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A neuro-fuzzy system for looper tension control in rolling mills

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Abstract

A looper tension control system is common to many rolling processes. Conventional tension controllers for mill actuation systems are based on a rolling model. They therefore cannot deal effectively with unmodeled dynamics and large parameter variations that can lead to scrap runs and machinery damage. In this paper, this problem is tackled by designing a fuzzy controller that possesses different tuning schemes for both off-line and on-line tuning of fuzzy control elements. It is shown that the proposed methods outperform conventional control techniques. Finally, the effects of various design options are discussed and some practical remarks are made.

Keywords: Fuzzy control; Self-tuning control; Tension control; Rolling; Neural networks; Automatic process control (closed loop); Steel industry

1. Introduction

Looper control techniques are common to strip tension control of flexible cross-sections at many intermediate and finishing submills. For this purpose loopers are installed between rolling stands (Fig. 1). Employing deflectors and proper motor speed adjustments, a bar loop is formed between a couple of stands and loop height serves as a tension indicator. The height of a loop (H) is measured and compared with a reference height (H_0, indicating zero tension) to obtain a correction command for motor speed control. By adjusting motor speed ratios, a constant loop height is maintained and a constant tension state is achieved. Improper speed adjustments result in *push* or *pull* conditions that might lead to scrap runs, strip breakage, and machinery damage.

Several factors make looper control design challenging. These include significant parameter variations and disturbances caused, for example, by low-temperature heating of slabs, roll eccentricity, wear, thermal expansion, bearing oil film thickness, mill chatter, and speed control (Seki et al., 1997; Janabi-Sharifi & Fan, 2000b). Further examples of potential disturbances may be found in the works of Imanari et al. (1997) and Seki et al. (1997). Owing to their simplicity, conventional control techniques (e.g., PD and PID control laws) are common control methods (Neilson & Koebe, 1983). However, conventional controllers are noninteractive and cannot compensate for parameter variations and resonance within a looper system. Several other control methods have also been proposed. These include optimal multivariable control (Seki et al., 1997; Ringwood, 2000), active disturbance rejection control (Boulter, Hou, Gao, & Jiang, 2001), inverse quadratic control (Anbe, Sekiguchi, & Imnari, 1996), and H_∞ control (Hearns, Katebi, & Grimble, 1996) techniques. Again, lack of intelligence, learning, and adaptation capability in such control methods requires continuous expert (human) intervention for speed regulations. The difficulty of this nonlinear control problem is underscored by the fact that, in existing mills, manual control actions continue to be necessary. This need coupled with an increasing demand for high-precision rolling means that the development of a robust and adaptive looper control remains an important rolling control problem.

Alternatively, fuzzy logic control (FLC) provides a systematic method of incorporating human expertise and implementing nonlinear algorithms. To the author's best knowledge, this paper presents the first comprehensive application of an intelligent controller to the tension control problem in rolling mills using looper height comparison. Some applications of fuzzy logic for

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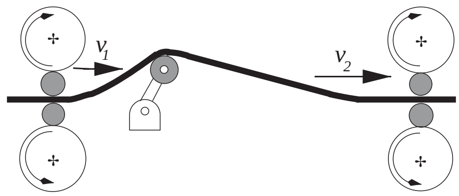

Fig. 1. A rolling mill with looper control.

modeling and thickness control in rolling mills do exist (Jung & Im, 1999, 2000). However, the methods introduced in those papers are fundamentally different than the present approach. First, Jung and Im's approach involved thickness control using AGC and provided the prediction of tension variations for specific thickness maintenance. This is different than purely tension control. Second, their method was not based on height measurements. Third, they incorporated some empirical modeling and their results relied on those models. The incorporation of empirical equation and reliance on finite element simulations using a set of mill data made their modeling very specific to the particular plant and rolling conditions they studied. Even under those limiting conditions, roll radius, speed, and friction coefficient were assumed to be constant. The authors included only input thickness and carbon equivalent as control variables despite the absence of 100% correlation for these parameters. As Jung and Im concluded, other processing parameters must be considered. Given all these limitations, their tension prediction scheme is not reliable, even for general thickness control.

The motivations for the development and application of FLC for tension control included the following reasons (Janabi-Sharifi & Fan, 2000b). (1) In contrast to FLC, conventional noninteractive controllers fail to meet high precision and disturbance robustness requirements, mainly due to the presence of large disturbances. (2) In rolling mill applications, no accurate mathematical model of a system under control is available. Conventional nonadaptive control methods require an exact mathematical model of a system, while most adaptive control techniques deal only with linear systems. FLC does not require a formal model of the system. (3) In contrast to the conventional control methods, FLC can incorporate linguistic fuzzy descriptions (knowledge) about a system by interviewing a mill operator. Since considerable human knowledge is available in rolling mills and could be represented in linguistic terms, systematically integrating it into controllers is important. (4) Recently, some researchers have proposed using artificial neural networks as building blocks of adaptive controllers for unknown nonlinear systems (Miller, Sutton, & Werbos, 1990; Jansen, Broese, Feldkeller, & Poppe, 1999). However, such systems cannot incorporate linguistic rules or system descriptions into controllers and, moreover, training of neural nets and their convergence might be problematic. In certain cases, other difficulties must also be addressed; e.g., adjusting learning rate and momentum for the net and designing an appropriate net topology. (5) Finally, FLC, if simplified, offers low development costs and high-speed implementation.

Despite its advantages, there are obstacles to the design and tuning of FLC. For instance, redundant or insufficient rules might be specified. Also, translation into fuzzy set theory has not yet been formalized and arbitrary choices regarding the shape of membership functions or aggregation operators might be made. Without a self-tuning mechanism, FLC's performance may be unsatisfactory if a system's parameters vary too much (Kruse, Gebhardt, & Klaonn, 1994). Involving multiple tunings (e.g., membership functions, rules, operators, and gains) makes optimum tuning more difficult. One problem with fixed sets of fuzzy parameters is that once they have been determined, they will neither change nor adapt to different operating conditions. Many researchers, such as Jang (1992) and Nomura, Hayashi, and Wakami (1989), have therefore attempted to improve the performance of self-organizing mechanisms and to establish a more systematic method of designing and tuning fuzzy controllers. However, those approaches are unable to be sufficiently generalized and the acquired knowledge cannot be entirely expressed. Furthermore, our experiments indicated lengthy training requirements for those approaches.

This paper contributes by presenting a detailed description of FLC design for looper control. Furthermore, it addresses FLC tuning by incorporating self-tuning algorithms for membership function, rule-base, and aggregation (T) operator. The consideration of both off-line and on-line learning contributes to a rapidly tunable FLC framework for looper control in rolling mills. This paper also compares the performance of the proposed controllers with conventional controllers and with untuned FLC. Finally, different design issues are discussed and practical conclusions derived from the analysis.

The structure of the paper is as follows. Section 2 presents the system model, and then Section 3 describes the FLC system. Tuning algorithms for membership functions, rule-base, and T-operator are explained in Section 4. The simulation results and discussion are given in Section 5, and concluding remarks are presented in Section 6.

2. System model

Although the proposed FLC system is almost model free, an approximate model is required to serve as a