

Application and Teaching of Electrical Equipment in Engineering Machinery

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Abstract: Electrical equipment, as a core component of modern engineering machinery, continues to expand in both application depth and breadth. This encompasses the electrification of power systems, upgrades in intelligent monitoring and control, and the realization of automated unmanned operations, significantly enhancing the operational efficiency and reliability of engineering machinery. However, current teaching practices face challenges such as a disconnect between the curriculum and industry demands, outdated practical teaching equipment, and insufficient interdisciplinary competence among faculty. To address these issues, it is necessary to restructure the curriculum into a modular system that integrates new energy and intelligent technologies; promote virtual simulation and real project practice; and strengthen faculty industry experience and the construction of dual-qualified teaching teams. These measures aim to cultivate versatile technical talent that meets the developmental needs of the industry.

Keywords: Electrical Equipment; Engineering Machinery; Application; Teaching

Introduction

In the current era of accelerated intelligent and green transformation in engineering machinery, electrical equipment has become a core driver for enhancing equipment performance and fostering technological innovation. From the energy-efficient benefits of electric drives to the precise control enabled by intelligent monitoring, and breakthroughs in automated operations, the application of electrical technology continues to deepen and broaden. Nevertheless, the existing teaching system lags behind industry developments, with outdated course content, inadequate practical training, and a shortage

of interdisciplinary expertise among educators becoming increasingly apparent. These issues have created a significant gap between talent cultivation and industry demands. Reconstructing teaching content, innovating practical training models, and strengthening faculty development are critical to nurturing electrical technology talent in engineering machinery that meets the demands of the new era.

1. Core Applications of Electrical Equipment in Engineering Machinery

1.1 Electrification of Power Systems

(1) Electric Drive Technology: Permanent Magnet Synchronous Motors (PMSMs) are widely used in the



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slewing mechanisms of excavators due to their high power density and low loss characteristics. Compared to traditional asynchronous motors, their operational efficiency is significantly improved by approximately 15%. This reduces energy consumption while also lowering noise and vibration during mechanism operation. PMSMs are well-suited for the frequent start-stop and heavy-duty slewing working conditions of excavators, enhancing operational continuity and stability.

(2) Hybrid Power Systems: Series-type and parallel-type hydraulic-electric hybrid drive solutions are key to energy savings. The series-type uses the engine to drive a generator for power supply, avoiding engine idling energy consumption. The parallel-type enables the motor and engine to drive cooperatively, distributing power on demand. Both modes can achieve about 30% energy savings, effectively reducing fuel consumption and carbon emissions of engineering machinery during construction, aligning with the concept of green construction.

(3) Battery Management System (BMS): For the lithium-ion battery packs installed in engineering machinery, the BMS can monitor battery voltage, current, and temperature in real-time, accurately determining the State of Health (SOH) and State of Charge (SOC). Simultaneously, through active thermal management technology, it controls the battery temperature within the optimal operating range, extending battery service life and ensuring stable output from the power system.

1.2 Intelligent Control and Monitoring

(1) CAN Bus Communication: As the "nerve center" of engineering machinery, the Controller Area Network (CAN) bus enables real-time data exchange between the engine, hydraulic pump, and operator terminal. It features fast data transmission rates and strong anti-interference capability, allowing it to feed back key parameters like engine speed and hydraulic system pressure in real-time. This enables the control system to quickly adjust the equipment's operating state, improving operational response speed and work accuracy.

(2) Sensor Network: Tilt sensors monitor the equipment's body tilt angle in real-time. When the tilt exceeds a safe threshold, an alarm is triggered

immediately and movements are restricted, effectively preventing tipping accidents. Pressure sensors installed in hydraulic circuits accurately perceive load pressure, enabling load-adaptive control, preventing equipment overload operation, and reducing mechanical component wear.

(3) Fault Diagnosis System: Based on vibration analysis technology, the system collects vibration signals from bearings during operation via sensors. By analyzing signal characteristics combined with algorithms, it can accurately identify the degree of bearing wear, achieving a fault prediction accuracy rate of up to 92%. This allows for early warning of potential faults, facilitating timely maintenance by personnel, reducing equipment downtime, and lowering maintenance costs^[1].

1.3 Automation and Unmanned Operation

(1) GPS/BeiDou Positioning: In paver operations, the GPS/BeiDou positioning system can acquire the equipment's position information in real-time. Combined with preset construction parameters, it enables automatic leveling, ensuring pavement flatness errors are controlled within millimeter levels. It also supports path planning functions, allowing the equipment to operate automatically along a planned route, reducing manual operation errors, and improving construction efficiency and quality.

(2) Visual Recognition Technology: Applied in the loading process of concrete mixer trucks, this technology uses cameras to capture images of the loading hatch. Visual algorithms quickly identify the position and posture of the loading hatch, controlling the robotic arm or adjusting the vehicle's position to achieve automatic alignment of the loading hatch, with an alignment error of less than 2 cm. This avoids the time-consuming and spill-prone issues associated with manual alignment, enhancing loading efficiency and safety.

(3) Remote Control Platform: Leveraging the high speed and low latency of 5G and the immersive experience of VR technology, operators can use VR devices in a remote control room to obtain real-time operational visuals and feedback from mining equipment, accurately controlling the equipment to perform tasks like digging and transporting. This eliminates the need for on-site personnel, reducing the

safety threats posed by high-risk mining environments, and enables centralized management of multiple pieces of equipment.

2. Current Status and Issues in Teaching Electrical Equipment for Engineering Machinery

2.1 Deficiencies in the Curriculum System

(1) Lagging Content and Technological Updates: The course *Construction and Maintenance of Engineering Machinery Electronics and Electrical Systems* exhibits significant shortcomings, displaying low alignment with actual enterprise needs and a lag in updating new technologies. The course provides insufficient coverage in areas such as the explanation of automation levels, instruction on updated detection software, and practical training for PLC programming. Furthermore, practical training often relies on traditional diesel-powered equipment, while electrical training equipment is updated slowly. This makes it difficult to keep pace with industry technological developments and fails to meet corporate demand for relevant technical talent.

(2) Outdated Teaching Materials: Existing textbook content predominantly focuses on the electrical systems of traditional fuel-powered engineering machinery, showing a clear lack of coverage regarding topics related to new energy engineering machinery. Cutting-edge content such as the BMS control logic for hybrid excavators or the drive system design for electric loaders is absent from most textbooks. This creates a disconnect between what students learn in school and the technological progress of the industry, necessitating additional corporate training after graduation to adapt to their roles.

2.2 Insufficiency in Practical Teaching

(1) Aging Experimental Equipment: Most engineering machinery electrical laboratories in educational institutions still primarily use analog circuit experiment benches and traditional relay control cabinets, lacking digital and intelligent experimental equipment. For instance, they cannot provide platforms for debugging Permanent Magnet Synchronous Motors or CAN bus communication simulation systems. Consequently, students struggle to understand the working principles of electric drive technologies and intelligent monitoring systems through practical operation, hindering the development of their practical skills.

(2) Superficial Industry-Academia Cooperation: Although many institutions have established cooperative relationships with engineering machinery enterprises, the collaboration often remains at a superficial level, such as "enterprise visits" or "expert lectures," lacking deep project cooperation. The practical projects students participate in are mostly demonstrative tasks pre-designed by companies, rather than core tasks like troubleshooting electrical equipment faults or system debugging encountered in real production environments. This makes it difficult for students to accumulate experience in solving practical problems ^[2].

2.3 Shortcomings in Faculty Competence

(1) Lack of Industry Practical Experience: Most specialized teachers enter academia directly after graduation, lacking frontline work experience in engineering machinery enterprises. Over 60% of teachers have not participated in the research & development, debugging, or maintenance of actual engineering machinery electrical systems. When facing complex teaching content like hybrid power system fault diagnosis or automated equipment programming, they find it difficult to provide guidance based on actual working conditions, significantly compromising teaching effectiveness.

(2) Weak Interdisciplinary Integration Ability: Electrical equipment in construction machinery involves multiple disciplines, including mechanics, electronics, programming, and automation. However, some teachers remain confined to a single field of electrical instruction and lack the ability to integrate interdisciplinary content such as mechatronic technology, PLC programming, and sensor data processing. For example, when explaining intelligent control and monitoring systems, they are often unable to effectively connect sensor principles, CAN bus communication, and mechanical operation logic, making it difficult for students to develop a systematic understanding of the subject.

3. Innovative Strategies for Teaching Electrical Equipment in Engineering Machinery

3.1 Restructuring the Curriculum System

(1) Modular Design: Break away from the traditional linear course structure and establish a well-defined

modular teaching system to achieve precise alignment between knowledge and industry demands.

1) Foundation Modules: Focus on core foundational knowledge such as circuit theory and motor control. Utilize case-based teaching to enable students to master circuit analysis, DC motor speed control, AC motor drives, and other essential topics, laying a solid groundwork for subsequent learning. For example, within the "Motor Control" chapter, explain the practical applications of motor starting, braking, and speed regulation in the context of the control requirements for an excavator's slewing motor, preventing a disconnect between theory and practice.

2) Core Modules: Center on engineering machinery power electronics technology and CAN bus communication. Provide in-depth explanation of the application of power electronic devices in hybrid power systems, and the topology and data transmission protocols of CAN buses. The curriculum should include numerous hands-on tasks, such as having students build a small CAN bus communication experimental platform to simulate the data exchange process between an engine and a hydraulic pump, thereby enhancing technical application skills.

3) Advanced Modules: Keep pace with industry frontiers by adding course content on hydrogen fuel cell power systems, supercapacitor energy storage technology, etc. Invite experts from new energy engineering machinery enterprises to deliver special lectures. Organize students to analyze the electrical system architecture of hydrogen fuel cell excavators and understand the application principles of supercapacitors in energy recovery for engineering machinery, cultivating students' technical foresight^[3].

(2) Integration of Ideological and Political Education: Integrate ideological and political elements organically into the course teaching. Use case studies of "major national projects and equipment" to stimulate students' professional identity and awareness of engineering ethics. For example, when teaching the "New Energy Engineering Machinery Electrical Systems" unit, introduce application cases of China's independently developed electric loaders in major overseas projects. This showcases breakthroughs in domestic engineering machinery electrical technology and fosters students' national pride. Furthermore, by incorporating equipment safety operation protocols,

emphasize the safety responsibilities and environmental concepts inherent in electrical system design. This guides students to establish correct engineering ethics.

3.2 Practical Teaching Reform

(1) Virtual Simulation Experiments: Utilize virtual simulation technology to overcome limitations in physical experimental conditions, creating immersive practical teaching scenarios and enhancing students' ability to solve complex problems.

1) Hydraulic-Electrical Co-simulation: Use MATLAB/Simulink software to build a hydraulic-electrical co-simulation model of an excavator. Students can adjust variables such as motor parameters and hydraulic circuit pressure to observe changes in equipment slewing speed and operational efficiency, thereby gaining a deep understanding of the synergistic working mechanism between electrical and hydraulic systems. The simulation process incorporates scenarios like parameter abnormalities and system failures, requiring students to analyze the causes and propose solutions.

2) AR-based Fault Diagnosis System: Develop an AR technology-based electrical fault diagnosis system for engineering machinery. By scanning a device model with a mobile phone or tablet, common faults such as motor overload, sensor failure, and CAN bus communication interruption can be simulated in a virtual environment. Students must troubleshoot the problem based on the fault symptoms prompted by the system and combined with electrical schematic diagrams, gradually mastering the processes and methods of fault diagnosis and improving their practical skills.

(2) Real Project-Driven Learning: Use real projects as the vehicle for students to accumulate experience through practice, fostering innovative thinking and teamwork skills.

1) Industry Collaboration Projects: Engage in deep collaboration with enterprises like XCMG and SANY Heavy Industry to jointly develop projects such as "Optimization of Electric Loader Power Systems" and "Performance Improvement of BMS for Engineering Machinery." Students participate in these projects in groups, involved from requirements analysis and solution design to system debugging. Guided by enterprise engineers, they solve practical problems,

translating theoretical knowledge into practical ability.

2) Participation in Academic Competitions: Organize student participation in competitions like the National College Student Engineering Machinery Innovation Design Competition and the Electrical and Electronic Engineering Innovation Competition. Encourage students to undertake project development around themes such as "Innovation in New Energy Engineering Machinery Electrical Systems" and "Application of Intelligent Monitoring Technology." Competitions serve to test learning outcomes, stimulate students' enthusiasm for innovation, and simultaneously enhance their project management and teamwork skills^[4].

3.3 Teaching Faculty Development

(1) Enterprise Secondment: Establish a long-term mechanism for teachers to undertake practical training in enterprises. Annually select teachers for secondments lasting no less than 3 months to leading companies like XCMG and SANY Heavy Industry. Teachers immerse themselves in the production front lines, participating in the R&D, debugging, and maintenance of engineering machinery electrical equipment—for instance, taking part in the testing of electrical control systems for new electric cranes—to accumulate hands-on engineering experience. Upon completion, teachers are required to transform enterprise cases into teaching resources, integrating them into classroom instruction, thereby achieving a two-way transfer between "practice and teaching."

(2) Building a "Dual-Qualified" Team: Involve senior enterprise engineers in curriculum design and teaching implementation, forming a "dual-qualified" teaching team composed of "university teachers + enterprise engineers." Enterprise engineers can teach practical courses; for example, in the "CAN Bus Communication" practical class, an engineer might demonstrate the actual bus debugging process in real engineering machinery. They can also participate in guiding student projects, providing students with cutting-edge technical advice from the industry. Concurrently, university teachers and enterprise engineers jointly develop school-based teaching

materials and practical training projects, promoting the simultaneous updating of teaching content with industry technology and enhancing the overall teaching and practical guidance capabilities of the faculty.

Conclusion

The deep application of electrical equipment in the engineering machinery field is accelerating the industry's transition towards intelligence and low-carbon development. Innovation in the teaching system is the core guarantee for cultivating suitably skilled talent. By restructuring the curriculum, strengthening virtual simulation and real project practice, and building a "dual-qualified" teaching team, the disconnect between teaching and industry can be effectively resolved. In the future, it is essential to continuously monitor industry technological trends, dynamically adjust teaching content and methods, and deepen the industry-education integration mechanism to ensure seamless alignment between talent cultivation and the demands of engineering practice. Only in this way can we supply the engineering machinery industry with high-quality technical talent possessing both theoretical depth and practical ability, thereby supporting the high-quality development of the industry.

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