

Analysis of Dynamic Matching Mechanism of Mechanical-Electrical Systems and Energy Efficiency Enhancement Paths in Intelligent Manufacturing

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Abstract: Under the background of intelligent manufacturing, the dynamic matching mechanism of mechanical-electrical systems is of vital importance for enhancing production efficiency and energy efficiency. This paper analyzes the dynamic matching mechanism from aspects such as system architecture, data interaction, and collaborative control. It also explores the paths for improving energy efficiency from dimensions such as energy management, equipment optimization, and process improvement, providing theoretical support for the development of intelligent manufacturing.

Keywords: Intelligent Manufacturing; Mechanical-Electrical Systems; Dynamic Matching Mechanism; Energy Efficiency Improvement Path

1. Introduction

With the intensification of global manufacturing competition and the rapid development of technology, intelligent manufacturing has become the core force driving the transformation and upgrading of the manufacturing industry. Intelligent manufacturing integrates advanced information technology, automation technology and artificial intelligence technology to achieve intelligent management and control throughout the production process. Its core objective is to enhance production efficiency, quality and flexibility, while reducing resource consumption and environmental pollution [1]. In the intelligent manufacturing system, the dynamic matching degree between the mechanical system and the electrical system directly affects the operational efficiency and energy efficiency of the entire system. The mechanical system provides physical motion and execution functions, while the electrical system is responsible for control, monitoring and energy transmission. The two need to achieve deep

integration through real-time data interaction and coordinated control [2]. For example, in the automotive manufacturing field, the precise movement of mechanical arms and the real-time feedback of the electrical control system need to be highly synchronized; otherwise, it may lead to a decrease in production efficiency or an increase in the defect rate of products [3].

Currently, the research on the dynamic matching of mechanical-electrical systems still faces many challenges. On the one hand, the mechanical and electrical designs of traditional manufacturing systems are often carried out independently, resulting in parameter mismatches and response delays during operation [4]; on the other hand, the dynamic changes in production tasks in intelligent manufacturing scenarios (such as multi-variety small-batch production) place higher requirements on the adaptive ability of the mechanical-electrical system [5]. Therefore, in-depth research on the dynamic matching mechanism of mechanical-electrical systems and the path for energy efficiency improvement not only helps to break through existing technical bottlenecks but also provides theoretical support and practical guidance for the green and sustainable development of the manufacturing industry [6].

2. Overview of the Mechanical-Electrical System in Intelligent Manufacturing

2.1 Concept and Characteristics of Intelligent Manufacturing

Intelligent manufacturing is a new production mode, which combines advanced information technology, automation technology and artificial intelligence to realize intelligent management and control of the whole production process [7]. Its core idea is to make the best arrangement and flexible adjustment of the production process by means of digitalization and networking, so as to maximize the use of resources and reduce energy

consumption and environmental pollution. Intelligent manufacturing has the obvious characteristics of digitalization, networking, intelligence, flexibility and environmental protection. Digitalization can help us collect and analyze the data in the production process accurately and provide the basis for production decision. Networking connects and shares resources such as equipment, products, personnel and data efficiently through the industrial Internet platform; Intelligent use of artificial intelligence, machine learning and other technologies, so that the production process can make its own decisions and optimization; Flexibility can quickly adapt to changes in market demand and achieve customized production; Greening pays attention to environmental protection and sustainable development, and reduces resource consumption and environmental pollution in the production process.

2.2 The Position and Role of the Mechanical-Electrical System in Intelligent Manufacturing

In the intelligent manufacturing system, the mechanical-electrical system is the basic support. The mechanical system covers various production equipment, robots, transmission devices, etc., which complete the processing and assembly of products through physical movement. The electrical system includes sensors, controllers, actuators, power electronic devices, etc., responsible for monitoring, controlling, and regulating the operation status of the mechanical system, as well as achieving energy transmission and conversion [8]. The mechanical system and the electrical system collaborate and influence each other, forming the hardware foundation of the intelligent manufacturing system. For example, on an automated production line, the movement of the mechanical arm requires the electrical system to provide precise control signals, and the operation status of the mechanical arm is fed back to the electrical system through sensors for real-time adjustment. Only when the mechanical-electrical system works closely together can the production process be efficient, accurate, and stable.

2.3 The Connotation and Significance of Dynamic Matching of the Mechanical-Electrical System

Dynamic matching of the mechanical-electrical system refers to the fact that in the operation of intelligent manufacturing, the mechanical system and the electrical system can adjust their states and parameters in real time according to production tasks, environmental changes, etc., in order to make them work well together and achieve the best operation effect. This dynamic matching is not a simple mechanical connection and electronic control, but involves the deep integration of system architecture, data interaction, collaborative control and other levels. The significance of dynamic matching lies in improving production efficiency, optimizing the operation of electromechanical system, reducing waiting time and waste in production process and improving equipment utilization rate; improve product quality, precise mechanical movement and electrical control can ensure the accuracy and consistency of product processing; Enhance the flexibility and adaptability of the system, so that we can quickly respond to changes in market demand and realize multi-variety and small-batch production; Reduce energy consumption, reduce unnecessary energy waste and realize green production through reasonable energy distribution and optimal control.

3. Dynamic Matching Mechanism of Electromechanical System in Intelligent Manufacturing

3.1 Dynamic Matching at the System Architecture Level

Establishing an integrated system architecture is the basis of realizing dynamic matching of electromechanical systems. Starting from the lowest equipment layer, we need to ensure that mechanical hardware and electrical control components are completely compatible in physical interface and communication protocol. For example, the joint drive motor of the mechanical arm should be accurately connected to the corresponding electrical control module, and the layout of data transmission lines should be reasonable to reduce signal interference.

On the middle floor, we need to establish a unified data processing and communication platform to integrate the mechanical operation data and electrical control parameters so that they can communicate smoothly. We can use Industrial Ethernet to quickly transmit the real-time working conditions of mechanical

processing equipment to the electrical control system, so that the control strategy can be adjusted in time. At the top level, we need to build an intelligent decision-making system, which is based on various fused data sources. Using data analysis and artificial intelligence algorithm, it provides decision support for production process optimization and equipment maintenance, realizes the integrated cooperative operation from equipment execution to high-level decision, and improves the operation efficiency and intelligent level of the whole intelligent manufacturing system.

Modular design divides the system into many independent and interchangeable modules, and each module is responsible for one or several specific production tasks. Through modular design, the production line can be easily expanded, upgraded or replaced to meet the ever-changing production requirements. For example, in an automated production line, different processing stations can be designed as independent modules. When the product is changed, just replace the corresponding module. Reconfigurable design emphasizes that when the system switches between different production tasks, it can be reorganized quickly without large-scale equipment replacement or rewiring. This design can make the electromechanical system automatically adjust the operation parameters of each equipment according to the change of production order, ensure efficient and stable production, and comprehensively improve the performance of intelligent manufacturing system.

3.2 Dynamic Matching of Data Interaction Layer

Data acquisition is the basic step of dynamic matching of electromechanical system. By deploying various sensors in mechanical and electrical systems, such as temperature sensors, pressure sensors and displacement sensors, we can collect the key parameters and state information of equipment operation in real time. These sensors convert the analog signals they collect into digital signals, and then transmit them to the data processing center through wired or wireless communication. In the process of data transmission, we need to ensure the accuracy and real-time performance of data, and use high-speed and stable communication protocols and network architecture to avoid data loss and delay. For example, in the industrial

Internet of Things environment, 5G technology can be used for high-speed transmission of sensor data to meet the requirements of real-time monitoring and control.

The collected electromechanical system data are often varied and complicated, so it is necessary to fuse and process them to provide effective support for dynamic matching. Data fusion is to integrate the data of different sensors and data sources, remove duplication and contradictions, and form a comprehensive and accurate data description. We can use some data fusion algorithms, such as weighted average method and Kalman filtering method, to deal with these multi-source data. Data processing includes data cleaning, feature extraction and data analysis. By preprocessing and analyzing the data, we can dig out the hidden information and laws and provide decision-making basis for the dynamic adjustment of electromechanical system. For example, by analyzing the equipment operation data, we can predict when the equipment will break down, and then carry out maintenance and adjustment in advance, so as to avoid production interruption.

Data feedback and control are the key steps in the dynamic matching at the data interaction level. The processed data is fed back to the control modules of the mechanical system and electrical system, and the operating parameters and control strategies of the system are adjusted in real time according to the analysis results. For example, when we find that the load of mechanical equipment is too high, the electronic control system can adjust the output power of the motor itself to reduce the load of the equipment; If the quality deviation of products is detected, the parameters of machining can be adjusted to correct these deviations. This control method based on data feedback can realize the closed-loop control of electromechanical system, improve the dynamic response ability and stability of the system, and make the two achieve dynamic matching.

3.3 Dynamic Matching of Cooperative Control Layer

Cooperative control strategy is the core of realizing dynamic matching of electromechanical system. Common cooperative control strategies include centralized control and distributed control. Centralized control is to concentrate the control right of the whole electromechanical system in a central controller,

and the central controller will uniformly dispatch and coordinate the subsystems. This control strategy has the advantages of simple control and easy management, but it also has problems such as excessive load on the central controller and low system reliability. On the other hand, distributed control distributes the control function to each subsystem, and each subsystem has independent control ability. Through communication networks, subsystems can exchange information and work together. The advantage of distributed control is that the system has high reliability and strong expansibility, and can better adapt to the complex and changeable production environment. In practical application, we can adopt a mixed strategy of centralized control and distributed control, which can combine the advantages of the two control methods. Intelligent control algorithm can make the cooperative control of electromechanical system smarter. For example, the fuzzy control algorithm can deal with the uncertain and fuzzy information in the system and control flexibly according to the real-time state and empirical rules of the system; Neural network control algorithm has strong self-learning and self-adaptive ability, and can establish a nonlinear model of the system by learning a large number of data to realize precise control. Genetic algorithms can be used to optimize control parameters, simulate biological evolution process and find the best control strategy. Applying these intelligent control algorithms to the cooperative control of electromechanical system can improve the dynamic performance and robustness of the system and realize more efficient dynamic matching.

In the intelligent manufacturing system, there are often many electromechanical subsystems, such as multiple automatic production lines and robot workstations. It is the key to realize the overall dynamic matching to make these multiple systems cooperate and optimize. Multi-system collaborative optimization should consider the relationship and influence between subsystems, establish unified optimization objectives and constraints, and then use optimization algorithms to coordinate and adjust the operating parameters of each subsystem. For example, in production scheduling, it is necessary to comprehensively consider the production capacity, order demand, equipment status and other factors of each production line, reasonably

arrange production tasks, realize collaborative production of multiple production lines, and improve the efficiency and energy efficiency of the whole production system.

4. Ways to Improve the Energy Efficiency of Electromechanical System in intelligent manufacturing

4.1 Energy Management Level

Establishing a perfect energy monitoring system is the basis for improving the energy efficiency of electromechanical systems. By installing energy monitoring instruments at the energy supply stage and equipment end, energy consumption data such as electricity, water and gas can be collected in real time. Use data analysis technology to deeply analyze the collected energy data, understand the distribution and trend of energy consumption, and find out the key energy-consuming links and high-energy-consuming equipment. For example, analyzing the energy consumption data of production equipment can find the phenomenon of energy waste under some working conditions, which provides a basis for further energy optimization.

According to the results of energy monitoring and analysis, the energy optimal dispatching strategy is implemented. Arrange the production plan and equipment operation time reasonably, avoid the equipment running in low load or no-load state, and reduce invalid energy consumption. For example, the peak-to-valley electricity price strategy is adopted to arrange the operation time of high-energy-consuming equipment in the period of low electricity price to reduce energy costs. At the same time, by optimizing energy distribution, according to the energy demand and priority of different equipment, energy resources are reasonably allocated to ensure efficient use of energy.

During the operation of mechanical-electrical systems, there are a large amount of recoverable energy such as waste heat and pressure. By adopting energy recovery technologies, such as waste heat recovery devices and pressure power generation equipment, these recoverable energies can be recovered and reused, improving the efficiency of energy utilization. For example, in the industrial boiler system, waste heat recovery devices can be installed to recover the waste heat in the boiler exhaust gas, which can be used to heat the boiler feed water or preheat

the air, thus reducing energy consumption.

4.2 Equipment Optimization Level

In the early stage of intelligent manufacturing system construction, reasonable selection and configuration of electromechanical equipment is an important link to improve energy efficiency. Select energy-saving and stable equipment according to production requirements and process characteristics. At the same time, the matching and coordination of equipment should be considered to avoid energy transmission loss and compatibility problems between equipment. For example, when choosing a motor, we should choose the appropriate power and speed according to the load characteristics to avoid the phenomenon of "big horse-drawn car", thus reducing the energy consumption of the motor.

Regular maintenance and maintenance of mechanical and electrical equipment to ensure that they are in good working condition can reduce equipment energy consumption and prolong equipment life. Make equipment maintenance plan, and carry out maintenance work such as cleaning, lubrication and fastening according to the specified time and standard, so as to find and eliminate hidden trouble of equipment in time. For example, regularly check and replace contactors, relays and other components in electrical equipment to avoid poor contact due to aging of components and reduce power consumption.

With the continuous progress of technology, upgrading old mechanical and electrical equipment in time and adopting advanced energy-saving technologies and equipment can greatly improve the energy efficiency of equipment. For example, replacing the traditional AC motor with an efficient and energy-saving permanent magnet synchronous motor can reduce the energy consumption of the motor; The old production line is automatically reformed, and the intelligent control system is adopted to optimize the production process and reduce energy waste.

4.3 Process Improvement Level

Optimizing production process is an important method to improve the energy efficiency of electromechanical system. By adopting advanced process technologies and methods, energy consumption and material waste in the production process are reduced.

For example, in mechanical processing

technology, adopting high-speed cutting technology can improve processing efficiency, reduce cutting force and cutting heat, and reduce energy consumption and tool wear; in welding technology, adopting laser welding technology has advantages such as high energy density, fast welding speed, and small heat affected zone, which can reduce energy consumption and improve welding quality. Optimizing the production process and reasonably arranging the production process and logistics route can reduce the waiting time and transportation distance in production and reduce energy consumption. Adopting the concept of lean production and eliminating waste links in the production process, such as overproduction, overstock and unnecessary handling, can improve production efficiency and energy utilization level. For example, using the unitized production mode to integrate multiple processes into one production unit can reduce material handling and intermediate links, which can not only improve production efficiency, but also reduce energy consumption. Actively promoting green manufacturing technology and using environmentally friendly raw materials and energy can reduce pollutant emissions and energy consumption in the production process. For example, in the surface treatment, using green processes such as chromium-free passivation and water-based coatings can reduce environmental pollution; In terms of energy supply, the use of renewable energy such as solar energy and wind energy can reduce dependence on traditional fossil energy and realize green production.

5. Conclusion

The dynamic matching mechanism of electromechanical system and the path of improving energy efficiency in intelligent manufacturing are the key factors to promote the high-quality development of manufacturing industry. By constructing an integrated system architecture, realizing smooth data interaction and adopting collaborative control strategy, the dynamic matching of electromechanical system can be realized, thus improving production efficiency, product quality and system flexibility. Improving energy efficiency from energy management, equipment optimization and process improvement can effectively reduce the energy consumption of electromechanical system and realize green production. In the future,

with the continuous progress of science and technology, the dynamic matching mechanism of electromechanical system in intelligent manufacturing will become more refined, and the paths of improving energy efficiency will be more diverse, which will provide strong support for the sustainable development of manufacturing industry. At the same time, enterprises should strengthen the research and application of intelligent manufacturing technology, cultivate high-quality talents, actively promote the dynamic matching of electromechanical systems and improve energy efficiency, and enhance their competitiveness in the global market.

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