Study on Shield Machine Technology

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Abstract. The shield machine is a specialized construction equipment used for excavating tunnels, particularly in underground construction projects. The shield machine plays a pivotal role in modern engineering and construction, minimizing surface disruption and environmental impact. Shield machines can adapt to different geological conditions and project requirements, and efficiently excavate tunnels in various ground conditions, reducing construction time and costs. Shield machines improve worker safety by reducing risks associated with manual tunneling, and digging tunnels with high precision, crucial for projects like subways. In essence, shield machines are essential tools in modern tunnel construction, offering efficiency, safety, and precision in building underground infrastructure for various purposes, including transportation, utilities, and more. This paper summarizes the development history of the shield machine and its basic structure, discusses its limitations and challenges, and makes a certain analysis of the application of the shield machine while discussing the innovations and methods of the hydraulic propulsion mechanism of the shield machine. This paper may offer a reference for the development of shield machine.

Keywords: Shield Machine; Hydraulic system; Tunnel Excavation.

1. Introduction

Shield machines play a crucial role in modern construction and infrastructure development, especially in the construction of tunnels and underground structures. Shield machines are primarily used for tunnel construction, which is a critical component of modern infrastructure. Shield machines enable the efficient excavation of tunnels for various purposes, including transportation, utilities, and underground storage. In densely populated urban areas, creating underground infrastructure is often the only viable option due to limited surface space. Shield machines make it possible for cities to expand their transportation networks, improve utilities, and reduce traffic congestion while minimizing disruptions to daily life. Tunneling with shield machines is safer for workers compared to traditional manual methods, as the shield machine reduces the risks associated with working in confined spaces and minimizes exposure to hazardous materials. Additionally, the shield machine minimizes surface disruption and environmental impact, such as air pollution and noise, making it more environmentally friendly. Shield machines are designed for efficiency and speed. They can excavate tunnels continuously, significantly accelerating the construction process. Shield machines can create tunnels with high precision and accuracy, which is essential for projects like subway systems, where alignment and geometry are critical. This precision minimizes the need for costly corrections and adjustments during and after construction. Shield machines come in various types and sizes, allowing them to adapt to different geological conditions and project requirements. This versatility makes them suitable for a wide range of applications, from soft soil to hard rock tunneling.

This paper summarizes the development history and advantages of the shield machine. This paper discusses the classification of shield machines and related components, pointing out the challenges and limitations of shield machines. In addition, this paper discusses the innovation of the propulsion hydraulic system of the shield machine and the future development trend.

2. Characters of Shield Machines

Since the end of the 20th century, the hydraulic shield has been developed and applied extensively. Recently, as the need for city traffic and the bottom line is growing day by day, super-sized shield machines and smart shield machines are becoming one of the most important fields of study.

Shield machines have been widely used in metro tunnel building and are largely regarded as the most promising and competitive tunnel construction technology since its inception. The shield machine construction method has the advantages of safety, environmental protection, low public hazards, and high efficiency, as well as the disadvantages of large investment and high consumption.

Shield machines are tailored to the particular terrain. The shield machine needs to be modified if it meets a surface that is substantially different from the construction parameters, for example, soft earth, hard stone, or mixture. It is difficult and time-consuming to adjust the shield machine to unforeseen geologic changes. Simultaneously, shield machines are complicated machinery with many parts, making them expensive to maintain and repair, particularly when working in the depths of the earth or underwater. During the digging process, disc cutter wear is unavoidable, and severe wear can reduce tunneling efficiency and raise construction hazards [1]. The digging creates a large amount of excavated material that has to be handled and frequently shipped to the landfill, causing an effect on the environment. Under certain circumstances, digging with shield machine may be slower than other approaches, particularly when working with solid rock or complicated geologic formations.

3. Classification of Shield Machines

The earth pressure balance (EPB) shield machine and the slurry pressure balance (SPB) shield machine are the most often utilized shield machines [2].

3.1. Earth Pressure Balance Shield Machine

The earth pressure balance shield is divided into two types according to the difference in the transformation method of the cutting earth. The first type is applicable to digging the soft clay with low sand content. The second type is more widely used and suitable for sand layers with high groundwater pressure, fine grains, and poor fluidity.

The cutting cutter of the first type fills the soil chamber between the excavation surface and the shield partition wall with the cut soil and sand during the cutting process. The shield machine is pressurized by its own propulsion force during the process of advancing so that the earth pressure acts on the excavation surface to stabilize it, and there is also a screw conveyor to discharge the earth.

For the second type, additives are added to liquefy the plasticity of the cutting soil during the cutting process of the cutting cutter plate, at the same time, the soil and sand under the cutting are mixed into clay-like filling in the clay chamber by mixing mechanism, and pressurized with propulsion to make it act on the excavation surface and let it stabilize. The additive injection device consists of an additive injection pump and injection ports set up in the cutter plate or in the soil chamber. The diameter and number of injection ports should be changed according to the actual construction conditions, and the use of additives is also different with the different geological conditions.

3.2. Slurry Shield Machine

The slurry shield machine has a forward partition that compresses mud water during cutting to stabilize the digging face and transfer the debris as liquid. This kind of shield machine has a relatively complex structure, which consists of a digging machine, blending machine, slurry draining system, pressing sludge pressure, and transporting mechanism. Slurry shield machines are mainly used in sand, silt, and clay layers.

4. Components of Shield Machine

The shield machine is composed of a steel casing, a cutting unit, a propelling structure, a drainage structure, a hydraulic unit, an electric system, an auto control system and an auxiliary device. Protected by the steel casing, the inside device and the operating personnel will not be in danger. Meanwhile, it can operate continuously on the ground. The propulsion mechanism of a shield machine is a critical component that enables it to advance through the ground while excavating tunnels.

Shield machines are equipped with hydraulic jacks or other mechanical systems that provide thrusting force. This force is applied to the rear of the machine, pushing it forward into the tunnel face. Considering all kinds of resistance and adding some allowance, the overall thrust of the shield machine is decided. Different kinds of driving resistance are the frictional force of the shield and the dirt, the adhesive force, the cutting edge in the process of pushing, the friction of the shield and the dirt, and the adhesive force.

The shield machine's hydraulic drive unit is driven by a hydraulic system, which transfers mechanical power to the front of the shield machine. The system is generally composed of a hydraulic cylinder, a hydraulic pump, a valve, and a controller. The hydraulic cylinder is the key part of a hydraulic drive unit. It is composed of a plunger and a cylinder, which is driven by a hydraulic fluid. The design and dimensions of the hydraulic cylinder are determined by the dimensions of the shield and the driving power needed. Hydraulic pumps are equipment that transform mechanical power into hydraulic power. It is in charge of extracting and pressing the hydraulic fluid from the storage tank, and then transferring it to the hydraulic cylinder to propel the machine. Valves and control systems are used for the management of the fluid. Their function is to control the fluid flow, the pressure, and the flux, so as to make sure that the hydraulic cylinder is running at the right time and force.

In the process of digging, a hydraulic drive unit exerts a force that pushes the blade tip of the shield (cutter head) forward and makes it contact with the digging surface. The telescoping motion of the hydraulic cylinders pushes the machinery so that it can drill into the ground. Hydraulic drive equipment is applicable to all kinds of shield machinery, such as metro, highway, waterway, and so on. They are able to deal with all kinds of geologic situations, from soft earth to hard stone. The hydraulic system also enables accurate control of thrust, velocity, and location. This accuracy is essential for keeping the correct size and track of the tunnel. Generally speaking, the hydraulic drive system of the shield is one of the most important engineering techniques that enable the shield to drill into the ground with stable and accurate control. The equipment is very important in the construction of modern tunneling, which offers high efficiency, precision, and safety for the construction of the city's infrastructure.

5. Innovations of Shield Machine

Due to the fact that the hydraulic system is an essential part of the shield machine, its precision will have a direct influence on the results of the analytical work and the design strategy. Yang built a simulation ground pressure equilibrium shield propulsion system with AMESim [3]. It is proved that the PID controller has excellent dynamical and static performance when the system adopts the self-adjusting PID controller. The results of the experiment indicate that the proposed system can be used to improve the driving speed and thrust pressure. The system has achieved the equilibrium of ground pressure [4, 5].

However, the method's inherent linearization prevents it from being used in complicated nonlinear systems, without using any computer code, the graphical user interface allows for the growth or modification of its simulation model. As a result, the researchers may avoid doing challenging mathematical computations. Additionally, AMESim has a MATLAB/Simulink interface, making it simpler to run a collaborative simulation. It uses MATLAB/Simulink's powerful data processing capabilities in addition to AMESim's ease for mechanics modeling. Consequently, the system's simulation findings are more accurate [6-9].

The nonlinear system may be successfully preserved using the power bond graph approach. It represents the underlying qualities and is appropriate for hydraulic systems with many inputs and outputs; when comparing the power bond graph to transfer function modeling, its final model is state space equations, which may maintain the shield hydraulic system's nonlinearity and lower simulation error.

Additionally, the state space equation establishment process is standardized by the power bond graph, which also eliminates pointless computations. The clear physical relationship importance and benefit analysis of system attributes are provided by the state variables of the state space equation. Most crucially, mechanical, hydraulic, and electrical systems make up the earth pressure balance shield machine. The power bond graph model is capable of simulating several areas. It is feasible to develop a mixed system model with a normative formation thanks to the ability [10, 11].

6. Future Trends

The future of shield machines is likely to be marked by advancements and innovations that will further enhance their capabilities and expand their applications.

Shield machines will become more autonomous and intelligent. They will be equipped with advanced sensors, data analytics, and machine learning algorithms to optimize excavation processes, detect geological changes, and make real-time adjustments for greater efficiency and safety. Miniaturized and modular shield machines will be developed to access tighter spaces and enable tunneling in urban environments with minimal surface disruption. These smaller shield machines will also be more easily transported and assembled at project sites. Hybrid shield machines that combine traditional mechanical excavation with advanced technologies like laser cutting, water jets, or electrical discharge machining will become more prevalent. These innovations will improve the efficiency and speed of tunnel excavation. Shield machines will continue to evolve to minimize their environmental impact. This includes improved dust control, noise reduction measures, and more sustainable practices in tunnel construction and muck disposal. Shield machines will be increasingly customized for specific projects and geological conditions. This adaptability will ensure optimal performance and reduce downtime due to unexpected challenges. Shield machines and tunnel construction processes will align with the principles of sustainability and the circular economy. This includes recycling and repurposing tunneling materials and minimizing waste generation. At the same time, the shield machine technology will be adapted for deep-sea tunneling or excavation on other celestial bodies, such as the moon or Mars. These applications may require significant innovations in materials and engineering.

7. Conclusion

Shield machines are indispensable tools in modern construction and infrastructure development. Their significance lies in their efficiency, safety benefits, precision, and versatility, which enable the construction of tunnels and underground structures with minimal surface disruption and environmental impact.

These machines have evolved over time and are expected to continue advancing in the future. Predictions for the future of shield machines include increased automation, smaller and more versatile shield machines, hybrid technologies, enhanced environmental considerations, customization, and potential applications in deep-sea exploration and space.

As cities expand and infrastructure demands grow, shield machines will continue to play a crucial role in meeting these challenges efficiently and sustainably. Their development and innovation will be instrumental in shaping the construction landscape and addressing the infrastructure needs of the future.

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