Research on Cutting Performance Optimization of Diamond Wire Saw

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Abstract— Due to the wire sawing machine cutting technology has the advantages of more efficient, safer, higher yield and less pollution than the traditional quarrying method, it has been widely used in the mining of mine stone. In order to better analyze and study this technology, combined with the research progress of domestic and foreign scholars, the wire sawing machine cutting technology has been comprehensively analyzed and summarized. Firstly, the current advanced modular design of the wire sawing machine is introduced. Secondly, the structural innovation of multi-rope wire sawing machine is introduced. The influences of cutting speed and feed rate on the wear of diamond bead rope and the cutting efficiency of wire sawing machine are analyzed. And on the basis of this, the motor is under PID control to find the optimal speed value, and finally explain its future development.

1. Introduction

As one of the earliest natural materials developed by human beings, stone has been used in many industries such as construction, transportation and decoration because of its strong performance. As people's demand for stone continues to increase, stone mining technology has also developed rapidly. Common methods include flame band cutting, jumping drill, blasting and diamond bead wire sawing. Compared with other cutting technologies, the diamond bead wire sawing method has the advantages of strong adaptability, high efficiency, high yield, low cost, safety and environmental protection, and has been widely used in the mining and processing industries of mining blocks. Now it is used in the processing of special-shaped stone materials and sheet metal processing equipment, especially in recent years, focusing on multi-rope combined diamonds for sheet metal processing. Wire saws and research on CNC diamond wire saws for profiled stone processing.

The diamond wire sawing machine is composed of a main motion mechanism, a feeding motion mechanism, a driving wheel position adjustment mechanism and a control system. The main motion mechanism is responsible for driving the movement and guiding of the diamond bead; the feeding motion mechanism is responsible for the reciprocating walking of the wire sawing machine in the direction of block mining and the tension control of the diamond bead rope; the position adjustment mechanism of the driving wheel realizes 360° arbitrary angle by adjusting the position of the driving wheel. Cutting; the control mechanism is responsible for controlling and detecting the tension of the diamond bead rope and the cutting and feeding speed. This paper mainly introduces the research progress of wire saw machine in recent years. The structural design, cutting efficiency, wear efficiency and other aspects of
the rope saw machine are deeply elaborated and analyzed, and on this basis, the PID control of cutting and feeding speed is studied. I hope to provide a useful reference for the research of wire saw cutting technology in China.

2. Innovative design of wire sawing machine

2.1 The modular design of the wire saw machine
In order to achieve more efficient, safe, environmentally friendly, and high-margin stone recycling technology, the modularization of wire saw mechanism has become a new development trend. Yan, based on the analysis and research on the use of diamond wire saws, mining technology and wire rope saws in other fields, Through the circular mapping of requirements--functions--principles--structures, analyze the demand and function of the super-high power mine wire sawing machine, and determine the mechanical structure of the wire sawing machine for the ultra-high power mine blockage. F S Liang et al through the analysis of the structural function of the bead saw, according to the modular design idea, the power mechanism, the corner mechanism, the traveling mechanism and the control system of the bead saw are divided into a driving function module, a guiding function module, a walking function module and Control function module. Modular design technology makes it easy to design, manufacture, use and maintain. By improving the structure and motion parameters of the diamond bead saw, it improves its matching with the characteristics of the rock, the mining conditions and the flexibility of work mobility, and significantly improves the application level and adaptability of the diamond bead saw mining stone.

2.2 Multi-rope wire sawing machine innovation
In order to further improve the working performance, production efficiency and adaptability of the wire saw machine, a multi-rope wire saw machine has attracted the attention of many scholars. X M Xu et al introduced the structure of multi-rope wire saw machine, including: drive device, tensioning device, feeding device, support structure, guiding structure, control system, water cooling circulation device and so on. Z L Teng et al designed and developed the core part of the multi-rope diamond wire sawing machine, and explained the multi-rope operation mode. F K Wang proposed a simple and convenient two-wheel multi-rope wire sawing machine to make the main motion of the bead rope and maintain tension. In order to facilitate the manufacture and save cost, the diameter of the driving wheel should be minimized, and the height of the multi-wire saw processing block should be ensured. The upper and lower distances of the beaded rope cannot be reduced, and the innovation is based on the two-wheeled multi-rope wire sawing machine. The structural model of the six-wheeled multi-rope wire saw is designed as shown in Figure 1.

![Figure 1. Schematic diagram of a six-wheel multi-rope wire saw](image-url)
The effect of speed on the cutting of wire saws

Due to the increasing demand for stone materials in today's society, in order to extract more stone materials, the working efficiency of the wire sawing machine is getting higher and higher, but after the wire sawing machine is applied for a period of time, the diamond bead ropes appear asymmetric wear. The problem of large wear on the bead front end, which seriously affects the life of the diamond bead rope, so the control of cutting speed and feed speed has become the key to improve work efficiency and reduce wear, which has also attracted everyone's attention.

3.1 Effect on cutting efficiency

G Q Huang et al\textsuperscript{12,13} carried out a test study on the influence of cutting parameters of cutting granite on cutting force and cutting energy consumption, and considered that the feed rate is related to cutting force and cutting power with respect to cutting speed and cutting length. The impact is more obvious. Based on the sawing test, Y R Zhang et al\textsuperscript{14} studied the relationship between cutting speed, feed rate of diamond bead saw and cutting efficiency, and obtained the cutting line speed and feed rate on cutting efficiency. The law of influence is shown in Figure 2.

![Figure 2: Effect of cutting process of wire sawing machine on cutting efficiency](image)

3.2 Effect on wear resistance

Diamond wear on the wire saw bead includes wear wear, broken wear and shedding. The various wear patterns are closely related to the load and temperature of the diamond particles, which in turn depend on the cutting elements such as cutting, feed rate, cutting pressure and cooling lubrication conditions. Fratini L et al\textsuperscript{15} found that the internal force of the working machine external force and the beaded rope is the main cause of bead wear by analyzing the wear of the beaded rope, and the wear characteristics of the diamond bead rope are divided into: new diamond single crystal Four stages of broken diamond single crystal, abrasive diamond single crystal and detached diamond single crystal.

L W Cao et al\textsuperscript{16} divided the wear of diamond bead rope into macro wear and micro wear. The reduction in bead diameter can be regarded as macroscopic wear, and the wear of both the diamond single crystal and the carcass can be regarded as microscopic wear. In the study of micro-wear, R C Jiang et al\textsuperscript{17} found that if the carcass wear is slower than the diamond wear, the space between the diamond cutting rope and the carcass will be reduced, causing the cuttings to be removed in time, thus causing the diamond bead to lose the cutting ability.

J S Zhang et al\textsuperscript{18} analyzed the relationship between wear resistance, sawing force, cutting speed and feed rate of diamond bead saw beaded rope to explore the wear mechanism of diamond bead saw. B M Li et al\textsuperscript{19} believe that diamond bead has self-sharpness during the grinding process, because when the micro-blade of the abrasive grain becomes dull, the force acting on the abrasive grain increases, and the abrasive is partially crushed to form a new one. The micro-blade or the whole grain peels off to reveal a new abrasive grain micro-blade.
J S Zhang et al. established the relationship between sawing speed, feed rate and beaded rope wear of diamond bead wire sawing by experiment, as shown in Figure 3. For a certain length of block material, the relationship between feed rate and sawing speed is derived, and the beaded rope wear is minimized, and the sawing rate is the highest, as shown in Figure 4.

![Figure 3. Relationship between wear resistance and feed rate](image1)

![Figure 4. Relationship between wear resistance and sawing speed](image2)

4. Speed control system
As the control center of the wire saw machine, the control system provides automation for the cutting of the wire saw machine; it also serves as the key to whether the mechanical structure can work normally. The control system mainly has switching logic control, monitoring display, automatic segment cutting, broken rope/water shortage shut down protection. However, as the demand for rock and stone is getting larger and larger, the requirements for cutting efficiency are getting higher and higher. Since cutting efficiency and speed are closely related, speed control has gradually become an important part of the control system.

4.1 Speed control principle
Firstly, the sensor is used to detect the cutting speed in real time. Secondly, the PLC and the inverter are used to PID control the spindle speed of the stepping motor. Then, the feed rate is adjusted by the feed structure to realize the automatic control of the tension. Finally, the PLC and the inverter are used to PID control the spindle current to ensure current stability.

4.2 Double closed loop control system
Since the motor double closed loop control system has excellent speed regulation performance, speed regulation precision and system stability, in order to obtain more suitable cutting and feed speed, the double closed loop speed control system can be used to adjust the speed of the wire saw machine spindle motor.

The speed and current double closed-loop DC control system is controlled by a current regulator and a speed regulator, respectively, thereby ensuring good dynamic and static performance of the double closed loop system. The current in the double closed-loop speed control system is controlled by a current
regulator, and the speed is controlled by a speed regulator\textsuperscript{21}. The ASR is a speed regulator, and the ACR is a current regulator that performs negative feedback of speed and current when the two are in the loop.

The speed control system mainly consists of the variable speed parameter, so the speed loop is positioned outward as the main loop, and the current loop is located in the internal secondary loop, which can suppress the influence of interference on the network voltage. The current regulator and speed regulator are set in the system to adjust the speed and current to determine the speed and current negative feedback, as shown in Figure 5.

\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{figure5.png}
\caption{Block diagram of motor double closed loop speed control system}
\end{figure}

L G Wan\textsuperscript{22} found that the speed controller adjusts according to the speed of the input Un1 and the error of the feedback speed Un. The signal whose output is the current command is Ui1. The current controller is adjusted to take into account changes in the current reference signal Ui1 and the current feedback Ui, the output of which is the power converter control signal being Uc. Then the output of the power converter (the voltage of the motor) is adjusted. Since the speed cannot be varied widely, the current changes when the voltage changes, and the corresponding electromagnetic torque will also change when Te-TL=Jdn/dt. As long as Te and TL are different, the speed n will change accordingly. After n is unchanged, it is stable.

5. Conclusion
With the development of science and technology, the wire saw machine has made significant progress in structural modular design and multi-rope wire sawing machine innovation, but there are still defects such as the control system is not mature enough, and the speed intelligent adjustment is insufficient. The cutting performance of the machine and the intelligent control of the wire saw machine also need to further analyze the speed, work efficiency and wear efficiency, establish a mathematical model, and automatically adjust the speed by PID control algorithm to lay the foundation for subsequent research.

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