

Modeling, parameter estimation, and optimization of continuous annealing furnaces in strip rolling lines

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Für meine Familie
Debora,
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Cologne, October 2016
Sebastian Zareba

Kurzfassung

Für die Optimierung der Reglerperformance benötigt die Prozessindustrie zuverlässige und geeignete Methoden und Verfahren. Für gewöhnlich ist die Durchführung von Versuchen an einer realen Anlage im Betrieb nicht erlaubt und die Möglichkeit, neue Methoden zu testen, nur begrenzt verfügbar. Um dem zu begegnen, ist ein Framework zur Modellierung, Parameterschätzung und Optimierung der Reglerperformance von industriellen Prozessanlagen entwickelt worden, welches nun in dieser Arbeit vorgestellt wird. Das Framework wird am Beispiel einer kontinuierlichen Durchlaufglühe durchlaufen, wo einzelne Einflussfaktoren untersucht und verbessert werden.

Zu diesem Zweck wird ein neues und umfassendes mathematische Modell einer kontinuierlichen Durchlaufglühe hergeleitet. Es basiert auf den thermodynamischen Grundgleichungen und berücksichtigt alle relevanten Effekte und Zusammenhänge der drei am Prozess teilnehmenden Medien bestehend aus der Ofenisolierung, des im Ofen befindlichen (Ab-)Gases, sowie des im Ofen transportierten Stahlbandes. Ebenso werden die thermische Strahlung und Konvektion, wie auch verschiedene temperaturabhängige Parameter berücksichtigt.

Anschließend wird, basierend auf dem hergeleiteten Modell, die Fragestellung der Parameterschätzung umfassend untersucht. Aufgrund der geringen Konvergenzgeschwindigkeit vorhandener Schätzverfahren wird ein neu entwickeltes sequentielles Parameterschätzverfahren (SPEA) vorgestellt. Es verwendet Methoden zur strukturellen und praktischen (numerischen) Analyse der Identifizierbarkeit, um zu ermitteln, ob ein Parameter anhand des vorhandenen Messdatensatzes identifizierbar ist. Des Weiteren wird eine Klassifikation in Effektgruppen vorgestellt, sodass lediglich nur ein Parametersatz geschätzt wird. Abschließend werden Zwischenergebnisse des SPEA sowie die Ergebnisse der Validierung des Ofenmodells gezeigt.

Die Verbesserung der Produktqualität, der Anlagenproduktivität sowie des Energieverbrauchs bedeutet in erster Linie die Verbesserung der Reglerperformance. Der in der Prozessindustrie am meisten verwendete Regler hat die PID-Struktur, wo mehrere hundert in einer Anlage installiert sein können, von denen viele nicht optimal eingestellt sind. Eine kontinuierliche Optimierung der Reglerperformance ist für eine langfristige optimale Performance von entscheidender Bedeutung. Allerdings ist dies nicht nur zeitaufwändig, sondern aufgrund des Einsatzes von Fachkräften auch teuer. In dieser Arbeit wird eine auf dem Relative Damping Index (RDI) basierende iterative Regler-tuningmethode vorgestellt, welche nur Messdaten aus dem laufenden Betrieb benötigt, um die Reglerperformance der kontinuierlichen Durchlaufglühe zu verbessern. Der Einsatz von Personal ist, wenn gewünscht, nicht erforderlich. Abschließend werden die Ergebnisse eines verbesserten Verfahrens zur Reglereinstellung unter Berücksichtigung des momentanen Regelungsverhaltens präsentiert.

Abstract

The process industry needs robust and suitable methods for control performance optimization. Normally, the execution of experiments at the real plant at operational mode are not allowed and the possibility to test a new optimization method is limited. Therefore, a framework for modeling, parameter estimation, and control-performance optimization for industrial processes is proposed. The framework is applied to a continuous strip annealing furnace to investigate and improve single aspects.

For this purpose, a comprehensive derivation of a mathematical model of a continuous strip annealing furnace is performed. It is derived from thermodynamical fundamentals considering all relevant effects and relationships for the three different interacting media, the furnace insulation, the inner flue gas and the moving strip inside the furnace. The radiative and the convective heat transfer inside the furnace, as well as various temperature depending material parameters are considered.

Based on the derived model, the task of parameter estimation is examined subsequently in detail. Due to the low convergence of existing estimation techniques, a new sequential parameter estimation approach (SPEA) is developed and presented. It uses methods of structural and practical identifiability analysis to determine if a parameter is identifiable from the given measurement data. Furthermore, a classification into effect groups and estimation of only one of the parameter subsets is introduced. The intermediate results of the SPEA, as well as the validation results of the furnace model are shown.

Improving the product quality, plant productivity, and energy consumption also means improving the control performance. The dominantly implemented controller in the process industry is of PID type, where hundreds of control loops may be utilized in one plant and most of them are not optimally tuned. A continuous control performance optimization is crucial to attain maximum performance over time, but is very time extensive and costly if carried out by human experts. In this thesis, a relative damping index-based iterative tuning method using normal operating data is demonstrated to improve the control performance of a continuous strip annealing furnace. Human intervention is, if not wished, not necessary. An improved variation strategy considering the actual control behavior is introduced and the results are shown.

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