.96 seconds to rotate one circle. At this time, the rope arranging device can move 46.56 mm, which meets that when the rope wheel rotates one circle, the arranging rope device moving a rope diameter.

Analysis of Tensile Force and Contact Force of Wire Rope

The simulation results of the 6th, 30th, and 54th segments are taken from the numerous wire rope micro-segments for analysis. Figure 7 shows the tensile force changes of the three segments of the wire rope with time varying. The tensile force of the three rope segments at the beginning is equal to friction between the bottom plate and the wire rope, the value is 1000 N. When the wire rope of the 6th section starts to contact with the wheel at 3.5s, the tensile force fluctuates and becomes about 950 N at 5s, and then fluctuates upward to 1060 N. After 10 seconds, the tensile force of the 6th segment of the wire rope changes periodically with the amplitude of 50N near 1000 N. The 30th segment of the rope begins to contact the wheel at 17.75s, and the 54th segment of the rope begins to contact the rope wheel at 32s. The 6th segment is wound on the wheel before the other two segments, and after 40 seconds, the three segments are all wound on the wheel, so the change trend of the respective tensile force is almost the same.
Figure 7. Tensile force curve of rope segments.

Figure 8 shows the contact force between three rope segments and the rope wheel. The contact force is 0 when the rope segments are not wound on the wheel. The 6th segment begins to contact with the rope wheel at 3.5s. The wire rope and the wheel have extrusion contact in a relatively short time, and the contact force changes dramatically, reaching 374N instantaneously. After 10 seconds, the contact force between the 6th segment and the rope wheel is stable around 220N, the contact force varies periodically, and the magnitude of contact force is 10N. The 54th segment begins to contact the wheel at 2s, and the maximum contact force is 400N. After 40 seconds, the three wire rope segments are all wound on the rope wheel, so the contact force between them and the rope wheel shows the same value and fluctuates slightly near 220N.

Figure 8. Contact force between rope segments rope and rope wheel.

Figure 9. Contact force curve between rope segments and arranging device.

Figure 9 shows the contact force between the other four segments of the wire rope and the rope arranging device. The contact force is 0 before and after the wire rope segments pass through the rope arranging device. The 18th segment begins to pass through the rope arranging device at 4s, and the contact force with the rope arranging device increases directly to 54N, and has completely passed through the rope arranging device at 4.7s. The 30th segment passes through the rope arranging device at 10.8s, and the maximum contact force with the rope arranging device is 51N. At 11.7s, the wire rope has passed through the rope arranging device completely. The maximum contact force of the 42th and the 54th segment of wire rope that pass through the rope arranging device at 17.8s and 24.4s respectively is 35N and 43N. It shows that the rope arranging device is relatively stable in the whole process of rope arranging, and the impact of wire rope on the rope arranging device is negligible.

Figure 9. Contact force curve between rope segments and arranging device.

**Conclusion**

A device for continuous recycling of hoisting wire rope in underground mine has been designed, which improves the recycling efficiency. During the start-up of the recycling device, the impact
force of the driving lever shaft can reach 7244N, and the driving lever should be properly strengthened.

The rope arranging mechanism of the continuous recycling device have met the requirements of working conditions. The variation of the tensile force of the rope segment and the contact force with the rope wheel shows that the recycling process of the wire rope is relatively stable.

The resistance of the rope arranging for rope arranging mechanism is less than 50N, which indicates that the continuous recycling device can recycle the rope smoothly under its working conditions.

Through the simulation analysis of the dynamic performance of the continuous recycling device, it provides important reference data for the next prototype test and saves the development time of the prototype.

References


