CSD Project
Control of a Rolling Mill

Nathan Dwek – Thomas Lapauw

December 11th, 2015

Bruface
Brussels Faculty of Engineering

- 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
- Objectives:
  - Basic: control the traction of the metallic strip
  - Advanced: control the thickness of the metallic strip

- Actuators: 3 DC motors, armature current controlled
- Sensors:
  - 3 velocity sensors
  - 2 traction sensors
  - 2 thickness sensors
- 2 DAC and 8 ADC ports
- 2 ”useful” Butterworth filters
- Only basic objective is realistically doable for now

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

In this Presentation

Control of the Master Motor

Control of the Slave Motor

Outer Loop: Control of the Traction

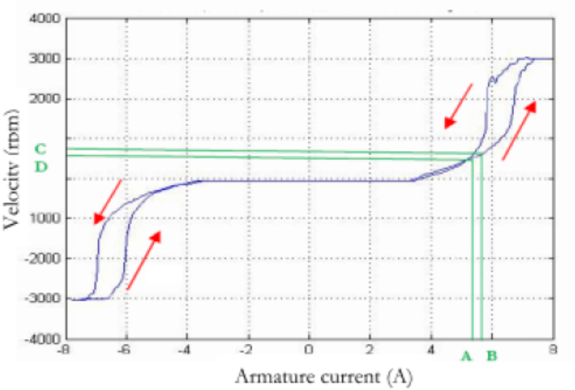
Discussion: Control of the Thickness

Bruface
Brussels Faculty of Engineering

Master Motor (Left)

Setpoint characteristics

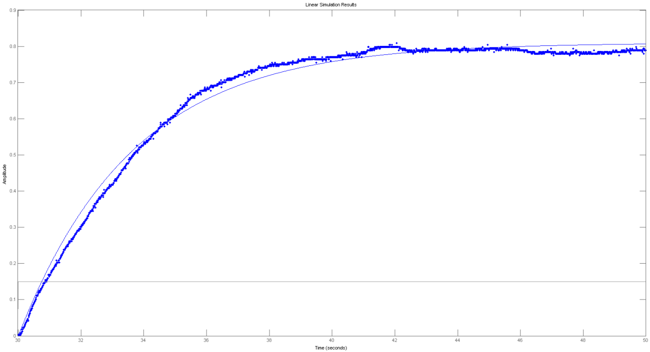
- Winds the metal strip
- Higher velocity than feeding motor due to elongation



Master Motor

Identification

$$LM(s) \simeq \frac{5.398}{3.642S+1}$$



PI Controller

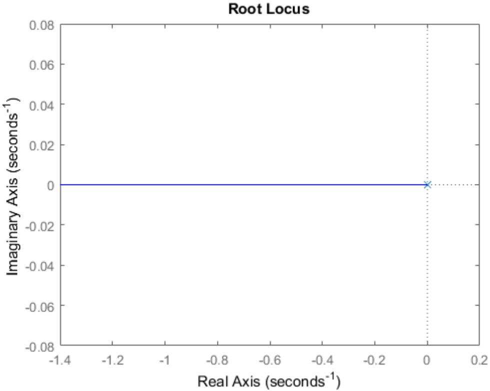
- Zero steady state error
- Disturbance rejection

$$LM(s) = \frac{1.482}{s + 0.274}$$

$$PI(s) = K_p + \frac{K_i}{s}$$

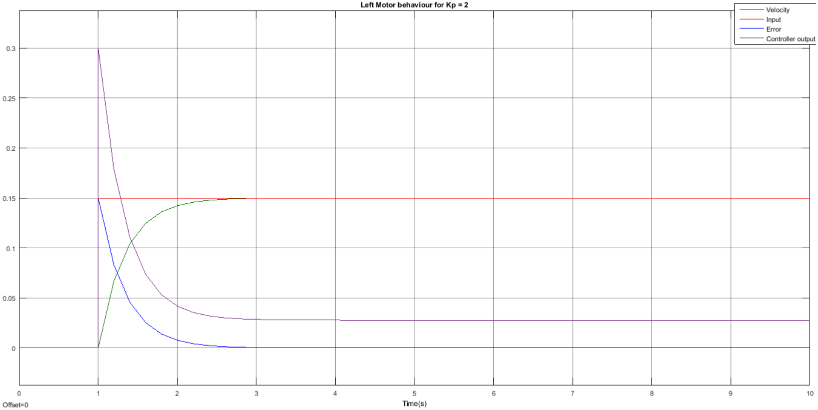
$$= K_p \cdot \frac{s + \frac{K_i}{K_p}}{s}$$

- $\frac{K_i}{K_p}$ = chosen at 0.294 to cancel plant pole
- $OL(s) = \frac{1.482}{s}$



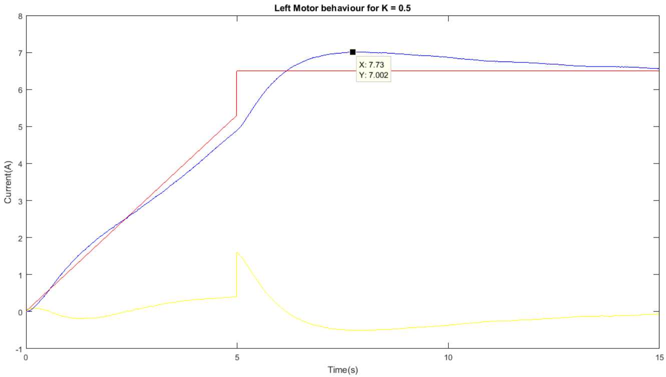
Master Motor

Simulation – $K_P = 2$



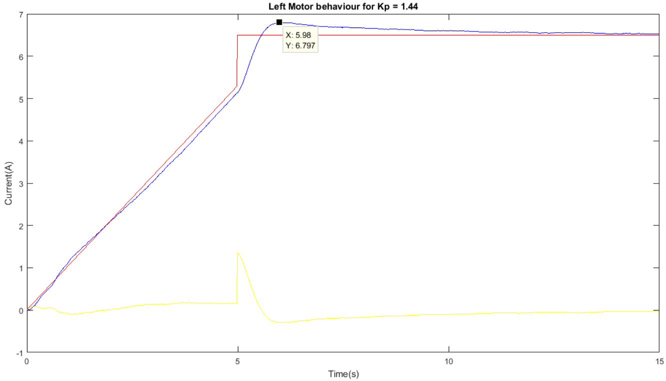
Master Motor

Verification



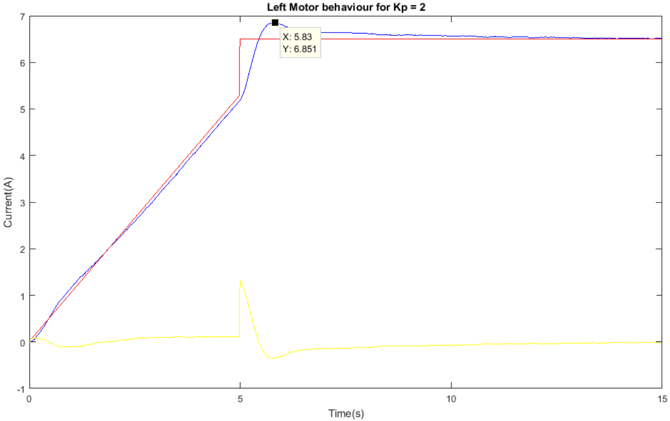
Master Motor

Verification



Master Motor

Verification

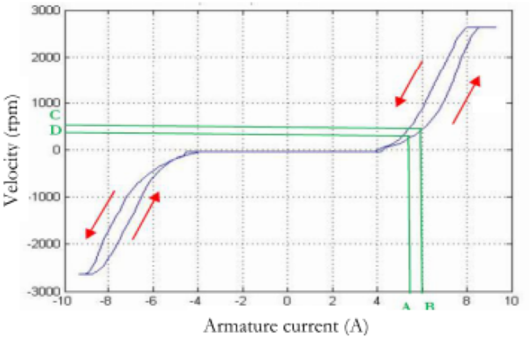


- PI Controller for zero steady state error
- Gain $K_P = 2, K_I = 0.588$ chosen for quickest settling time, reasonable overshoot
- Overshoot is due to non linearities and higher order effects

Slave Motor (Right)

Setpoint Characteristic

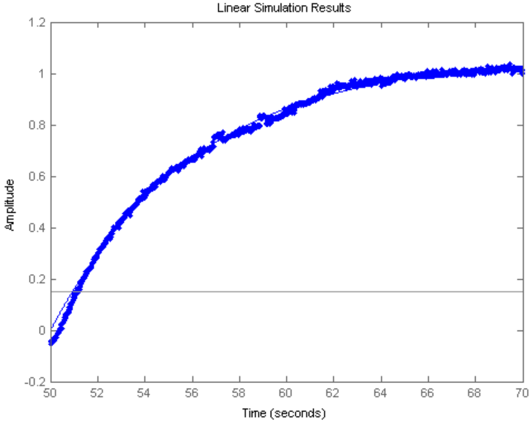
- Feeds the metal strip
- Lower Velocity



Slave Motor

Identification

$$RM(s) \simeq \frac{7.128}{6.0665s + 1} \tag{1}$$

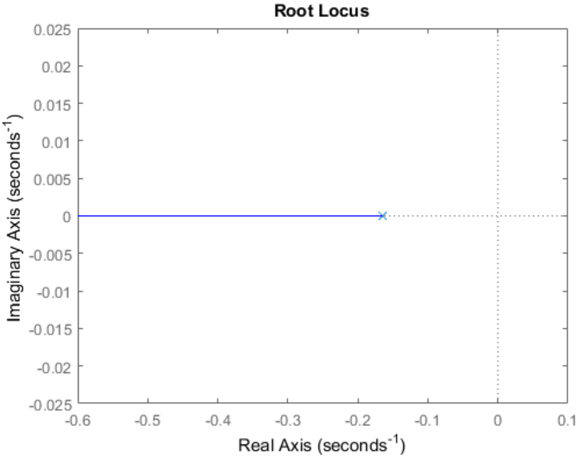


P Controller

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

Slave Motor

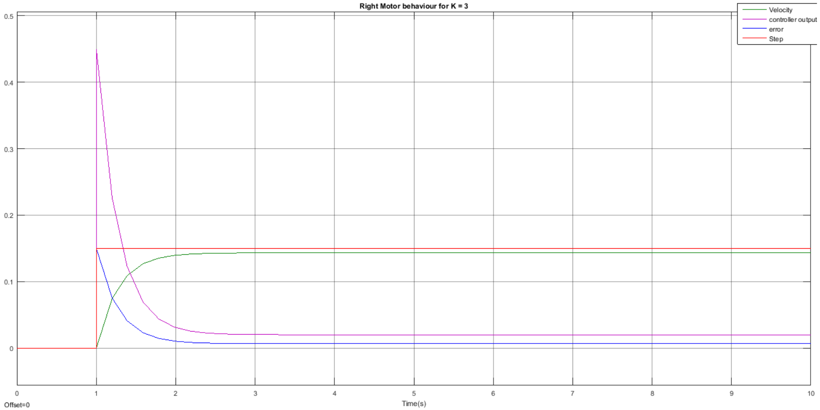
Controller Tuning



Bruface
Brussels Faculty of Engineering

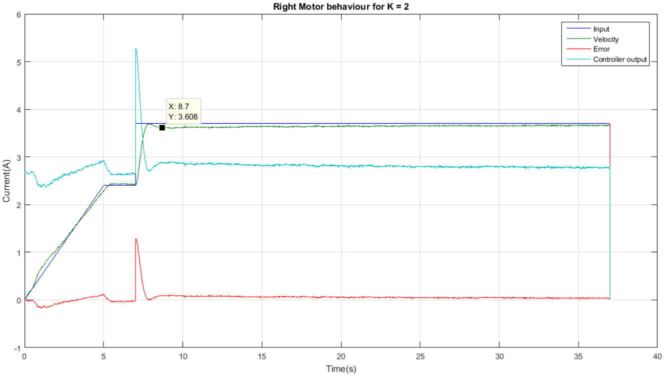
Slave Motor

Simulation – $K_P = 3$



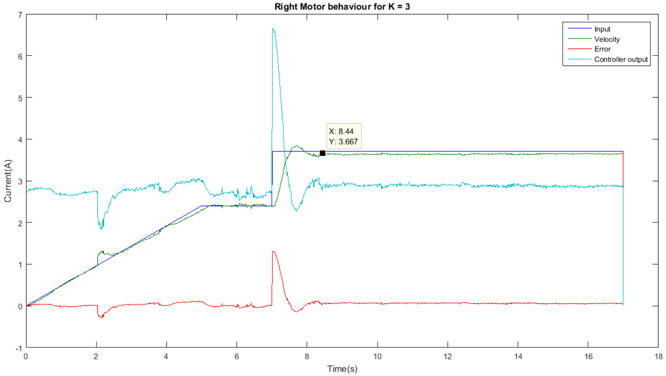
Slave Motor

Verification – $K_P = 2$



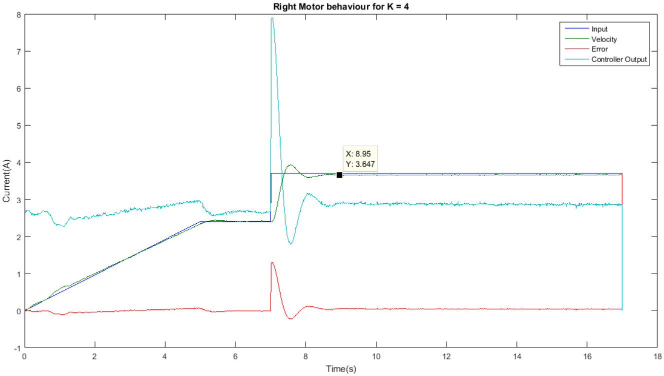
Slave Motor

Verification – $K_P = 3$



Slave Motor

Verification – $K_P = 4$



Final tuning

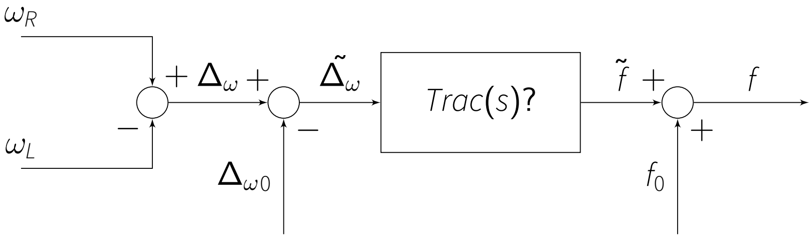
- P Controller for fast tracking
- Gain $K_P = 3$ to avoid actuator saturation
- Overshoot is due to non linearities and higher order effects

Closed loop experimental response

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

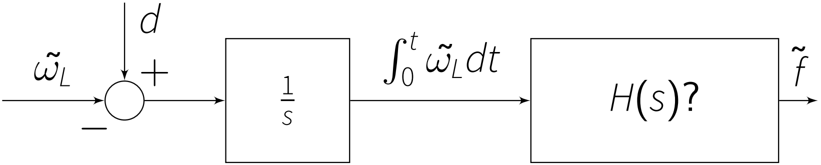
Traction Control

Gray Box Model

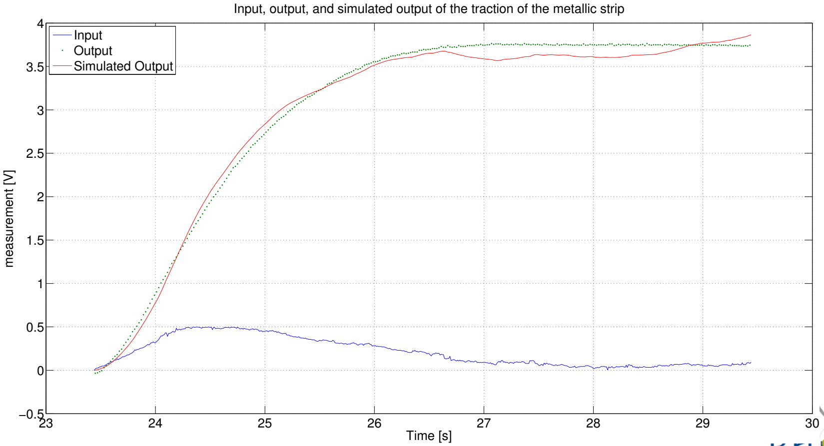


Traction Control

Gray Box Model – Refined



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

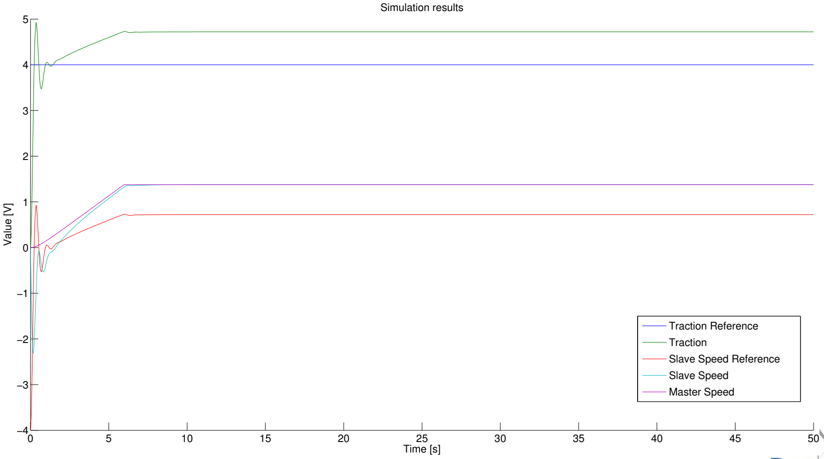


First tentative: simple P controller

- 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



Traction Control

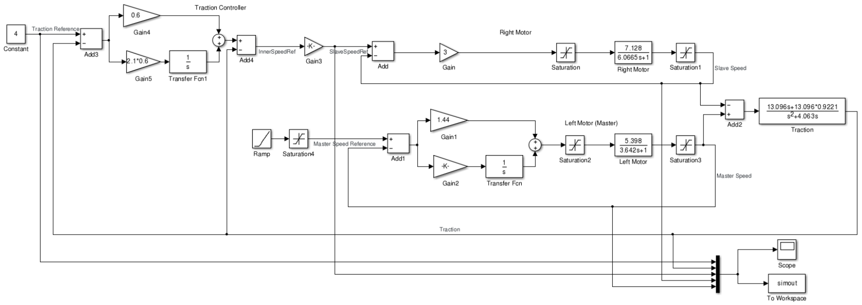
Controller Choice

- 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

Brussels Faculty of Engineering

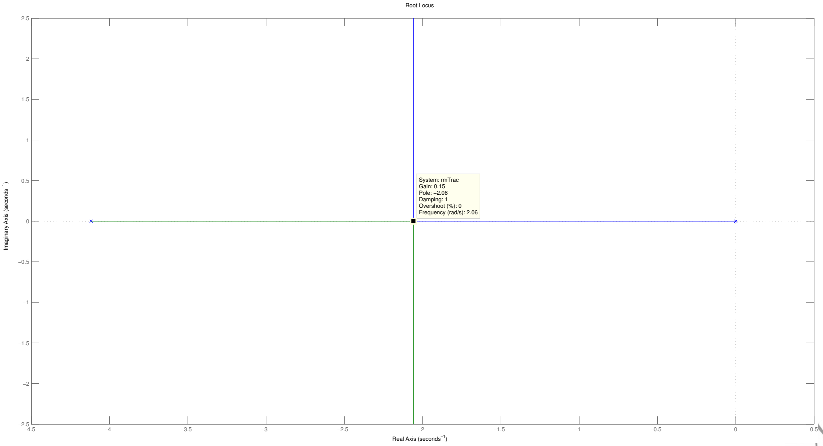
Traction Control

Final Controller



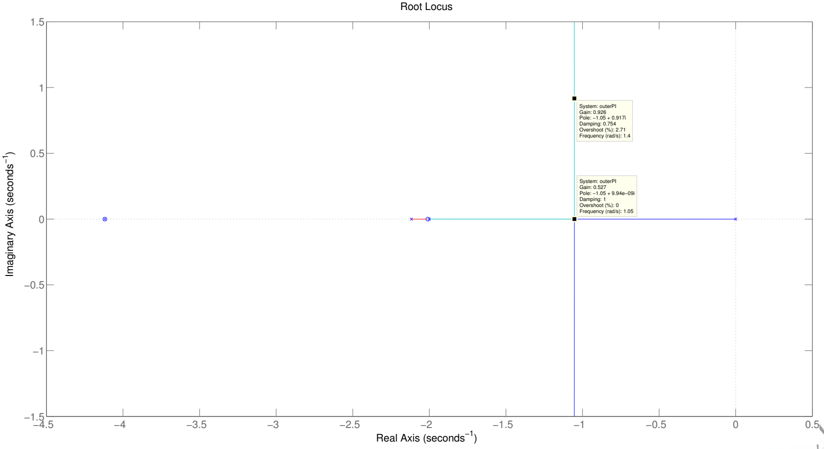
Traction Control

Controller Tuning – Inner Traction Loop



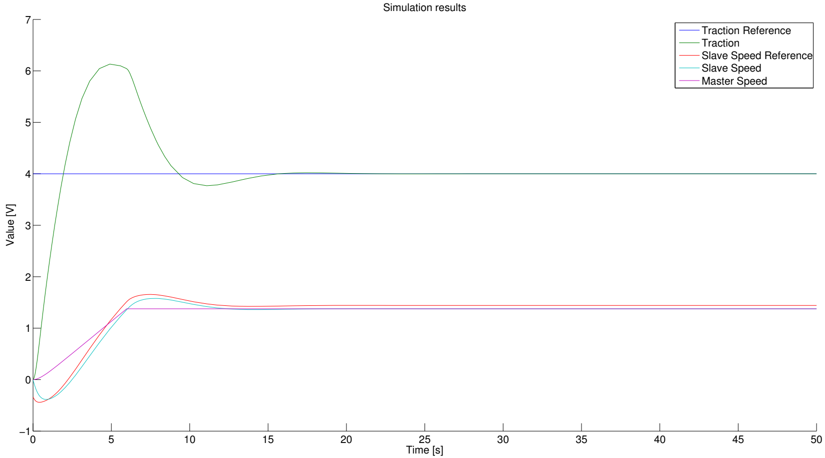
Traction Control

Controller Tuning – Outer Traction Loop



Traction Control

Simulation

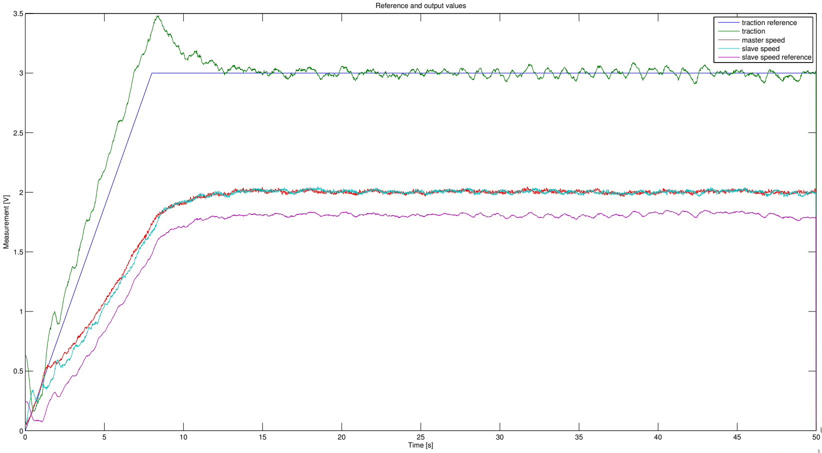


High overshoot

⇒ should be primary tuning constraint

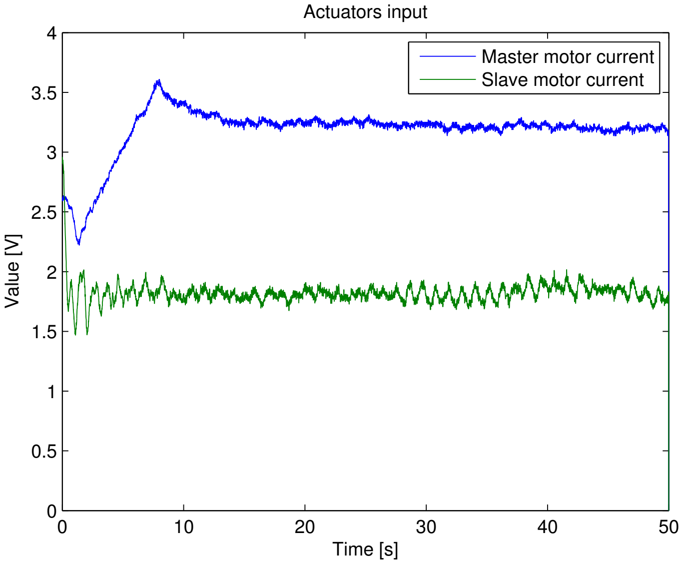
Traction Control

Final Controller Values



Traction Control

Verification: Actuator Input



Thickness

- Thickness control not technically feasible due to numbers of DAC outputs needed
- Design would more be difficult because
  - Thickness – traction – velocity relation: non-linear, look up tables are needed
  - Some bias point parameters must be currently set by hand

Thickness

Sensors and actuators

Actuators:

- Left Motor
- Rolling Motor
- Right Motor

Sensors:

- Thickness sensor before/after the rolling
- Traction sensor before/after the rolling
- Velocity sensors for each of the motors
- Rolling force sensor

Bruface
Brussels Faculty of Engineering

Thickness

Controller considerations

- Cascade control:
  - Left Motor - P controller
  - Rolling Motor - PI controller - Master
  - Right Motor - P controller
- Possible to get away with master/slave structure for the traction as well?
- Traction control using P-PI for master, probably just P for slave (what about the overshoot?)
- Possible to only work with small signals, or should the look up table be used during operation as well?

Bruface
Brussels Faculty of Engineering

Thank you!
Questions?