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Estimating Reheating Time for Steelmaking Ladles Using Optimization-Based Machine Learning Approach Integrated with a Physical Thermal Model

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Controlling molten steel temperature is pivotal in steelmaking as it influences energy efficiency, process performance, and product quality. Among the factors affecting molten steel temperature, steel ladles, massive refractory-lined vessels used to transport and refine molten steel from the tapping station to the continuous caster, play a crucial role. Ensuring the molten steel reaches the continuous caster at the proper temperature requires control of the tapping temperature, which is affected by the ladle's thermal state. When a ladle cools due to a prolonged waiting period before tapping, it can decrease the steel's temperature more than desired. Reheating the ladle helps prevent this temperature drop and reduces the need for a higher initial steel temperature. It also protects the refractory lining from thermal shock. However, determining the optimal heating time is complex as it depends on multiple factors influencing steel temperature and a range of process parameters. This study proposes an optimization-based machine learning approach to estimate the required heating time to achieve the target temperature for continuous casting. The algorithm operates within an environment integrated with a physical thermal model that simulates the steel temperature throughout the process. An agent adjusts heating times based on process variables, such as ladle empty time before tapping and initial refractory temperature to minimize the deviation from the target temperature. Through repeated adjustments, the agent learns to determine the minimum reheating time to ensure the molten steel arrives at the caster in an acceptable temperature range. By accurately estimating the minimum heating time, this hybrid framework adapts to different steelmaking scenarios, reducing excess energy use and minimizing the need for unnecessarily high tapping temperatures. This approach can enhance thermal management efficiency, dropping production costs and improving steel quality. It also helps reduce CO2 emissions, contributing to a more sustainable industry.

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