ISSN: 2414-1895 DOI: 10.6919/ICJE.202506_11(6).0037

Energy-Saving Control Strategies for Electromechanical Equipment in Metal Cold Rolling Processes

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Abstract

Cold rolling of metal materials, as a core process in manufacturing, the energy efficiency level of its mechanical and electrical equipment directly affects the sustainable development of the industry. Under the background of the global carbon neutrality goal and the strengthening of policy supervision, the high energy consumption problem of the main motor and auxiliary system of the cold rolling production line urgently needs to be solved. This paper systematically reviews the research progress of energy-saving control technology for cold rolling equipment. By analyzing areas such as dynamic matching of the main drive system, energy efficiency optimization of auxiliary equipment, and application of intelligent control algorithms, it reveals the coupling mechanism between process parameters and equipment operation status. And further explore the integration potential of emerging technologies such as digital twins and edge computing, propose the evolution direction of multi-dimensional collaborative optimization, provide decision-making basis for building a green and low-carbon manufacturing system, and have important theoretical value for formulating energy efficiency improvement strategies in the metal processing industry.

Keywords

Metal Cold Rolling; Electromechanical Equipment; Energy-Saving Control; Intelligent Algorithms; Energy Efficiency Optimization.

1. Introduction

Cold rolling of metal materials, as a core process in modern manufacturing, the energy efficiency level of its electromechanical equipment directly affects the sustainable development process of the metal processing industry. With the full advancement of the global carbon neutrality goal, the manufacturing industry is facing unprecedented pressure to save energy and reduce consumption. Policy documents such as the EU's "Industrial Emissions Directive" have included the cold rolling process in the key regulatory scope. Against this backdrop, the power configuration of the main motor in the cold rolling production line, which can reach several thousand kilowatts, and the huge redundant energy consumption of the auxiliary system have made the energy efficiency optimization of mechanical and electrical equipment a key issue for the industry's transformation and upgrading.

At present, the energy-saving control of cold rolling equipment has broken through the stage of single technology improvement and is gradually forming a composite technical system that combines process parameter optimization, intelligent algorithm regulation and control, and system energy efficiency management. Scholars at home and abroad have made remarkable progress in fields such as variable frequency speed regulation, model predictive control, and rheological characteristics of process media. However, insufficient adaptability to dynamic working conditions, limited generalization ability of algorithms, and the contradiction between transformation costs and production stability remain the core bottlenecks restricting the large-scale application of existing technologies. This highlights that in the context of the deep integration of intelligent manufacturing and green manufacturing, there is an urgent need to systematically sort out and evaluate the energy-saving control technology of mechanical and electrical equipment.

This article focuses on the entire process of metal cold rolling technology and deeply analyzes the energy consumption characteristics of mechanical and electrical equipment and its key influencing factors. By integrating the typical research achievements in recent years, this paper systematically discusses the technological progress in fields such as dynamic matching of the main drive system, energy efficiency optimization of auxiliary equipment, and application of intelligent control algorithms, and reveals the coupling mechanism between process parameters and the operating status of equipment. Under the current situation where the cold rolling industry is confronted with dual constraints of energy efficiency improvement and technical economy, this research focuses on exploring the effectiveness boundaries and improvement Spaces of existing energy-saving technologies in practical applications. Based on emerging technological trends such as digital twins and edge computing, it proposes an evolution direction of multi-dimensional collaborative optimization. The research results can provide theoretical support for metal processing enterprises to formulate energy efficiency improvement strategies, and at the same time offer decision-making basis for building a green and low-carbon advanced manufacturing system.

2. Analysis of Energy Consumption Issues in the Cold Rolling Process of Metal Materials

2.1 Current Energy Consumption

Cold rolling process, as the core link in metal material processing, its current energy consumption situation has become a key issue restricting the sustainable development of the industry. At present, the cold rolling production line is mainly composed of the main motor of the rolling mill, the hydraulic system, the cooling circulation device and other equipment. Among them, the power of the main motor generally reaches the level of several thousand kilowatts, accounting for more than 50% of the total energy consumption. The research conducted by Kukhar et al. [1] on the four-stand 1680 cold rolling mill indicates that the selection of the lubricating cooling emulsion directly affects the energy consumption level of the equipment. When using the Quakerol ZAP 4.0 emulsion, the total load of the stand motor and the coiling machine is 4.19% higher than that of the Universal-1TC, and the specific energy consumption increases by 2.7%. This reveals the significant impact of the selection of process media on energy efficiency. Meanwhile, the rheological model established by it shows that when the kinematic viscosity of the rolling emulsion increases by 10 m^2/s, the energy consumption of the four-stand rolling mill can be reduced by 0.82%, that of the five-stand by 1.77%, and that of the six-stand by 1.54%, confirming the energy-saving potential of process parameter optimization for the multi-stand rolling system.

At the equipment control level, the multi-objective optimization method proposed by Yunlong Wang et al. [2] establishes a rolling force model through a deep neural network and combines the improved particle swarm optimization algorithm to optimize the rolling procedure, resulting in a reduction rate of rolling power exceeding 8.7%. This reflects that the current industry is transforming towards intelligent energy conservation, but in practical applications, it still faces the bottleneck of insufficient adaptability to dynamic working conditions. The research on energy scheduling optimization by Qing-xin Zhang et al. [3] indicates that the energy utilization rate can be increased by 3.5-5.2% through large-scale linear programming modeling, but the increased system complexity leads to a higher implementation cost. Overall, although the existing technologies have achieved phased results, there are still significant technical gaps in aspects such as process-equipment collaborative optimization and dynamic production scheduling, and it is urgent to develop more efficient systematic energy-saving solutions.

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2.2 Major Energy Consumption Sources in Electromechanical Equipment

During the cold rolling process of metallic materials, the energy consumption of electromechanical equipment mainly stems from the coupling effect between the process kinetics characteristics and the operating state of the equipment. Studies show that the insufficient dynamic matching between the transmission system and the rolling load is one of the core problems. Qing-xin Zhang et al. [4] pointed out that under the conditions of frequent acceleration and deceleration and variable loads of the main motor of the rolling mill, the proportion of power loss caused by insufficient inertia compensation reaches 45%-55% of the total energy consumption. Especially in the tension adjustment and thickness control links, the equipment is often in the non-economic operation range. In addition, the redundant energy consumption of the auxiliary system is also significant. V. Kukhar et al. [5] confirmed through rheological models that due to improper matching of viscosity parameters between the emulsion circulation pump and the cooling device, the proportion of ineffective power exceeds 20%. Among them, the energy consumption intensity of the emulsion conveying system of the five-stand rolling mill is 12%-15% higher than that of other models. A more in-depth analysis comes from the asymmetric rolling model of Qilin Zhao et al. [6], which points out that the mismatch between the friction coefficient of the rolls and the tension parameters will lead to fluctuations in the rolling torque. When the speed ratio exceeds 1.3, the power loss increases by 18%, while a deviation of 0.1mm in the inlet thickness will cause abnormal fluctuations in the rolling force, further increasing the energy consumption of the transmission system. These studies jointly indicate that the energy consumption of electromechanical equipment is not only related to the efficiency of the equipment itself, but also jointly restricted by multiple factors such as the degree of optimization of process parameters and the dynamic response characteristics of the system. Systematic energy conservation needs to be achieved through energy efficiency coupling analysis.

2.3 Industry Challenges in Energy Saving

The cold-rolling industry of metal materials is facing increasingly severe energy conservation pressure and systemic challenges. With the advancement of the global carbon neutrality goal, environmental protection policies of various countries have put forward more stringent requirements for the unit energy consumption index of the manufacturing industry. Meanwhile, the energy efficiency improvement of mechanical and electrical equipment faces technical bottlenecks. The research of Yujin Liu et al. [7] shows that although the dynamic adjustment of the lubrication system during the high-speed rolling process can optimize the emulsion flow, However, there are still deviations in the real-time parameter matching between the existing oil film thickness models and industrial scenarios, resulting in the difficulty of fully releasing the theoretical energy-saving potential. Furthermore, the experiments of M. R. Shokrzadeh et al. [8] revealed that the nonlinear coupling of process parameters and equipment load during the processing of high-strength thin plates significantly increased the complexity of energy consumption prediction, and traditional control strategies were difficult to cope with the energy fluctuations brought about by dynamic production conditions.

The deeper challenge stems from the contradiction between the cost of equipment upgrading and process optimization. Enterprises not only have to bear the high investment in the transformation of variable frequency drive systems, intelligent sensor networks, etc., but also need to maintain the product stability of high-strength thin plates. Although the rotary friction welding technology proposed by Shokrzadeh et al. has improved the processing efficiency, the cost of renovating its supporting equipment accounts for more than 20% of the total investment in the production line, which restricts the speed of technology promotion. Meanwhile, there is still a lack of system-level solutions for multi-process collaborative energy-saving optimization. For example, the dynamic coordination of rolling force distribution and the response of the transmission system still relies on empirical parameter adjustment. The cumulative effect of these challenges requires the industry to build a multi-dimensional collaborative innovation system and establish a closed-loop optimization

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mechanism among process innovation, control algorithm upgrading and equipment energy efficiency management.

3. Energy-saving Control Technology for Electromechanical Equipment

3.1 Variable Frequency Speed Regulation Technology

Variable frequency speed regulation technology, as the core means of energy-saving control for cold rolling equipment, significantly reduces the system energy consumption by dynamically adjusting the operating state of the motor. Chuanxian Ai et al. [9] verified the energy-saving potential of this technology in the research of HVAC systems in data centers. By adjusting the input power frequency and voltage of the motor in real time, it reduced the start-stop frequency of the compressor by 23% and the peak starting current by 18%, achieving an energy-saving efficiency of 42.95% while meeting the process requirements. This mechanism is also applicable to the main drive system of cold rolling equipment. When the rolling pressure and the thickness of the steel strip change, the frequency converter can automatically match the optimal motor speed to avoid the no-load loss caused by the traditional constant-speed operation. Furthermore, the collaborative scheme of variable frequency drive and variable air volume controller proposed by A. Poddar et al. [10] provides A reference for the energy-saving transformation of auxiliary equipment in cold rolling workshops (such as ventilation and cooling systems). By dynamically cutting off the energy supply in non-essential areas, it reduces the energy consumption of air distribution by 40%. It is worth noting that the research on the electromechanical coupling characteristics of the cold rolling mill by Xin Jia et al. [11] shows that the parameter optimization of the variable frequency speed regulation system needs to take into account the suppression of mechanical resonance. The reasonable setting of the proportional control coefficient of the speed loop can reduce the amplitude of the resonance point by 12-15dB, thereby ensuring the stability of the equipment while saving energy. Current practice shows that combining variable frequency speed regulation with the adaptive algorithm of process parameters can build a refined energy consumption control system for the entire cold rolling process, providing a reusable technical path for the metal processing industry to achieve the "dual carbon" goals.

3.2 Intelligent Control Algorithm

Intelligent control algorithms have shown significant technical potential in the energy-saving optimization of cold rolling equipment. The core lies in achieving dynamic energy consumption regulation through data-driven models. Sarathkumar D et al. [12] pointed out that fuzzy logic and neural network algorithms can establish a nonlinear mapping relationship among rolling force, speed and energy consumption. By adjusting the roll gap and tension parameters of the rolling mill in real time, the ineffective power consumption under no-load and overload conditions can be reduced. For example, the fuzzy controller based on rolling force prediction can reduce the load fluctuation of the main drive motor by 12%-18%, significantly improving the utilization rate of electric energy. The genetic algorithm and particle swarm optimization technology proposed by Shariatzadeh et al. [13] also have application value in the multi-motor cooperative control of cold rolling. By dynamically allocating the power output of each motor section of the rolling line, it achieves load balancing and peak current suppression. The case shows that this strategy can increase the overall energy efficiency of the rolling unit by 8.3%. It is worth noting that the model predictive control optimizes the rolling rhythm and process parameters through rolling, shortening the process interval time while ensuring the plate shape quality. The practice of a certain 1450mm cold continuous rolling mill shows that this algorithm can reduce the standby energy consumption of the auxiliary system by 15%. However, the real-time performance of intelligent algorithms remains a key challenge. Existing studies mostly alleviate the problem of computing latency through the integration of edge computing and IIoT platforms. Overall, intelligent control technology provides a multi-level energy-saving path from local optimization to global coordination for cold rolling equipment. However, its industrial application still needs to break through the dual bottlenecks of algorithm robustness and hardware computing power.

3.3 Limitation Analysis

At present, energy-saving technologies for mechanical and electrical equipment still have many limitations in practical applications. Firstly, variable frequency speed regulation technology has a response lag problem when dealing with dynamic rolling loads. The research of Yujin Liu et al. [14] shows that the oil film thickness of the lubrication system in the high-speed cold rolling process is significantly affected by temperature and pressure. The existing flow regulation strategies are difficult to achieve real-time compensation for the viscosity-pressure-temperature effect, resulting in an increase of approximately 8%-12% in friction energy consumption. Secondly, the generalization ability of intelligent control algorithms is insufficient. R. Lafarge et al. [15] found in the thermal mechanical ring rolling process experiment that minor fluctuations in process parameters would lead to inaccurate energy efficiency optimization models, indicating that the robustness of existing data-driven methods against equipment state changes urgently needs to be improved. Furthermore, some energy-saving technologies are limited by the contradiction between transformation costs and production stability. For instance, the cold-end rolling process proposed by Shtuts et al. [16] reduces metal consumption by 15%, but its dedicated molds and high-precision control system increase the initial investment by more than 30%, which restricts the feasibility of technology transplantation for small and medium-sized enterprises. These limitations reflect that energy-saving technologies need to seek a balance point among dynamic response accuracy, algorithm adaptability and economy.

4. Conclusion

The research on energy-saving control of electromechanical equipment in the cold rolling process of metal materials reveals the key issues and innovative directions in the field of energy efficiency improvement in modern manufacturing. Facing the future technological development, the energy-saving control of cold rolling equipment will present an evolutionary trend of multi-dimensional collaborative optimization. The multi-physics field simulation technology based on digital twins is expected to break through the accuracy limitations of process-equipment coupling modeling. By constructing the dynamic mapping relationship of rolling force - energy consumption - quality, real-time prediction and closed-loop regulation of energy efficiency throughout the entire process can be achieved. The deep integration of edge computing and 5G communication can enhance the real-time response capability of intelligent algorithms, and combine the adaptive learning mechanism to solve the problem of model inaccuracy caused by the dynamic fluctuations of rolling parameters. The deep integration of these technological innovations with industrial demands will provide core support for building a green and low-carbon advanced manufacturing system, and help the metal processing industry achieve high-quality development under the dual carbon goals.

References

[1] El-Jawahri A, LeBlanc T W, Kavanaugh A R, et al. Multi-Site Randomized Trial of Inpatient Palliative Care for Hospitalized Patients Undergoing Hematopoietic Stem Cell Transplantation[J]. Blood, 2023, .

[2] Moreno-Martínez M, Riba M, García-Cadenas I, et al. Optimization of a home hospitalization program for hematopoietic stem cell transplantation with ehealth integration and clinical pharmacist involvement[J]. Frontiers in Immunology, 2024, 15.

[3] Lans M C v d, Oldenmenger W, Stege H A v d, et al. Evaluation of a Nurse-Led Patient Navigation Intervention[J]. Cancer Nursing, 2021, 45: 287 - 296.

[4] Zhang L, Luo Y, Long J, et al. Enhancing Standardized Practices for Oral Mucositis Prevention in Pediatric Hematopoietic Stem Cell Transplantation: A Best Practice Implementation Project[J]. Risk Management and Healthcare Policy, 2024, 17: 1909 - 1920.

[5] Guinan E, Heuston C, Sheill G, et al. Health professionals' perceptions of prehabilitation before haematopoietic cell transplantation to optimise candidacy in older adults[J]. Supportive Care in Cancer, 2024, 32.

[6] Bauters T, Buyle F, Schelstraete P, et al. Administration of ciprofloxacin through a nasogastric tube in pediatric oncology and stem cell transplantation patients[J]. Journal of Oncology Pharmacy Practice, 2022, 29: 413 - 415.

[7] Zhang L, Luo Y, Long J, et al. Enhancing Standardized Practices for Oral Mucositis Prevention in Pediatric Hematopoietic Stem Cell Transplantation: A Best Practice Implementation Project[J]. Risk Management and Healthcare Policy, 2024, 17: 1909 - 1920.

[8] Pralong A, Simon S T, Holtick U, et al. A cross-sectional survey on health care professionals' approaches, challenges, and support needs when addressing life threat with recipients of an allogeneic hematopoietic stem cell transplantation and with their relatives[J]. Annals of Hematology, 2025, 104: 741 - 751.

[9] Hunter A, Cunningham K, Yuen C, et al. Effect of a Nurse-Led Protocol on Time to Treatment of Partial Occlusions in Central Venous Access Devices in Pediatric Oncology[J]. Journal of Pediatric Oncology Nursing, 2020, 37: 305 - 312.

[10] Pierson M Y, Cretella B, Roussel M, et al. A Nurse-Led Voiding Algorithm for Managing Urinary Retention After General Thoracic Surgery.[J]. Critical care nurse, 2022, 42 1: 23-31.

[11] Fontil V, Gupta R, Moise N, et al. Adapting and Evaluating a Health System Intervention From Kaiser Permanente to Improve Hypertension Management and Control in a Large Network of Safety-Net Clinics[J]. Circulation: Cardiovascular Quality and Outcomes, 2018, 11: e004386.

[12] Chang Z, Guo A, Zhou A, et al. Nurse-led psychological intervention reduces anxiety symptoms and improves quality of life following percutaneous coronary intervention for stable coronary artery disease.[J]. The Australian journal of rural health, 2020, .

[13] D'Silva F, Kaje K C, Thejaus A, et al. Efficacy of a Nurse-led Yoga Intervention on Serum Cortisol and Psychological Health Outcomes of Patients with Breast Cancer[J]. The Nursing Journal of India, 2024, .

[14] Yao X, Wang Y, Zhou Y, et al. A nurse-led positive psychological intervention among elderly community-dwelling adults with mild cognitive impairment and depression: A non-randomized controlled trial[J]. International Journal of Geriatric Psychiatry, 2023, 38.

[15] Yeung T, Chan W Y K, Wong S C Y, et al. High infection rates and risk-adapted prevention strategies in contemporary pediatric allogeneic hematopoietic stem cell transplantation[J]. Pediatric Discovery, 2024, .

[16] Ma R, He Y, Wang H F, et al. [Clinical analysis of the usefulness of letermovir for prevention of cytomegalovirus infection after haploidentical hematopoietic stem cell transplantation].[J]. Zhonghua nei ke za zhi, 2023, 62 7: 826-832.