CSD Labs Report
Control of a Rolling Mill

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Contents

Chapter 1

Introduction

1.1 Description of the plant

The goal of this project is to control the rolling of a metallic strip using a rolling mill. The plant is composed of two DC motor driven single rolls which unwind and wind up the sheet of metal. Between those two, the strip passes through a pair of rolls driven by a third DC motor, in order to have its thickness reduced and made uniform.

The actuators of the plant are the three DC motors, which are controlled through their armature current. The speed of those motors are measured using three velocity sensors. There are also two traction sensors to measure the tension in the strip left and right of the middle pair of rolls. Finally, a thickness sensor measures the thickness of the metallic strip after it has been rolled.

The first requirement is to control the traction of the metallic strip. When this is achieved, a more advanced requirement is to control the thickness of the metallic strip.

1.2 Broad design of the controller

The plant will be controlled using a numerical controller implemented in matlab. To set this up, eight ADC and two DAC ports are available, along with second order Butterworth filters with various τ and an analog computer.

Intuitively, we know that the traction of the strip between two rolls will probably mostly depend on the difference of speed between the rolls. Similarly, we also know that the thickness reduction at the middle pair of rolls will probably mostly depend on the difference between the traction of the strip that is fed into the pair of rolls and the traction of the sheet that is pulled out of it. Knowing this, we propose to control this process using a cascade controller.

First, we control the speed of the DC motors using the current as input. Then, we control the traction of the metallic strip using the speed of the motors as input. Finally, we control the thickness of the metallic sheet using the tractions of the strips as input.

Moreover, since we know that the traction will depend on a *difference* of speeds, we also propose to simplify this scheme by modulating the speed of only one motor during the operation. One motor will be designated as "master": it will be controlled with a constant reference with the only goal of spinning at the setpoint speed as steadily as possible. The other will be designated as "slave": its reference will vary during operation in order to control the traction of the strip and it should have adequate transient response properties.

1.3 Structure of this report

First, in chapter 2, we describe the experimental setup which was used throughout this project. This report will then follow the chronological order of the work that was done during the labs. We used a bottom up approach where the inner loops are first implemented in order to then design the outer loops.

As stated before, to simplify the controller, only one motor – the slave – is controlled with a dynamic reference while the other – the master – is kept at a speed which should be as steady as possible. In chapter 3, the dynamics of the master motor are identified and a controller is designed to achieve zero steady state error and perturbation rejection. Then, in chapter **??** , the dynamics of the slave motor are identified and a controller is designed to achieve reasonably fast reference tracking.

reference

In chapter 4, the relation between both motors' speeds and the traction of the metallic strip is modelled and identified, and a controller is designed to stabilize the system and reduce the steady state error.

Finally, ...

What comes next?

Chapter 2

Description of the Experimental Setup

2.1 General Wiring

The setup is wired as described in figure 2.1. We use the maximum recom-

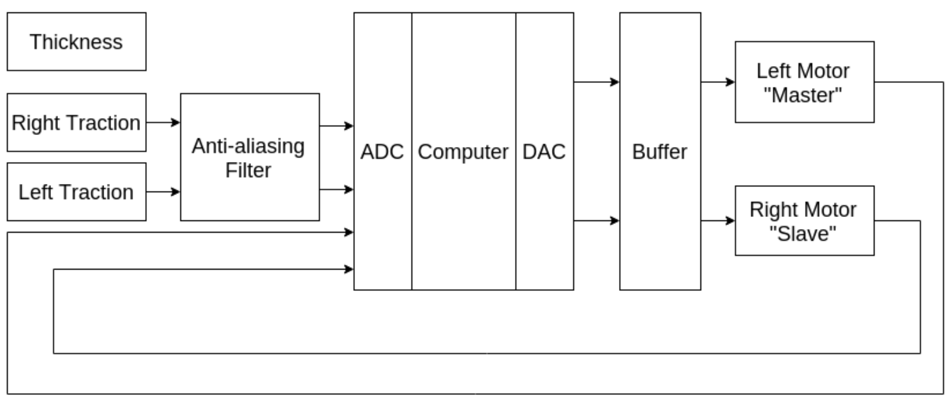


Figure 2.1: Wiring for the control of the rolling mill

mended sampling frequency $f_s = 100\,\text{Hz}$, which is a common value for the control of a DC motor.

2.1.1 Anti-aliasing filtering

To be perfectly rigorous, we should filter every input before sampling it. However, we only have a limited amount of single signal, second order Butterworth filters at our disposition, each with a different f_c. With the chosen f_s, those constraints on the available f_c, and the fact that second order Butterworth filters have a large transition band, only two of the available f_c values seem actually useful:

- $f_c = 40\,\mathrm{Hz}$, which provides 37.1 % attenuation at 50 Hz and 62.9 % rejection at 100 Hz.
- $f_c = 20\,\mathrm{Hz}$, which provides 62.9 % attenuation at 50 Hz and 80.4 % rejection at 100 Hz.

The other available filters either do not actually prevent aliasing, or have a too high passband attenuation. Even the two most adequate filters have a non ideal passband gain, and thus introduce a significant delay in the feedback loop. For this reason we choose not to use them in the inner loop, which should be fast, but rather in the outer loop. This is why only the two traction measurements are filtered in figure 2.1.

2.2 Structure of the Matlab Code

Chapter 3

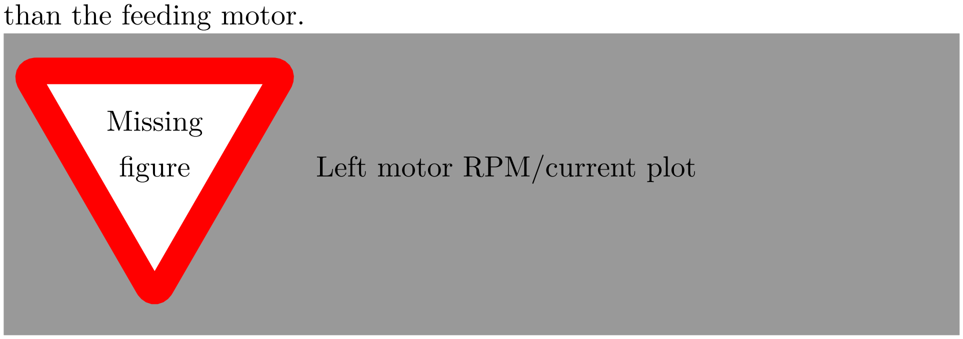
Control of the Master DC Motor

This chapter describes all the steps that were taken in the design of a controller for the rolling mill plant. Along the way all the design choices will be explained and substantiated.

3.1 Master motor

The master motor is the one that pulls the strip and winds it up on a spool. The left motor was chosen as master since its RPM at working current is higher. This is necessary since when the strip is compressed to reduce its thickness it extends. The speed of the winding motor needs to be higher than the feeding motor.

ref to figure of RPM in function of current



Chapter 4

Modelling and Control of the Traction

4.1 Modelling of the Traction of the Metallic Strip

As we said in the introduction, we know from a physical intuition that the traction in the metallic strip depends mainly on the difference of speed between the rolls, rather than on each of the speeds individually. For this reason, we only have to determine $G(p)$ as described in figure 4.3, where ω_i is the speed of a motor, and t is the traction of the metallic strip.

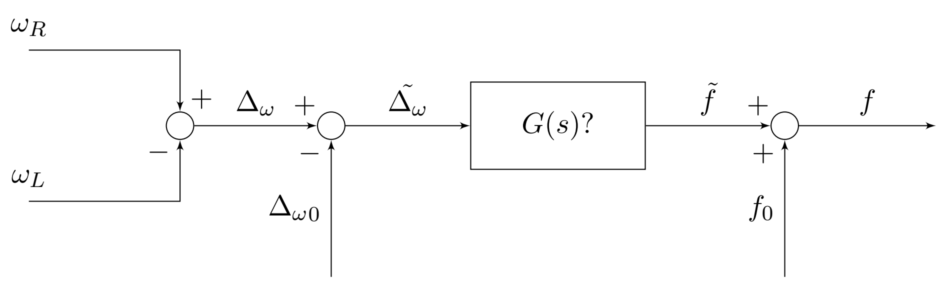


Figure 4.1: Simple gray-box model of the traction of the metallic strip

Furthermore, we also know that $G(s)$ should contain a close-to-perfect integrator. Indeed, if we increase Δ_ω slightly from the setpoint $\Delta_{\omega 0}$, we expect the tension in the metallic strip to rise indefinitely until breakage. This is also confirmed by the experience: we observe that the system's response to a real world pulse is really close to a step, as showed in figure 4.2. Finally, we also see that a second order numerical approximation of the dynamics

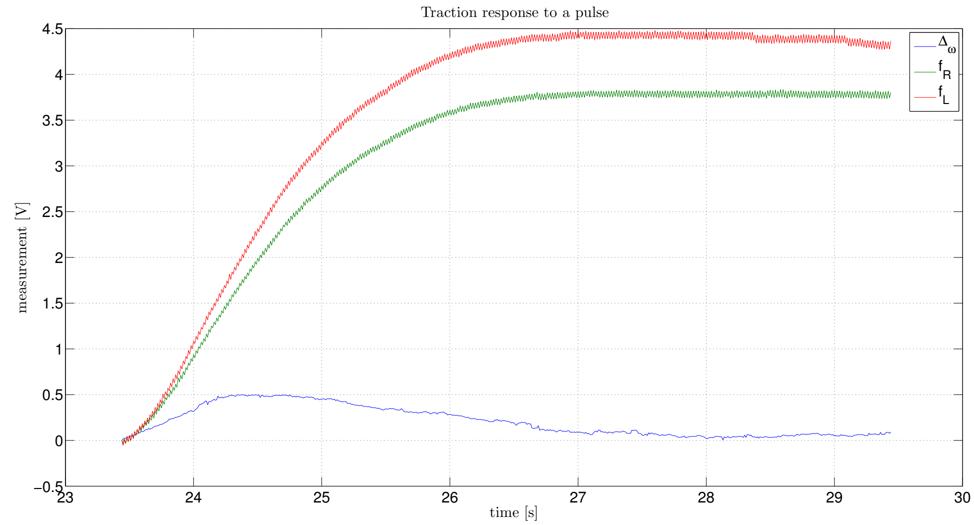


Figure 4.2: Traction response to a real world pulse

always yields a pole that is very close to zero. However this leads the rest of the optimisation problem to be badly conditioned. This means that the second pole is not reliably placed, and that the final result does not fit the real response accurately. Moreover, a system with zero very far from the origin takes a really long time to simulate with simulink.

To solve this, we refine our gray-box approximation by introducing an integrator in the system, computing its response to $\tilde{\Delta_\omega}(t)$ and trying to determine the rest of the dynamics based on this new input and the observed response, as shown in figure 4.3, where $G(s) = \frac{1}{s}H(s)$.

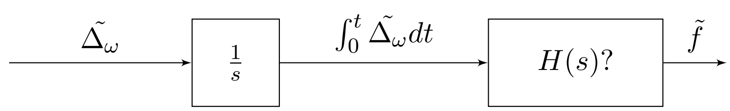


Figure 4.3: Gray-box model of the traction of the metallic strip

Fitting a simple first order transfer function to $H(s)$ is not easy because the dynamics between $\frac{\tilde{\Delta_\omega}(s)}{s}$ and $F_R(s)$ is very fast, as shown in figure 4.4. This leads to very large poles which are not well approximated and difficult to simulate, as previously stated.

To solve this, we tried to fit $H(s)$ with a transfer function of the form $K\frac{s-z_0}{s-p_0}$, because the introduction of a zero speeds up a step response, which would bring p_0 reasonably closer to the origin. The result is shown in fig-

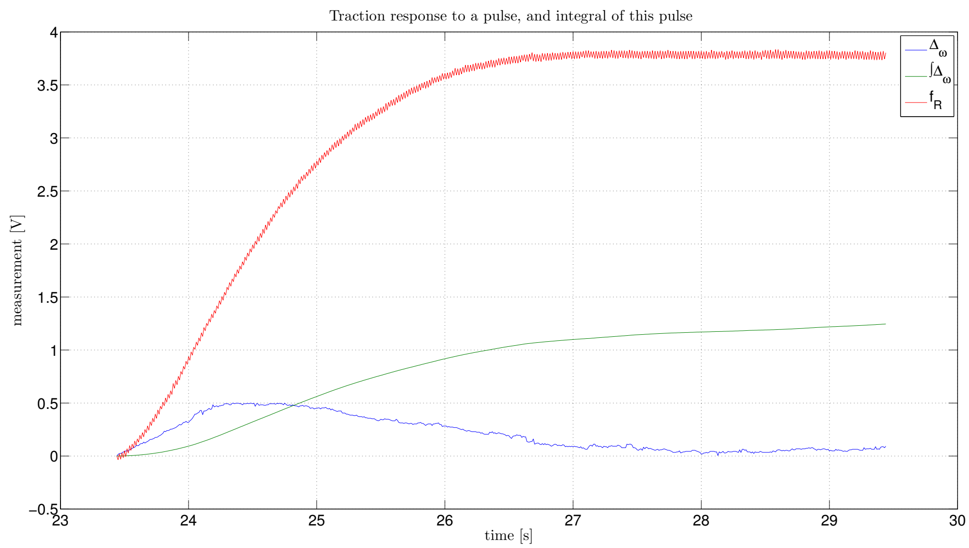


Figure 4.4: Right traction response to a pulse and output of the intermediate integrator

ure 4.5, where we see that the following transfer function seems to fit the experience very well.

$$H(s) = 13.096\frac{s + 0.9221}{s(s + 4.063)}$$

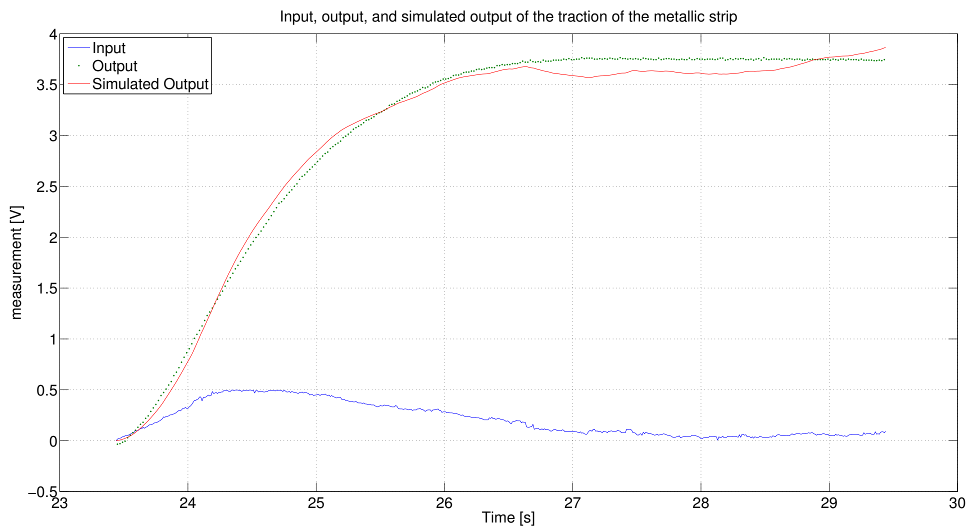


Figure 4.5: Input, output, and simulated output of the traction of the metallic strip