CSD Project
Control of a Rolling Mill

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- Process steps:
  - Strip is unwound from the right roll
  - Strip is rolled between the middle pair of rolls
  - Strip is wound up by the left roll
  - All rolls are driven by DC motors
- Process goal: control the output thickness

Introduction

Sensors and Actuators

- Actuators: 3 DC motors, armature current controlled
- Sensors:
    - 3 velocity sensors
    - 2 traction sensors
    - 2 thickness sensors
- Current setup $\Rightarrow$ only control sheet traction

- Cascade plant
  ⇒ Cascade controller:
  - Inner loop: DC motor speed control
  - Outer loop: traction control
- Traction system has differential input
  ⇒ ”master–slave” architecture
  - Master: steady speed setpoint
    ⇒ zero static error, disturbance rejection
  - Slave: small signal speed
    ⇒ tracking

In this Presentation

Control of the Master Motor

Control of the Slave Motor

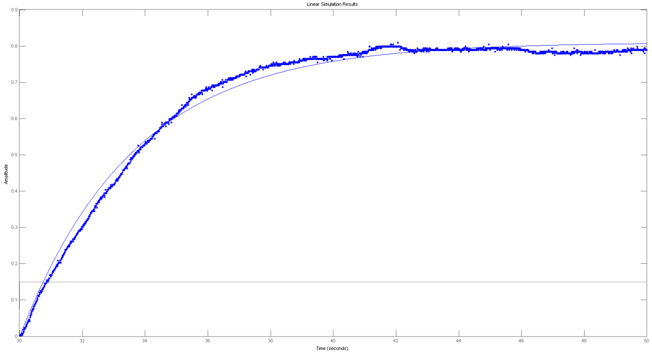
Outer Loop: Control of the Traction

Discussion: Control of the Thickness

Master Motor (Left)

Setpoint and Response

- Winds the metal strip $\Rightarrow$ Higher velocity (elongation)
- Dynamic model: $LM(s) \simeq \frac{5.398}{3.642S+1}$

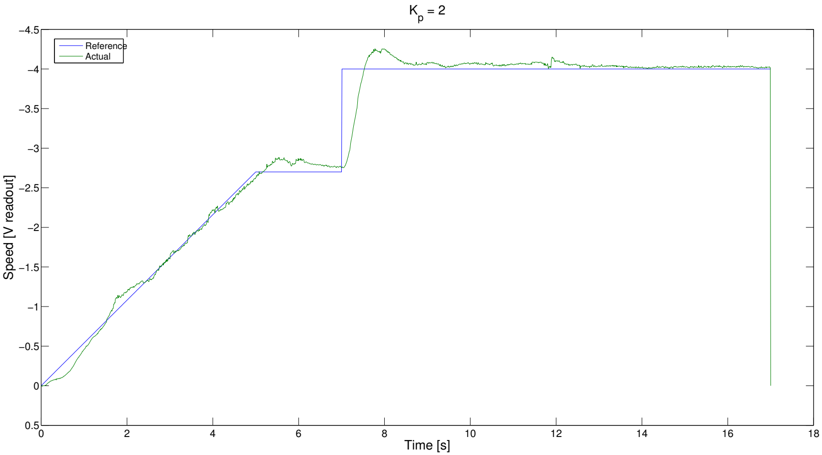


PI Controller

- Zero steady state error
- Disturbance rejection
- $\frac{K_i}{K_p}$ = chosen at 0.294 to cancel plant pole

Master Motor

Tuning result

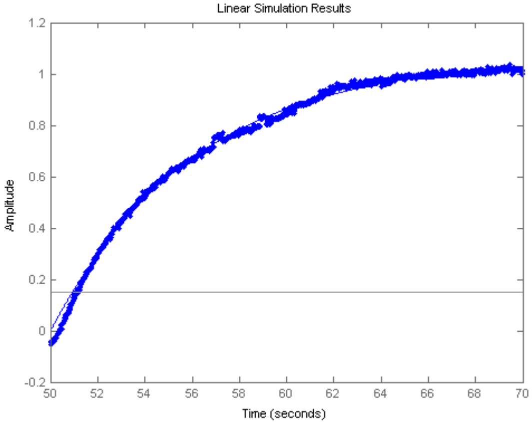


- PI Controller for zero steady state error
- Gain $K_P = 2, K_I = 0.588$ chosen for quickest settling time, reasonable overshoot
- Overshoot is due to non linearities and higher order effects

Slave Motor (Right)

Setpoint and Response

- Feeds the metal strip ⇒ Lower velocity
- Dynamic Model: $RM(s) \simeq \frac{7.128}{6.0665s+1}$

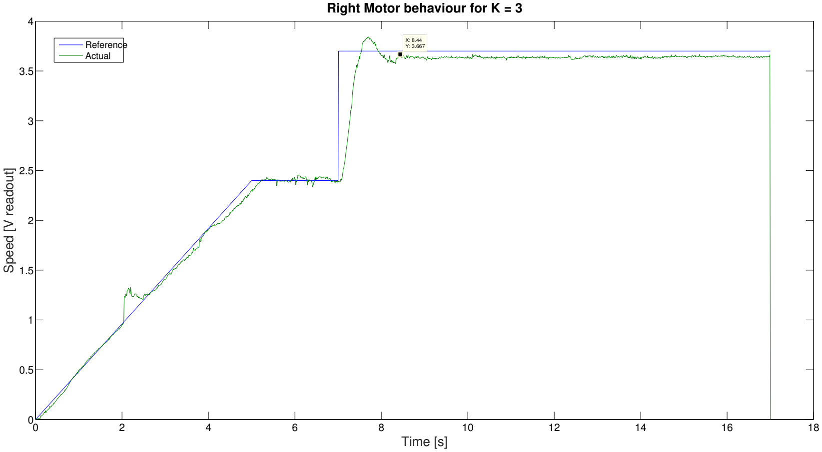


P Controller

- Fast response, better tracking than PI
- Steady state error rejection not necessary due to cascade control

Slave Motor

Tuning Result



Final tuning

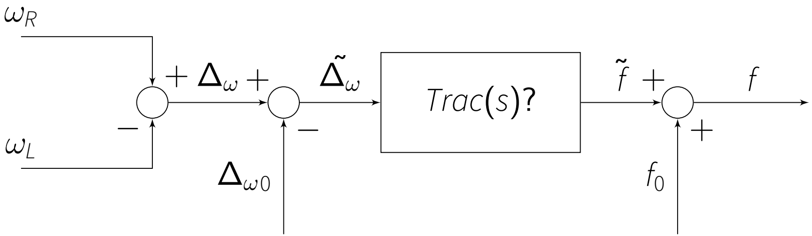
- P Controller for fast tracking
- Gain $K_P = 3$ to avoid actuator saturation
- Overshoot is due to non linearities and higher order effects

Closed loop experimental response

$$Slave(s) \simeq \frac{0.9577}{0.2428s + 1}$$

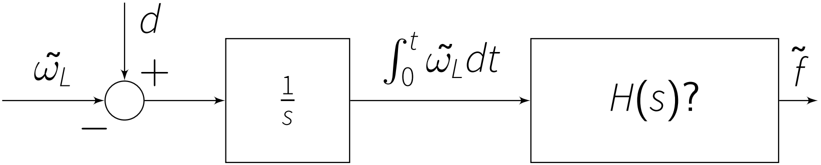
Traction Control

Gray Box Model



Traction Control

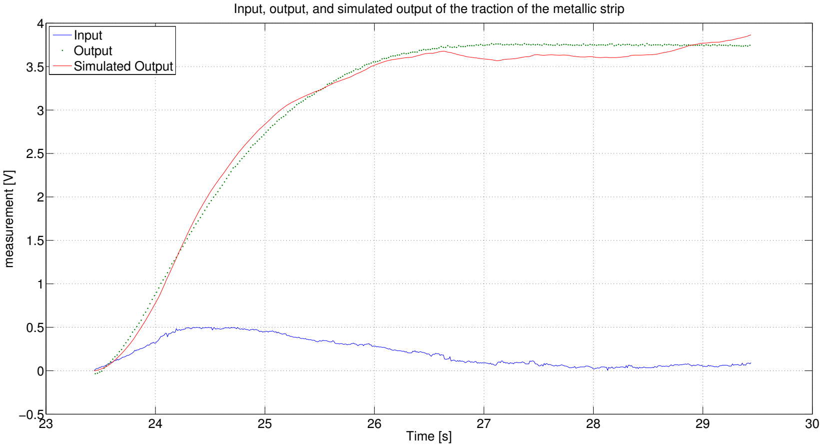
Gray Box Model – Refined



Traction Control

Dynamic Model

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

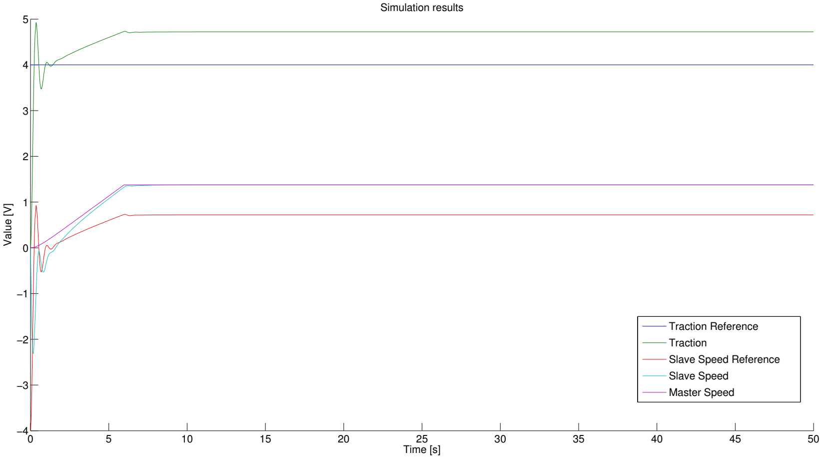


First tentative: simple P controller

- Integrator in the plant should provide zero steady state error
- Added integrator would degrade the phase margin
- No specification on the transient

Traction Control

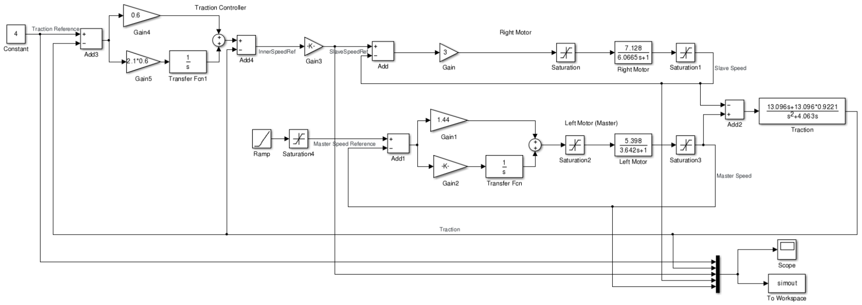
Simulation – Simple P Controller



- Steady state error is due to perturbation from the master speed, constant in regime
- Simple P controller
  $\Rightarrow$ No perturbation rejection
  $\Rightarrow$ But removes integrator from the closed loop!
- Idea: second outer PI loop to reject the constant perturbation
- Possible in terms of phase margin thanks to the inner P controller

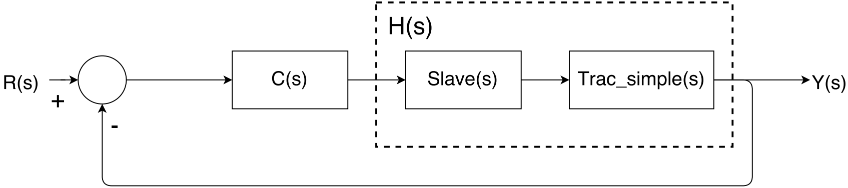
Traction Control

Final Controller



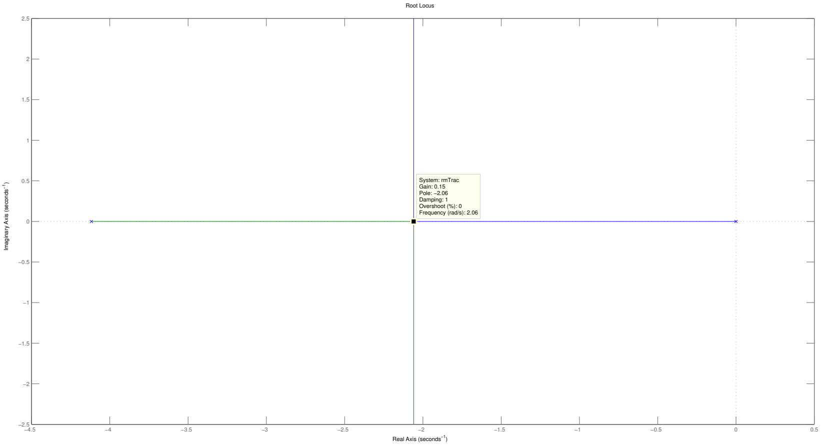
Traction Control

Plant model



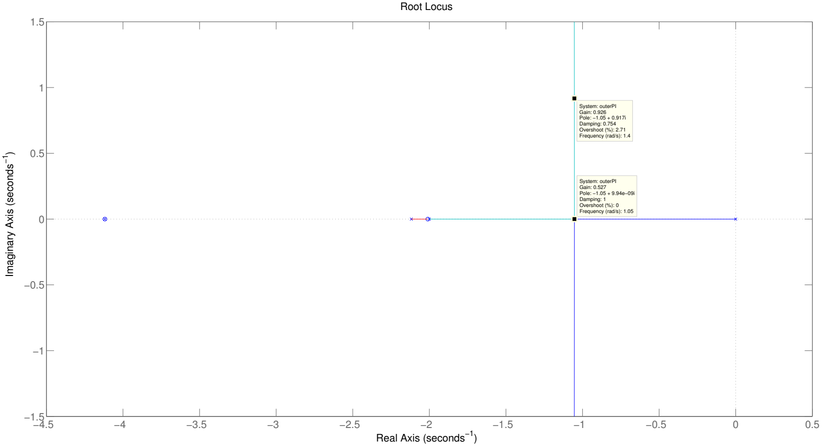
Traction Control

Controller Tuning – Inner Traction Loop



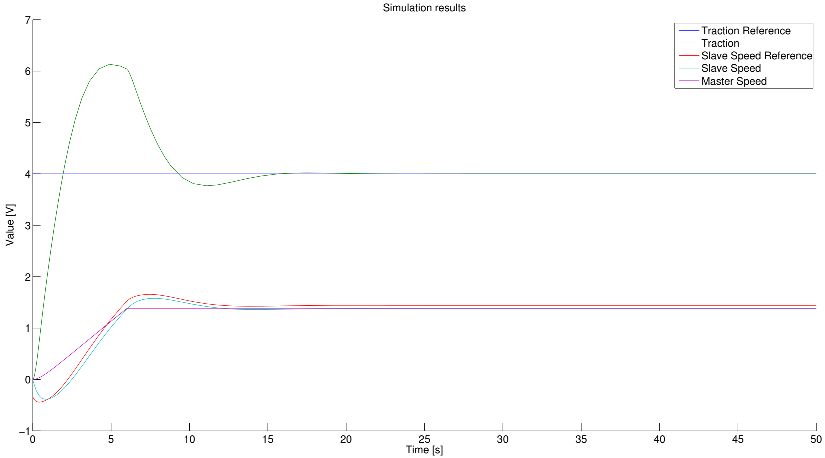
Traction Control

Controller Tuning – Outer Traction Loop



Traction Control

Simulation

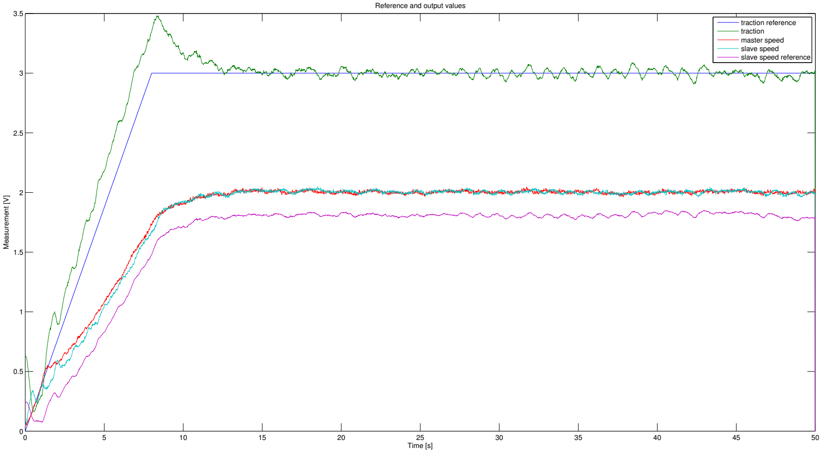


High overshoot

$\Rightarrow$ should be primary tuning constraint

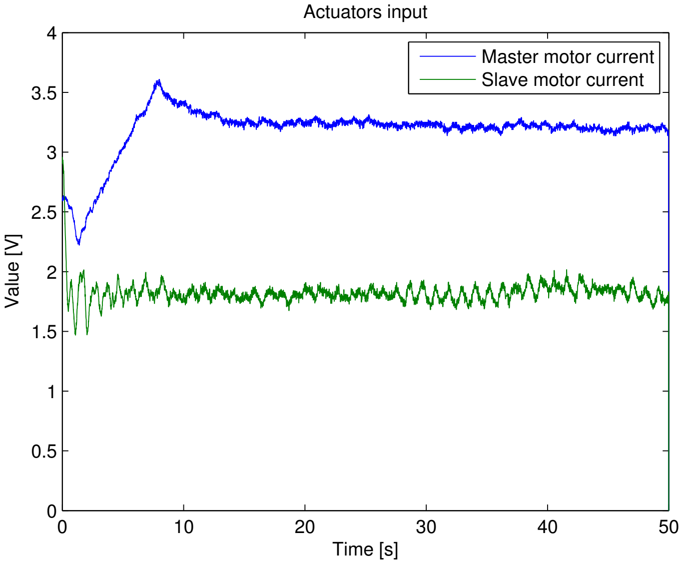
Traction Control

Final Controller Values

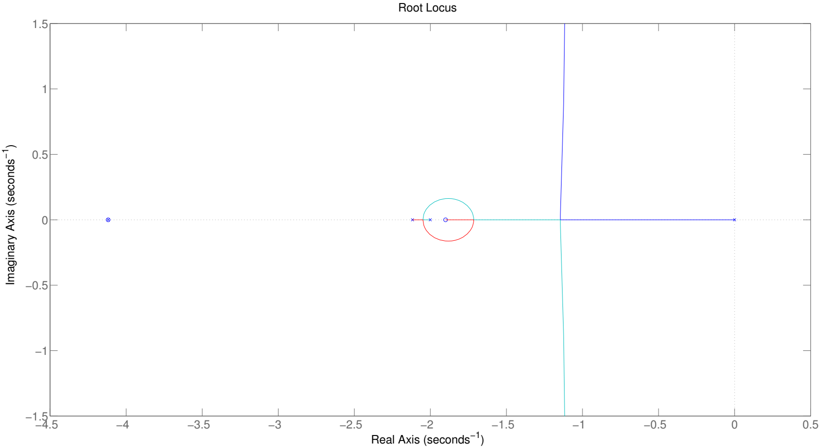


Traction Control

Verification: Actuator Input



Thank you!
Questions?


Root Locus
Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})
1.5
1
0.5
0
−0.5
−1
−1.5
−4.5
−4
−3.5
−3
−2.5
−2
−1.5
−1
−0.5
0
0.5