Current State of Tension Machines and Advantages of Electric Tension Machines

Shiliang Weng[a], Wei Cai[b], Chao Yang[c*], Hanhong Xie[d], Yijun Xing[e], Chuandi Wu[f], Yefen Su[g]

[a] wnwsL@163.com,, [b]1318102228@qq.com, *Corresponding author:[c] 273498086@qq.com, [d]1184532203@qq.com, [e] 2580886921@qq.com, [f] 956291847@qq.com, [g] 1591698360@qq.com

Construction Branch of Hainan Power Grid Co., Ltd., Haikou, Hainan Province, China

Abstract: This paper commences with an exploration of the current product technology development and research and development innovations in the field of tension machines. It combines an evaluation of the existing equipment landscape within the industry, elucidating the pivotal significance of upgrading and modernizing tension machines to incorporate intelligent features. Simultaneously, it underscores the inherent limitations of hydraulic-driven tension machines in terms of parameter control, energy management, and deep-level automation. Furthermore, it elaborates on the manifold advantages of electric tension machines, including enhanced efficiency, energy conservation, heightened precision in control, and ease of achieving intelligent functionalities. The paper also proposes product research and development strategies aimed at addressing critical issues, such as energy recovery and equipment reliability assurance. Ultimately, the analytical research presented in this paper furnishes the relevant industries with innovative technological pathways and references, facilitating the sustainable development of the industry.

Keywords: Electric tension machine, parameter control, energy management, Coordinated control of multiple tension machines.

1. Introduction

Tension machines are the core equipment used in the tension stringing of transmission lines. They work in conjunction with traction machines to apply controllable and reasonable damping tension. Since the late 1970s, China has been importing foreign equipment, and over nearly four decades of development, the country has transitioned from merely digesting and absorbing imported equipment to independently developing and manufacturing tension machines. The research and development capabilities in this field have matured significantly. The advancement of this technology can effectively address the challenges encountered in power line construction, and it gradually leads to an overall improvement in the level of construction machinery equipment [1-3]. However, the current state of intelligentization in existing tension machine products still falls short of meeting the increasing demands for construction efficiency, quality, and safety management. Therefore, construction stakeholders urgently require tension machines with improved performance indicators, safety features, and reliability [4-6].

This paper delves into the current landscape of product technology and research and development innovations associated with tension machines, shedding light on the technical

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and economic importance of their intelligent upgrade and transformation. When it comes to electric tension machines, this paper underscores their merits, which encompass heightened efficiency, energy conservation, precise control, and the ease of implementing intelligent functionalities. Furthermore, it outlines strategies for product research and development designed to tackle pivotal challenges such as energy recovery and equipment reliability assurance. With the market expanding and user requirements evolving, the broadening of applications for electric tension machines is an inevitable trend. Consequently, it becomes crucial to formulate corresponding technological research and development pathways to facilitate the sustainable advancement of the industry [7-9].

2. Product Technology and Research & Development Innovations of Tension Machines at Home and Abroad

2.1. Comparative product technology levels of domestic and foreign tension machines

Presently, the mechanization level of construction equipment within electric power companies has matured significantly, and domestic equipment manufacturers are continuously advancing. As shown in Figure 1, the evolution of these machines has transitioned from scattered valve blocks to integrated valve blocks, from traditional instrumentation to integrated instrumentation, and from purely manual control to the adoption of electrical control.

Figure 1 Foreign tension machines

With the advancement of electrical control technology, electro-hydraulic technology, and computer networking technology, foreign tension machines have made significant explorations and applications in equipment tension control, fault diagnosis, remote control, and communication technology. This has led to substantial progress in aspects like machine performance stability and controllability. The Italian brand TESMEC, for example, has earned a reputation in the industry for its advanced technology and stable, reliable products. However, it's important to note that foreign brands are not without their imperfections. For instance, besides being costly, the German brand ZECK faces challenges in terms of post-sales maintenance, issues related to mechanical structural strength, low efficiency in hydraulic systems, and problems with human-machine interfaces and operating methods that don't align with the requirements of construction personnel.

Figure 2 Domestic tension machine

As shown in Figure 2, domestic tension machine manufacturers have been gradually narrowing the technological gap through a combination of absorbing and digesting foreign equipment and pursuing independent innovation. While commendable progress has been made, the domestic industry still lags behind in the development of intelligent control systems and the research and development of new products, resulting in a noticeable disparity in equipment quality and performance compared to foreign brands. The reasons behind this disparity can be attributed to unhealthy competition, excessive cost control, and limited investment in research and development innovation. These factors have hindered the improvement of technological levels, to the extent that domestic products, while possessing their own advantages, often fall behind foreign products, which may also have their respective shortcomings.

2.2. Technological improvements and innovations of tension machines

According to industry research, the general consensus is that the future development of tension machines will primarily focus on the following aspects:

(1) Digitalization: With the rapid advancement of information technology, tension machines will gradually enhance their digital and information technology capabilities. This will involve the use of automation control, data collection, and processing techniques to improve operational efficiency.

(2) Intelligence: Tension machines will possess the ability for autonomous diagnosis and adaptation to various working conditions. This will involve utilizing intelligent algorithms and artificial intelligence technology for full-process control and management during tension stringing operations.

(3) Lightweight and user-friendly features: To boost operational efficiency, future tension machines will become increasingly lightweight, smaller in size, and easier to operate.

(4) Environmentally friendly and sustainable property: Future tension machines will prioritize environmentally friendly and sustainable development. This will involve the use of clean energy sources, noise reduction, and pollution mitigation measures.

(5) Modular and multifunctional integration: Future tension machines will be characterized by modularity and multifunctionality, making them adaptable to rapid deployment in outdoor environments. Additionally, they will have the capability to integrate with traction equipment in terms of functionality.

2.2.1 Digitalization and Informatization

Manufacturers from countries like Germany, Italy, and Canada have already introduced electric tension machines, employing a fully electric control system that simplifies operation. In recent years, various domestic manufacturers have also launched similar products. For instance, Germany's ZECK uses a hoisting reducer directly installed inside the tension wheel, driving a motor through a proportional relief valve to generate tension. During wire pulling, it employs a gear pump as the power source, which transmits power to the reducer through a hydraulic motor, subsequently driving the tension wheel's rotation. Controlling the proportional relief valve and adjusting the overflow rate regulates the working tension or pulling force. This system is characterized by the following functions:

(1) The tension machine allows for the monitoring and storage of its operational status.

(2) It can save operational status data offline, and this data is accessible via computer software, as depicted in Figure 3.

(3) The machine is equipped to detect equipment malfunctions, conduct self-diagnosis, and store and output error codes, facilitating reference and maintenance by repair personnel.

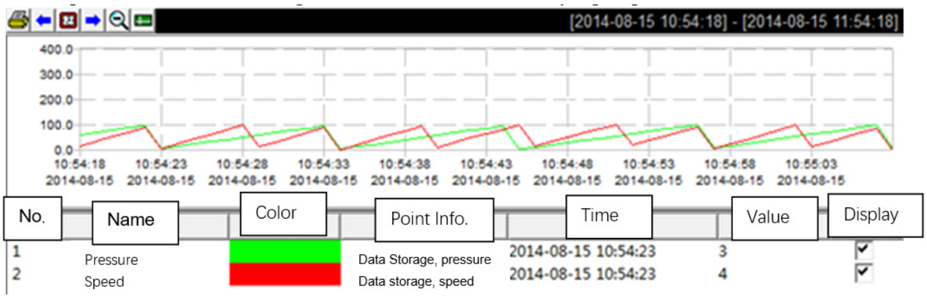


Figure 3 Data monitoring and storage of German ZECK tension machine

(4) The machine provides active maintenance and upkeep prompts based on the engine's operating hours. It includes routine maintenance and inspection items for the engine and hydraulic system, such as engine oil, oil filter, fuel filter, fuel-water separator filter, and hydraulic oil filter replacement reminders, as well as periodic lubrication reminders for mechanical systems and inspection prompts for components like traction wheels and wire entry roller wear.

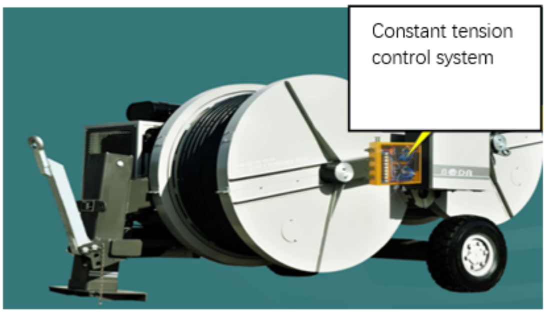
(5) It features an electric lubrication system that automatically lubricates components like traction wheel bearings and gears at scheduled intervals and in precise quantities based on the equipment's workload, eliminating the need for manual lubrication.

(6) The entire machine is electronically controlled, with control and parameter display for the power and transmission systems achieved through a controller and display.

(7) The machine incorporates remote data communication capabilities that connect to the master controller. It collects operational data, transfers it to an internet server via mobile internet networks, and allows users to access current and historical data via mobile phones or computers. It also includes built-in GPS for global positioning.

2.3. Constant tension control

As depicted in Figure 4, the tension machine of constant tension stringing addresses issues encountered with traditional tension machines, such as inconsistent wire deployment, unstable tension, and insufficient tension control accuracy. Using a tension machine of constant tension stringing ensures that the tension of the deployed wire remains constant, with an adjustable and preset constant tension value. This facilitates precise tension control during the simultaneous deployment of multiple split wires.



Constant tension control system

Figure 4 Constant tension tension machine

The constant tension control system primarily consists of a wire tension setting circuit, tension sensors, a tension feedback signal transmission system, an integrated data processing module, a tension setting controller, and an electrical proportional tension control valve. The constant tension control system operates on the fundamental principles of programmable logic controller (PLC) computation and feedback. It detects the actual tension of the wire during deployment, calculates it, compares it to the set tension, amplifies the result, and transmits it to the controller. The controller then regulates the proportional valve to achieve precise tension control. This centralized control of the stringing speed, tension data acquisition system, and data processing system during overhead wire installation effectively enhances the response time of the equipment's deployment mechanism and ensures precise tension control. The system can achieve the set tension value to execution in 0.4 seconds with a tension control accuracy of ±5%.

This system ensures the smooth deployment of each wire and maintains consistent tension relaxation for each wire after deployment. Consequently, it obviates the necessity for subsequent "tensioning" work or simplifies the post-deployment "tensioning" process.

2.4. Coordinated control of multiple tension machines

In the case of simultaneous deployment of multiple split wires, if each tension machine requires an operator, discrepancies can arise due to the coordination among multiple operators. This misalignment is not conducive to wire deployment, and tension can fluctuate with changes in the stringing speed.

As shown in Figure 5, to facilitate the simultaneous deployment of large cross-section split wires, two or three ZQT2×70 tension machines are coordinated and controlled. This setup allows for the one-time deployment of four or six split large cross-section wires. Each of the two/three tension machines is equipped for coordinated control, with both manual and automatic tension adjustment systems. They each have a wired electrical remote control interface, connected via cables to a remote control panel. At the remote control panel, an operator can simultaneously control two or three tension machines while monitoring their system pressure and tonnage, allowing for centralized control during the one-time deployment of four-split and six-split large cross-section wires. Through this coordinated control system, a single operator can manage multiple machines, achieve synchronized tension adjustment for two or three tension machines, and facilitate wire leveling. In straight-line sections, intelligent control can be applied to automatically adjust the pressure, keeping it stable and not varying with speed changes. This precise tension control reduces the physical demands on workers.

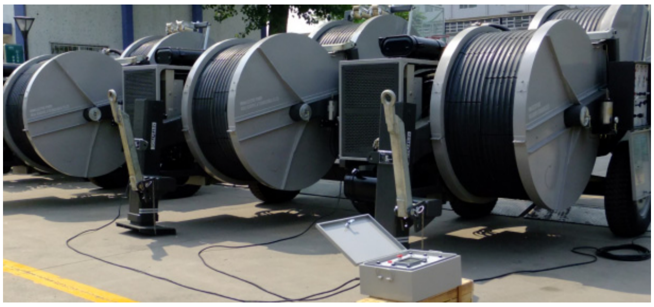


Figure 5 Coordinated control of multiple tension machines

2.5. Integrated intelligent control of the whole machine

A domestic manufacturer's integrated intelligent control system for the whole machine aims to safeguard the wire and enhance overhead wire installation efficiency, as shown in Figure 6. During the wire installation process, it ensures stable tension, preventing wire tension from varying with changes in traction speed, thus improving the efficiency and quality of wire installation. The specific steps involved are as follows:

(1) Data acquisition from hydraulic systems: The pressure signal from the hydraulic system, hydraulic oil temperature signal, hydraulic oil filter blockage signal, and brake system's brake status signal are transmitted to the controller.

(2) Engine information acquisition: Using sensors such as the rotational speed sensor, oil pressure sensor, water temperature sensor, fuel oil quantity sensor, and throttle motor position feedback, it collects the working status signals of the engine and sends them to the controller. It also collects the number of rotations of the tension wheel and reflects this to the controller for calculating the stringing length and speed.

(3) Hydraulic system control: The controller adjusts the opening size of the electro-hydraulic proportional relief valve core to regulate the operating pressure of the hydraulic system. It employs electro-hydraulic directional valves to control the flow of oil in certain on/off states.

(4) Hydraulic system operation principle: The electro-hydraulic proportional relief valve is controlled using a potentiometer, which adjusts the pressure of the hydraulic motor to generate tension. During wire pulling, it utilizes a variable-displacement piston pump as the power

source, transmitting power through a hydraulic motor to the reducer, which subsequently drives the tension wheel's rotation.

(5) Engine control: The engine throttle is controlled using a throttle motor.

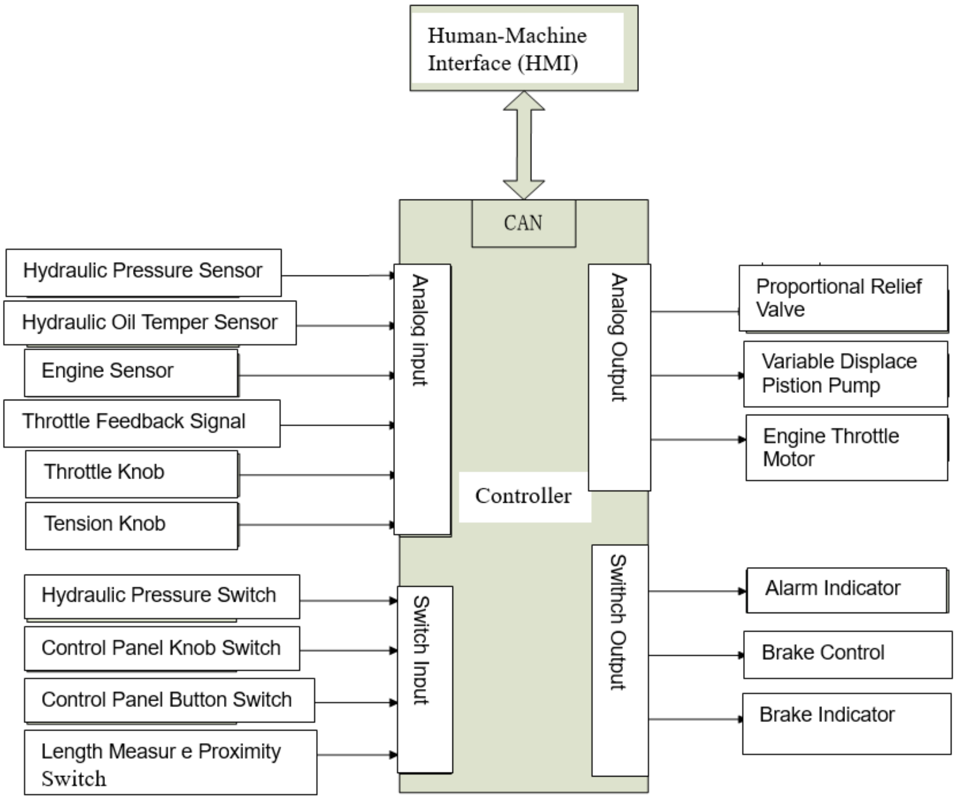


Figure 6 Master controller of integrated intelligent control tension machine

The intelligent control system primarily comprises a wire tension setting circuit, tension sensors, a tension feedback system for signal transmission, an integrated data processing module, a tension setting controller, and an electrical proportional tension control valve.

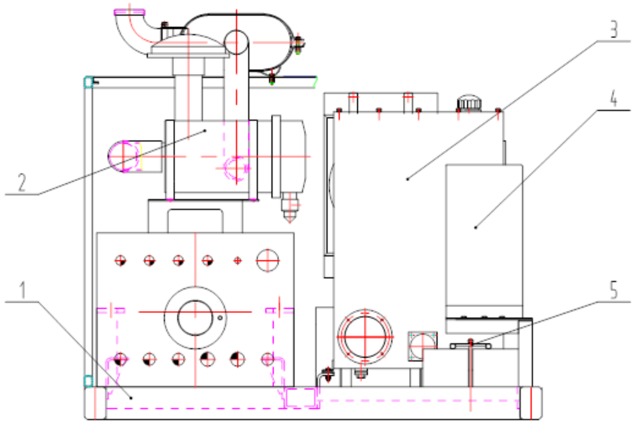
The intelligent control system operates on the fundamental principles of PLC computation and feedback. It detects the actual tension of the wire during deployment, conducts calculations, compares it to the set tension, amplifies the result, and then transmits this data to the controller. The controller regulates the proportional valve to achieve precise tension control. By centralizing control of stringing speed, the tension data acquisition system, and the data processing system during stringing construction, the system effectively enhances the responsiveness of the equipment's stringing mechanism and improves tension control accuracy, ensuring that the set tension value is met.

By utilizing electro-hydraulic and automatic control technology, precise control of tension values and the assurance of their stability have been achieved, building upon the foundation of a conventional hydraulic tension machine. A programmable controller serves as the control component of the automatic control system, utilizing a variety of sensors for data acquisition. The PLC controller controls the actions of the executive components. The equipment incorporates an onboard computer that digitally displays all tension machine parameters and operational status, featuring an alarm function to facilitate human-machine interaction.

2.6. Modular design of tension machines

In the course of research and engineering applications for large cross-section wires measuring 1250 mm² and 1520 mm² (such as the Ningdong-Zhejiang ±800 kV Ultra-High Voltage Direct Current Transmission Line Project and the Mengxi-Hubei ±800 kV Ultra-High Voltage Direct Current Transmission Line Project), it was recognized that existing tension machines couldn't meet the requirements for deploying 1520 mm² large cross-section wires. Consequently, the development of tension machines capable of accommodating 1250 mm² and 1520 mm² large cross-section wires was initiated. The designed tension machine is modular, consisting of a hydraulic power unit and a stringing drum unit.

As illustrated in Figure 7, the hydraulic power unit is a ground-based structure with a low center of gravity, rendering it easily maneuverable for lifting and transportation purposes. Its principal components encompass an engine, a variable pump, a hydraulic oil tank, and a meter box. Conversely, the stringing drum unit adopts a trailer-based structure designed for effortless equipment installation and relocation. Its core elements include a trailer frame structure, a tension wheel, a hydraulic motor, and wire entry rollers.



1. Base; 2. Engine assembly; 3. Hydraulic oil tank; 4. Meter box; 5. Battery assembly

Figure 7 The power unit of the modular tension machine

2.7. Technology innovations in safety enhancement

In response to the safety concerns associated with wire slipping and running off the track in tension machines, domestic manufacturers have primarily concentrated on enhancing the hydraulic system's design to mitigate issues stemming from hydraulic factors. One notable innovation, as illustrated in Figure 8 and covered by the patent technology "Anti-Runoff Valve Block of Tension machines" (CN 207111567 U), involves the development of a valve block. This valve block comprises an oil inlet, a low-pressure supplementary oil inlet, and at least one high-pressure supplementary oil inlet. The oil inlet facilitates oil inflow, while the low-pressure supplementary oil inlet connects to the main valve block's oil inlet, and the high-pressure supplementary oil inlet is linked to the main valve block's high-pressure oil outlet. A first oil passage connects the oil inlet and the low-pressure supplementary oil inlet, featuring an overflow valve that regulates the oil pressure within the valve block. Furthermore, a second oil passage connects the oil inlet and the high-pressure supplementary oil inlet, housing a directional valve. The directional valve is connected to the low-pressure supplementary oil inlet through a third oil passage. This valve can select either the low-pressure supplementary oil inlet or the high-pressure supplementary oil inlet. This innovative design effectively reduces pressure differentials at the high-pressure oil outlet, preventing wire runoff and addressing the issue of system overheating caused by prolonged high-pressure supplementary oil usage.

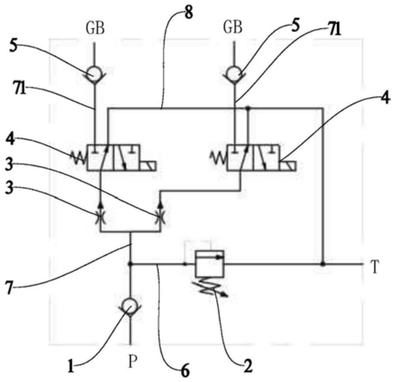


Figure 8 Anti-runoff valve block of tension machines

3. Upgrade and Innovation for the Digitalization and Intelligence of Existing Tension Machines in the Industry

The majority of tension machines currently in use within the industry are manual hydraulic, and they are plagued by several issues:

(1) Wire slippage: These machines are prone to "wire slipping" when the tension wheels are subjected to high tension and significant loads.

(2) Jerky wire running: Under conditions where the tension wheels are braked and subjected to substantial loads, manually releasing the brakes often leads to the occurrence of "jerky wire running."

(3) Hydraulic control system stability: The stability of the hydraulic control system tends to be subpar when operating on-site, making it a significant contributing factor to abnormal "wire running" accidents.

(4) Operator skill dependency: Machine operation is heavily reliant on the experience and skills of construction personnel, rendering them susceptible to construction accidents or equipment damage.

(5) Lack of self-diagnostics and equipment informatization: These machines lack self-check mechanisms and equipment informatization capabilities. Equipment maintenance relies entirely on manual interventions, increasing the risk of overlooking essential maintenance tasks. Additionally, operational and maintenance data cannot be effectively preserved.

Domestic electric power construction units possess a rich inventory of equipment. Upgrading and renovating tension machines is a low-risk, high-return, and cost-effective approach. This upgrade can enhance their functionality and reliability while utilizing existing equipment resources, requiring minimal cost. The direct result is an improvement in the efficiency and safety of tension machines. This endeavor is essential for facilitating the smooth progress of power transmission line projects, serving as a critical proactive measure for engineering safety protection.

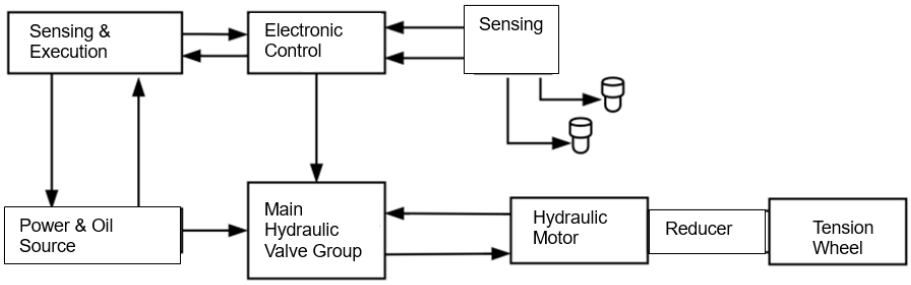


Figure 9 System upgrade and retrofit of tension machines

As shown in Figure 9, the primary approach to the upgrade and renovation is to retrofit the tension machine with electro-hydraulic control and electronic control assemblies. This entails adding sensors, electronic control valve groups, power pump source sensors, and actuators based on the hydraulic system of the tension machine. This modification achieves coordinated operation between the output load and driving power, ensuring real-time and reliable control, as well as safe operation of the tension machine.

4. Analysis of the Advantages of Electric Tension Machines in the New Energy Era

In the new energy era, electric drive technology is increasingly pivotal across diverse domains. In contrast to conventional fuel-based drive technology, electric drive technology not only delivers enhanced environmental sustainability and energy efficiency but also augments user convenience. The adoption of electric equipment can elevate production efficiency while concurrently curbing environmental pollution. Embracing electric drive technology as the cornerstone of electric tension machines heralds a novel phase in equipment technology evolution. Unlike their fuel-driven hydraulic counterparts, electric tension machines have yet to witness extensive product proliferation and application due to the historical dearth of specialized research and development initiatives by various manufacturing units.

4.1. Analysis of advantages of electric tension machines

Electric tension machines, harnessing the remarkable attributes of electric drive technology, confer distinct advantages, especially in the realms of product innovation and intelligence.

(1) Reduced carbon emission: Electric drive systems rely on electricity instead of chemical fuels, effectively mitigating carbon emissions and minimizing environmental pollution.

(2) Energy conservation: Electric drive systems convert mechanical energy into electricity through energy recovery and utilize this electricity to power electric motors, resulting in energy savings.

(3) Prolonged equipment lifespan: Electric tension machines employ tensioning with energy recovery, allowing for the conversion of a substantial portion of mechanical energy into electricity. This significantly diminishes mechanical heat generation, thereby reducing wear and friction. Consequently, it extends the lifespan of equipment and diminishes maintenance and repair costs.

(4) Streamlined automation and intelligence implementation: In comparison to fuel-driven systems, electric drive systems boast simpler components and control methods. Electric drive mechanisms exhibit swift response and offer controllable speed. The system's controller can continuously monitor the motor's real-time operational status without necessitating specialized sensors, simplifying the integration of intelligent features.

4.2. Challenges faced by electric tension machines in overhead line construction scenarios

(1) Disadvantages of electric tension machines and product development strategies

Electric drive technology, when juxtaposed with hydraulic technology, exhibits certain limitations, primarily manifesting in two key aspects:

(a) Reduced motor torque: In high-power applications, electric motors may have a lower load-bearing capacity compared to hydraulic systems. This mandates meticulous gearbox selection and optimization of the transmission's structural layout.

(b) Vulnerability of electrical components: Electrical components, such as batteries, are susceptible to wear and tear during usage. Ensuring proper maintenance and timely replacement is imperative to mitigate the occurrence of failures.

To address the aforementioned issues, the development of electric tension machines can explore the following measures:

(a) Selection of high-efficiency, high-performance motors: Opting for high-efficiency, high-performance motors can enhance torque and operational efficiency. Moreover, harnessing the motor's inherent advantages, such as precision and responsiveness, and combining it with a more precise controller can bolster the system's control capabilities, thereby improving robustness.

(b) Adoption of high-strength, durable electronic components: Employing high-strength and durable electronic components can augment the longevity and load-bearing capacity of electrical parts. Additionally, software upgrades and firmware updates can serve to compensate for any inherent design limitations in electronic components.

(c) Deliberate protective design: Conceiving the electric drive system with a focus on elevating the product's protection level is of paramount importance.

(2) Application of energy recovery technology in tension machine operation

During the primary working conditions of a tension machine, the electric motor remains in a passive traction state for an extended period, continuously generating electrical energy. Therefore, a reasonable technical solution is needed to transfer or dissipate excess electrical energy that cannot be accommodated by the machine itself.

The following approaches can be considered to manage surplus electrical energy:

(a) Conversion of electrical energy into thermal energy: This method involves transforming excess electrical energy into thermal energy and dissipating the generated heat through a cooling system. While relatively straightforward to implement, it may not yield substantial energy savings.

(b) Transfer of surplus electrical energy to other electrical devices within the tension area: This approach involves routing excess electrical energy to power other electrical devices in the vicinity of the tension machine. However, it necessitates careful consideration of electrical safety concerns and potential interference with the operational characteristics of the tension machine to mitigate safety risks.

(3) Ensuring reliability for field operations of electric tension machines

To ensure reliability and maintainability of electric tension machines during field operations, the following points should be taken into consideration:

(a) Environmental considerations in design: During the design phase of electric tension machines, the prevailing environmental conditions of field operations must be carefully taken into account. This entails the use of appropriate structural designs, materials, and special features, such as dust and waterproofing, to enhance the reliability and safety of the equipment when subjected to harsh operating conditions.

(b) Maintenance-centric design: Electric tension machines should be designed with maintenance in mind. Adopting a modular and disassemble design allows for seamless component replacement when maintenance becomes necessary, minimizing downtime.

(c) Well-structured equipment maintenance schedule: Establishing a well-structured equipment maintenance schedule is paramount for ensuring the long-term stability of the equipment. Regular maintenance of the electric drive system, including equipment cleaning and replacing faulty components, is imperative to maintain the equipment's smooth operation. Additionally, for field operations, it is crucial to develop emergency measures and contingency maintenance plans to swiftly address potential equipment failures and ensure minimal disruption to operations.

5. Conclusions

In conclusion, following a comprehensive examination of the present landscape of tension machine products and technological advancements on both domestic and international fronts, it is evident that domestic manufacturers are trailing their foreign counterparts in the realms of intelligent control equipment and new product development. To secure a competitive advantage in the market, we advocate that the industry prioritize the enhancement of digital and intelligent enhancements for tension machines, the refinement of their functionalities, and the resolution of operational challenges.

Moreover, given the prominent advantages of electric tension machines regarding performance stability, controllability, energy efficiency, and environmental sustainability, it is imperative to place a significant emphasis on the research and implementation of electric tension machines in the realm of tension machine technology development and innovation. This strategic approach will elevate their competitiveness within the market. Furthermore, this paper delved into the characteristics and benefits of electric tension machines and furnished recommendations for addressing pivotal issues, with the ultimate goal of fostering swift and robust growth in the industry.

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