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EXECUTIVE SUMMARY OF THE THESIS

Control and Simulation of Steel Strips in Galvanization Lines

LAUREA MAGISTRALE IN 473 ENGINEERING - INGEGNERIA DELL'AUTOMAZIONE

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1. Introduction

In this thesis the clear objective is to implement a control for a galvanization line to maintain a steel strip in the coating segment as steady as possible. In this specific segment, the steel strip is anchored at two distant extremities and exposed to various sources of transverse disturbances, both known and unknown. While known vibrations have been addressed in previous industry works, we tackle the unknown vibrations. We study their effects using a Frequency Response Function (FRF) approach, validated through experimental data.

We construct a one-dimensional Finite Element Model (FEM) of the system for simulation, aiding in the design of new galvanization lines. This method facilitates the easy derivation of the receptance FRF from any position to any position on the system for planar strips of varying materials and dimensions.

A control scheme is implemented to mitigate vibrations in the steel strip at specific natural frequencies, while preserving stability in other frequency ranges. The control scheme is designed to leave the natural frequencies of the steel strip unaffected, altering only the damping ratio. The control scheme is integrated into Simulink, and the obtained results are presented. Furthermore, the control scheme is tested in a simulation scenario where the system is disturbed by a chirp signal to stimulate all possible frequencies, and the results are also presented.

2. Chapters

2.1. Galvanization Line

In this chapter, we offer a concise overview of the continuous hot-dip galvanization process for steel strips, with a particular emphasis on the coating segment. This phase necessitates subjecting the steel strip to high longitudinal loads to maintain its longitudinal position and exposes it to a varied range of vibrations transversely, encompassing both known and unknown sources. Additionally, we delve into previous research conducted in the coating segment of the process. It is crucial to note that, for simplification, we make the significant approximation of considering the strip as static rather than dynamic, as it is in reality.

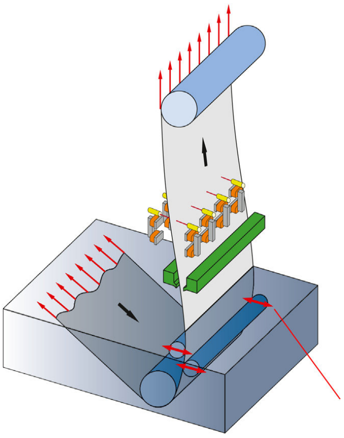

Figure 1: Coating Segment of the Galvanization Line [4]

2.2. Vibrations

In this chapter, we delve into the fundamental theory of vibrations and its various representations. The steel strip in the coating segment is influenced by various sources of interferences. We introduce three modes of vibration [2] and specifically focus on the string mode to develop a one-dimensional model. Subsequently, we elucidate the process of obtaining the $\overline{M}$, $\overline{C}$, and $\overline{K}$ matrices for the one-dimensional FEM, acknowledging certain limitations in length.

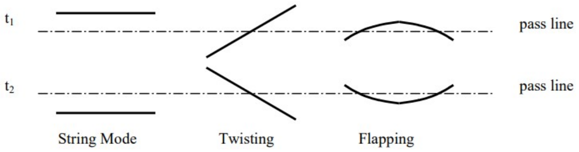

Figure 2: Three Modes of Vibration [2]

2.3. Frequency Response Function

In this chapter, we elaborate on the different actuators (air knife and electromagnets) and sensors (inductive sensors) integrated into the system. We justify our decision to exclude the magnetic circuit of the electromagnets in the final transfer function, considering its relative speed to mechanical reactions and nonlinearity. Additionally, we provide an overview of the fundamentals of a FEM and detail the excitation signal employed for the vibrational analysis.

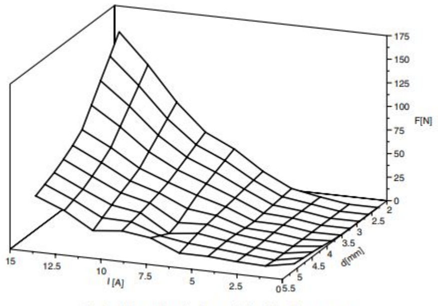

Figure 3: Attractive Magnetic Force in function of the air gap distance and current in magnetic circuit [3]

2.4. Finite Element Model

In this chapter, our aim is to deduce the natural frequencies of the steel strip by analyzing the impulse response of the real system. We then compare the theoretical model to the experimental data, assessing the quality of the match and elucidating any disparities. Additionally, we explore the simulation of this model using a state space representation.

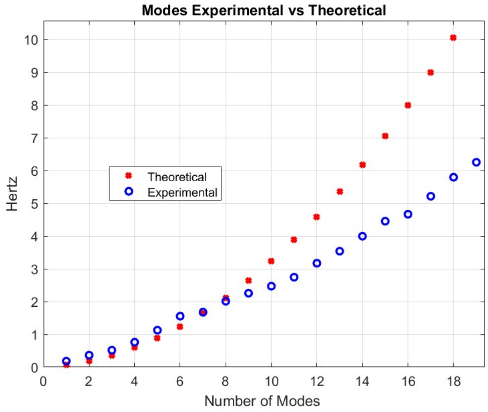

Figure 4: Theoretical vs Experimental

2.5. Control Scheme

We present two transfer functions for the system, one for the air knife and one for the electromagnets. We sum the effects to determine the final position of the steel strip. In this chapter, we elucidate the concept of control using a pole placement technique sourced from [1]. The control scheme is designed to leave the natural frequencies of the steel strip unaffected, altering only the damping ratio. We provide insights into the implementation of the control scheme in

Simulink and present the obtained results. Since the state variable involves the natural modes of vibration, which are not directly measurable, we use a Kalman observer to estimate the state variables. We determine sensitivity functions for the control scheme from different inputs to the output of the system. Additionally, we detail the application of the control scheme in a simulation scenario where the system is disturbed by a chirp signal to stimulate all possible frequencies. We observe the effects of the control scheme on the steel strip, by also considering also the sensitivity functions.

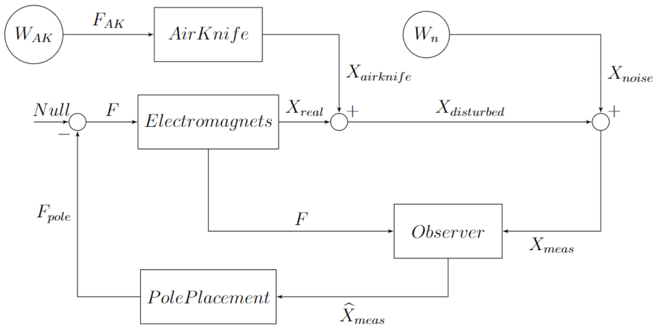

Figure 5: Control Scheme

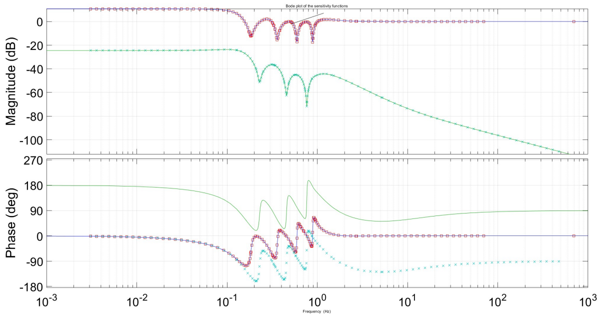

Figure 6: Control Scheme

- $S_{Measurement}$ is the sensitivity function of the system with the measurement noise as input.
- $S_{AirKnife}$ is the sensitivity function of the system with the air knife as input.
- $S_{Control}$ is the sensitivity function of the system with control signal as an input.

2.6. Chapter 6: Conclusions

In this research, the primary objective was to create a user-friendly tool for simulating and predicting the behavior of steel strips during the hot-dip process. A new mathematical model was developed to predict vibrations in the steel strip, and a control scheme using the pole placement algorithm effectively dampened vibrations at specific frequencies. Simulations demonstrated that the closed-loop system significantly reduced vibrations compared to an open-loop system, showcasing selective control capabilities based on the identified natural frequencies of the steel strip. Additionally, a novel approach using the FEM was introduced for modeling the FRF of the steel strip, validated with satisfactory results from industrial plant data.

2.7. Future Work

The future work in this research aims to enhance the model's accuracy by developing a two-dimensional FRF model that considers the width and thickness of the steel strip, accounting for additional modes of vibrations like twisting and flapping. This advanced model could leverage data from multiple sensors across the strip's width, providing a more comprehensive understanding of its dynamics. Another potential future direction involves the use of Virtual Reference Feedback Tuning to estimate nonlinear systems for steel strips, leveraging abundant data to predict the strip's upcoming position. This data-driven approach proves effective in accurately predicting nonlinear systems without relying on a complete mathematical model.
Additionally, a promising avenue for future research involves adopting a plug-and-play approach for simulating mechanical systems. The system developed by Professor Gianni Ferretti and Bruno Scaglioni, utilizing Modelica or Dymola with an acausal approach, allows easy modifications and setups without the need for extensive computations. This system is particularly adept at handling open-chain mechanical systems, providing a potential avenue for efficient simulation and analysis in the field of steel strip behavior.

References

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