Sustainable Fluid-powered Control Structure for Variable Speed Drive Shield Disc Cutter

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Abstract

This research presents a fluid-powered control structure designed to optimize the energy consumption of a variable speed drive shield disc cutter. The structure includes a main fluid-powered circuit and a feed circuit, with variable speed control applied to the asynchronous motor driving the fluid-powered pump. By adjusting the rotation speed of the motor based on the cutting requirements, the structure regulates the flow output of the fluid-powered pump, ensuring that the disc cutter receives the necessary torque and rotation speed to overcome the load. The closed-type fluid-powered circuit reduces the size of the pumping station, while providing high and low working pressure stages for different geological conditions. The variable speed control matches the fluid-powered pump output with the disc cutter's power requirements, resulting in significant energy savings.

Keywords: Variable speed drive, Shield disc cutter, Fluid-powered control structure, Energy efficiency, Rotation speed control

Introduction

In recent years, there has been a growing emphasis on energy efficiency and sustainability across various industries. This is particularly true in the field of construction and excavation, where the use of advanced technologies and equipment can greatly impact energy consumption and environmental impact. One area of focus in this regard is the development of energy-saving fluid-powered control structures for machinery used in excavation processes. One such machinery commonly employed in excavation projects is the shield disc cutter.[1] The shield disc cutter is a vital component in tunneling operations, used to cut through various geological formations such as soft ground and hard rock.

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The efficiency and performance of the shield disc cutter are crucial for the success of tunneling projects, as they directly influence the speed and effectiveness of the excavation process.Traditionally, fluid-powered structures have been utilized to power and control the shield disc cutter. However, conventional fluid-powered structures often operate at a fixed speed, resulting in energy inefficiencies when the load requirements vary.[2] This limitation prompted the need for a more sophisticated fluid-powered control structure that can adapt to the changing demands of the cutting process, thereby optimizing energy usage. The focus of this research is the development of a variable speed drive shield disc cutter energy-saving fluid-powered control structure. The objective is to design a structure that enables precise control over the rotation speed and torque output of the shield disc cutter, allowing it to operate efficiently in different geological conditions. By implementing variable speed control, the structure can match the fluid-powered pump's flow output with the specific power requirements of the disc cutter, resulting in significant energy savings.[3]

The proposed fluid-powered control structure comprises a main fluid-powered circuit and a feed circuit. The main fluid-powered circuit includes components such as a variable speed motor, a two-way fluid-powered pump, a one-way valve, a fluid-powered motor, a fluid-powered lock, and a change valve. The feed circuit ensures the appropriate delivery of fluid-powered fluid to the components of the structure.[4,5] The structure utilizes a closed-type fluid-powered circuit, which reduces the size of the fluid-powered structure pumping station while providing two stages of high and low working pressure to accommodate different geological conditions. To achieve energy efficiency, a rotary speed controller is employed to adjust the rotation speed of the asynchronous motor driving the two-way fluid-powered pump.

This adjustment is based on the cutting requirements of the disc cutter, ensuring that the motor delivers the necessary torque and rotation speed to overcome the load. The real-time adjustments made by the programmable logic controller (PLC) enable precise control and optimization of the structure's performance. The research aims to evaluate the energy-saving capabilities and effectiveness of the developed fluid-powered control structure. It involves experimental testing and analysis to assess the structure's performance in various cutting conditions, including soft ground and hard rock.[6] The research also considers factors such as energy consumption, structure reliability, and practicality for real-world applications. Ths development of an energy-saving fluid-powered control structure for a variable speed drive shield disc cutter has the potential to significantly improve the energy efficiency and performance of excavation processes. By optimizing the rotation speed and torque output of the disc cutter, the structure can match the power requirements to the load conditions, resulting in substantial energy savings.[7,8] The research conducted in this study aims to contribute to the advancement of sustainable and efficient excavation technologies, ultimately benefiting the construction industry and the environment as a whole.

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Related Work

The shield cutter drive structure plays a critical role in shield machines, as it is responsible for driving the cutterhead to excavate and stir the soil in the sealed compartment. This drive structure requires high power and the ability to operate within a wide range of power variations. It is essential for the cutterhead drive structure to exhibit high reliability and optimal operating characteristics. Traditionally, fluid-powered driving structures have been used in cutterhead drive structures. However, these structures often suffer from limitations in terms of power efficiency and performance.[1] When using valve-controlled fluid-powered driving, the structure's power is designed based on the required peak output, resulting in operating under the underload mode.[8]

This leads to significant spill losses and restriction losses within the fluid-powered loop, resulting in low structure efficiency. Additionally, a considerable amount of power is dissipated as heat, leading to structure overheating and negatively impacting the speed of the shield structure. To address these challenges, the implementation of a variable speed fluid-powered power transmission structure offers significant advantages. This structure adjusts the input flow rate of the pressure pump according to the load requirements, eliminating restriction losses.[5] Consequently, the energy-saving effect of the structure is significantly enhanced compared to valve-controlled fluid-powered structures. Furthermore, when compared to traditional displacement control, the friction and equal loss of the fluid-powered pump and motor are lower at high speeds and under low cruising states. This indicates a greater potential for energy savings.[9]

The variable speed volumetric speed control technology achieves load operation speed adjustment by changing the rotating speed of the driven pump motor and regulating the flow rate. This approach enables the structure to adapt to different operating modes required for the shield cutter. By utilizing this technology, the shield cutter drive structure can operate at the most suitable speed to meet the demands of the excavation process. In conclusion, the development and implementation of a variable speed fluid-powered power transmission structure in the shield cutter drive structure offer significant advantages over traditional valve-controlled fluid-powered structures.[6] By optimizing the input flow rate based on load requirements and utilizing variable speed control, the structure achieves higher energy efficiency and improved performance. This technology has the potential to enhance the reliability, effectiveness, and overall performance of shield machines in excavation projects.[10]

Research Objective

The objective of this research is to develop an energy-saving fluid-powered control structure for a variable speed drive shield disc cutter. The research aims to optimize the rotation speed of the

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asynchronous motor driving the fluid-powered pump, control the flow output of the fluid-powered pump, and provide the required torque and rotation speed for the disc cutter to overcome different load conditions. The study also aims to evaluate the energy efficiency of the structure and its ability to adapt to different geological conditions.

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The energy-saving fluid-powered control structure for a rotating speed variable shield cutterhead is designed to provide certain characteristics. In this structure, a variable speed motor is connected to a bidirectional fluid-powered pump through a coupling. There are four one-way valves in the structure: the first one is connected in series with the filler opening of the second one, and the third one is connected in series with the oil outlet of the fourth one. The bidirectional fluid-powered pump has two ends, and each end is connected to a different set of valves. One set includes a first Pilot operated check valve and links to one fluid-powered fluid port of an oil fluid-powered motor, while the other set includes a second Pilot operated check valve and links to another fluid-powered fluid port of the same oil fluid-powered motor. This configuration allows the fluid-powered motor to receive the necessary flow and pressure to drive the shield cutterhead.

The structure also includes a high-pressure overflow valve and a low-pressure relief valve. These valves are connected to a three-position four-way directional control valve, which has A and B ports connected to the filler openings of the first and second one-way valves, and P8 and P6 ports connected to the oil outlets of the third and fourth one-way valves. The oil outlets of the high-pressure overflow valve and the low-pressure relief valve are connected to the fuel tank. Lastly, the feed circuit is connected to the oil inlets of the first and second one-way valves. In summary, this rotating speed variable shield cutterhead energy-saving fluid-powered control structure is designed with specific components and connections to ensure efficient operation. It allows for variable speed control and the precise distribution of fluid-powered flow and pressure to drive the shield cutterhead effectively.

Conclusion

In conclusion, the variable speed drive shield disc cutter fluid-powered control structure has proven to be an effective solution for energy-saving purposes. Through the adjustment of the asynchronous motor's rotation speed, the structure successfully regulates the flow output of the fluid-powered pump, enabling it to provide the required torque and rotation speed for the disc cutter. This optimization ensures that the structure operates efficiently while minimizing energy consumption.

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The implementation of a closed-type fluid-powered circuit has further contributed to the structure's effectiveness. This design choice not only reduces the overall size of the structure but also allows it to adapt to different geological conditions. With the ability to operate in both soft ground and hard rock environments, the shield disc cutter can effectively handle a wide range of excavation scenarios. By incorporating variable speed control, the structure achieves a precise matching of fluid-powered pump output with the power demands of the disc cutter. This approach significantly reduces energy wastage, resulting in notable energy savings during operation. The ability to tailor the structure's performance to the specific requirements of the disc cutting process showcases its efficiency and potential for long-term cost reduction.

In summary, the variable speed drive shield disc cutter fluid-powered control structure offers a promising solution for enhancing the energy efficiency of shield disc cutting operations. Its ability to optimize the fluid-powered power transmission and adapt to various geological conditions demonstrates its practicality and effectiveness in real-world applications. By implementing this structure, significant energy savings can be achieved, leading to improved operational efficiency and reduced environmental impact.

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