Chapter VIII

Practical Aspects of Digital Control

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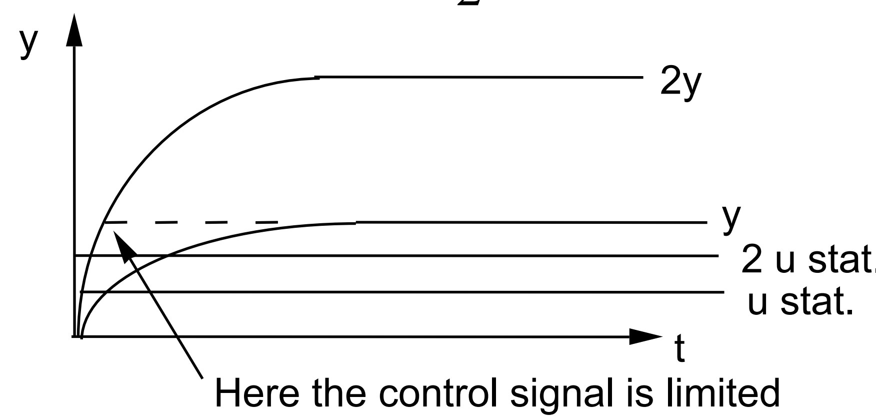
Chapter 8. Practical Aspects of Digital Control

Choice of the desired performances

The acceleration of the natural response of a plant requires control “peaks” during transients that are greater than the steady state values.

Example : Plant = $\frac{1}{1+sT}$ Desired response : $\frac{1}{1+s\frac{T}{2}}$

During transients: $u_{max} = 2u_{stat}$



$$\frac{u_{\max}}{u_{stat}} \approx \frac{desired \quad speed}{natural \quad speed} \approx \frac{desired \quad pass \quad band}{natural \quad pass \quad band}$$

- Choice of the performances depends on the power availability of the actuator
- Choice of the actuators depends on the desired performances and on the open loop plant response

Choice of the desired performances

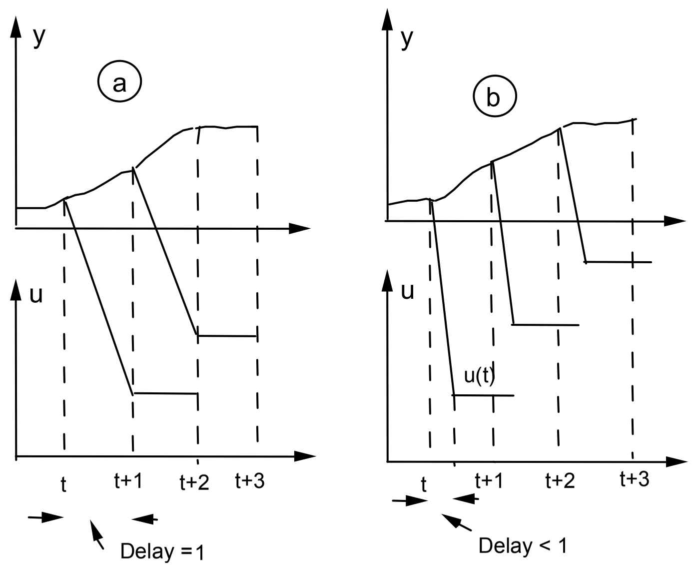
It is better to choose a 2^{nd} order model for the tracking (Am) and the regulation (P) dynamics instead of a first order model.

Explication :
Smaller stress on the actuator during transients for the same time response.

Effect of the computational time delay

a) Computation time greater than 0.5 T_s

The values measured at instant *t* are used to compute the control *u* that will be sent at instant $t+1$. The computer thus introduces an additional time delay of 1 and the delay becomes $d' = d+1$.

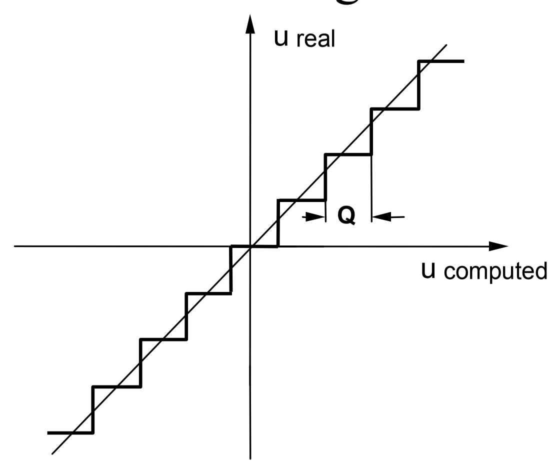


b) Computational time smaller then 0.5 T_s

The control is sent at the end of the computation (time delay $L<0.5T_s$). The computer introduces a fractional time delay (introduction of a zero, or modification of the existing zeros in the pulse transfer function of the plant).

Effect of the Digital-to-Analog Conversion

The control signal generated by the digital controller is often computed with floating (or fixed) point arithmetic on 16, 32 or 64 bits. A digital to analog (D/A) converter in general does not have more than 12 bits (4096 different values). There is an effect of rounding!



Q – quantization step

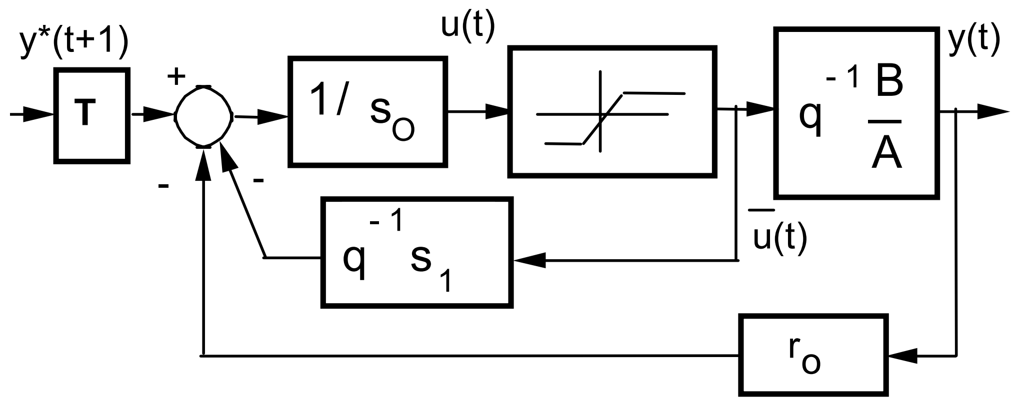
Consequence : It is therefore necessary to round the control *u(t)* inside the digital controller in order to correctly compute the future values.

$$u(t) = \frac{1}{s_0}\left[T(q^{-1})y^*(t+d+1) - S^*(q^{-1})u_r(t-1) - R(q^{-1})y(t)\right] \qquad \left|u_r(t) - u(t)\right| \le 1/2Q$$

Real value of the control applied

Anti Windup Devices

The effect of the actuator saturation has to be taken into account since for the computation of $u(t)$ the previous values of the control must be considered.

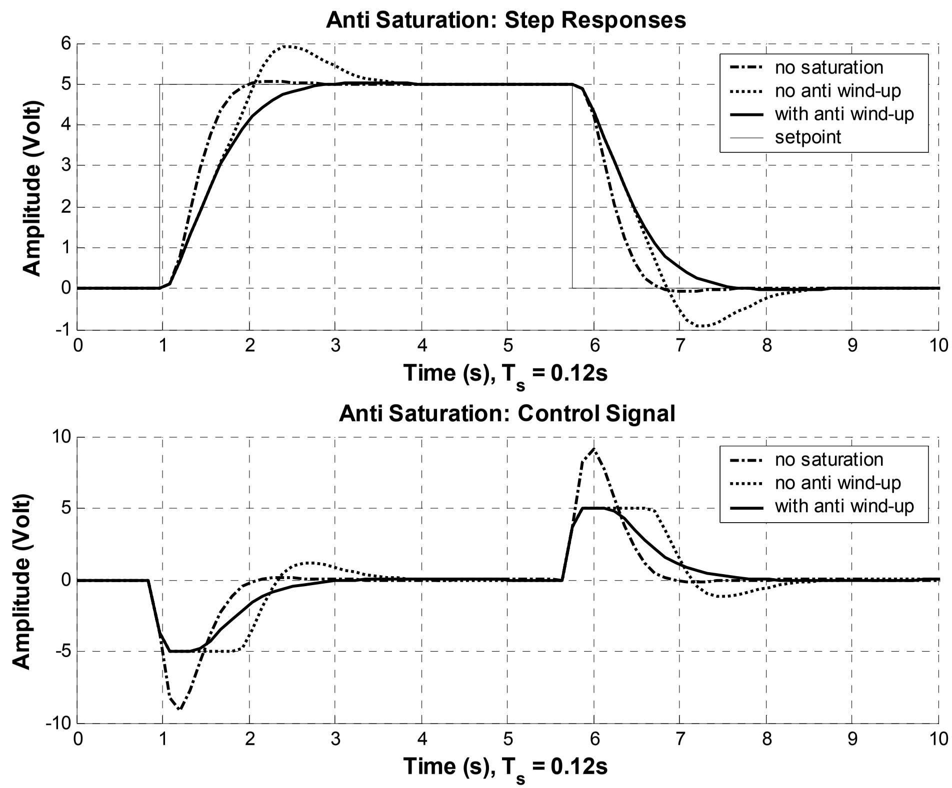


Introduction of a "copy" of the nonlinear actuator characteristic in the controller **:**

$$u(t) = \frac{T(q^{-1})y^*(t+1) - r_0 y(t) - s_1 \overline{u}(t-1)}{s_0}$$

$$\overline{u}(t) = \begin{cases} u(t) & si \quad |u(t)| < u_{sat} \\ u_{sat} & si \quad u(t) \geq u_{sat} \\ -u_{sat} & si \quad u(t) \leq -u_{sat} \end{cases}$$

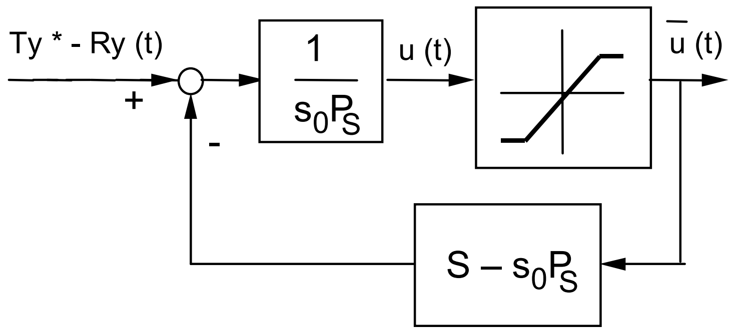
Anti Windup Devices



Example:
The plant contains an integrator (position loop)
The controller contains an integrator

Anti Windup Devices

Tuning of the dynamics of the anti windup device



$$P_S(q^{-1}) = 1 + p_{S_1} q^{-1} \; ; \quad -0.8 < p_{S_1} < 0$$

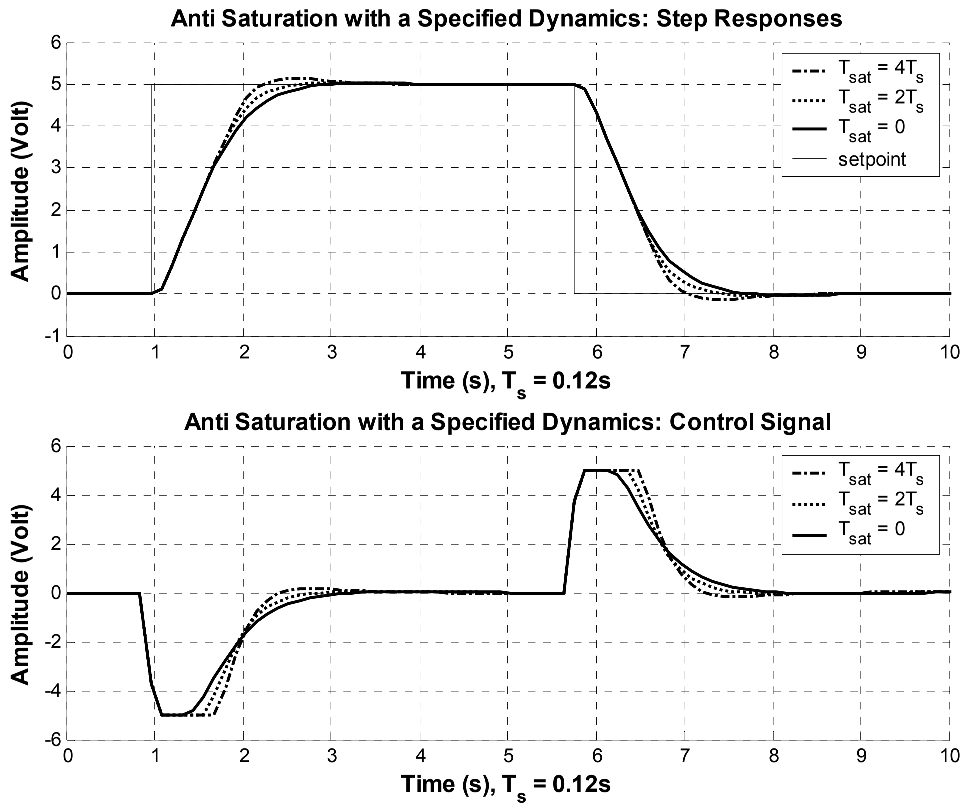
The effect of the polynomial P_s is present only during the anti windup phase (exit from saturation).
For tuning the anti windup dynamics just consider a first order system associated to P_s

$$0 < T_{sat} \le 4T_s \rightarrow 0 < -p_{S_1} < 0.778 \quad T_{sat} = 2T_s \rightarrow p_{s_i} = -0.602$$

T_{sat} = equivalent time constant for the anti windup device

Anti Windup Devices

Tuning of the dynamics of the anti windup device



A fine choice for p_{S1} depends on the specific application

Bumpless Transfer

How to initialise the controller in order to avoid « bumps » when swithching from open loop to closed loop operation?

Initialisation procedure :

1 – replace the setpoint and the desired output by the measure (obtained in O.L.) $(y^*(t+d+1) = y(t)\ ;\ r(t) = y(t))$,
2 – store in the controller memory the control signal $u(t)$ applied in open loop,
3 – repeat steps 1 and 2 for n times where n is
$n = max\ (nA + nS,\ d + nB + nR)$,
4 – switch from open loop to closed loop operation

The control signal at the first step of the close loop operation has the same value as the control in open loop at the previous instant

For the « proof » please refer to the book (pg. 326).

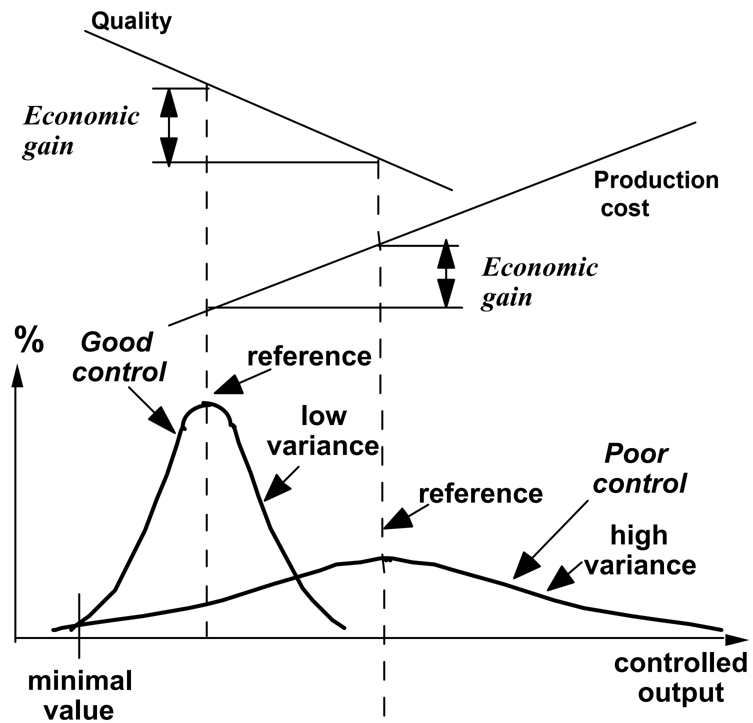
Hardware for Controller Implementation

- Wintrac (Adaptech)
- Vissim (Visual Solutions) and Simulink (Mathworks)+ RT Workshop
- PC Oriented Real time Softwares
- DCS (Digital Control Systems)
- PLC (Programmable Logic Controller)
- Micro-controllers

Leroy LT 160
(PLC)

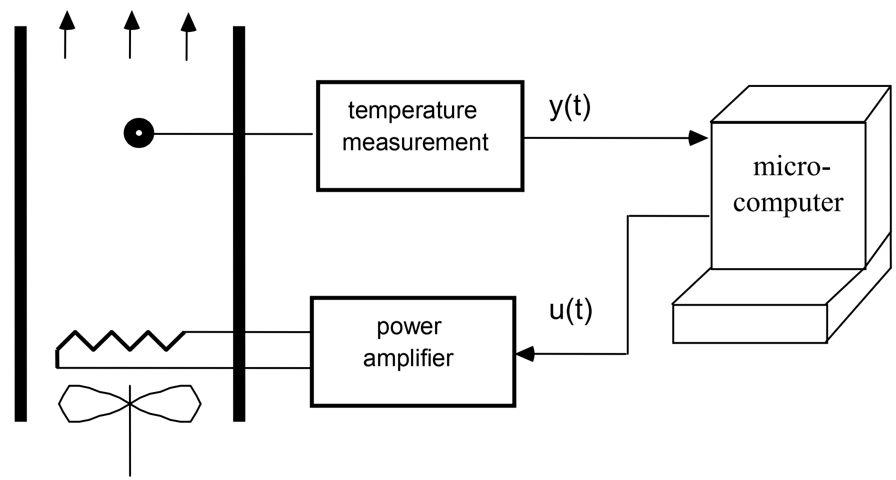
Measuring the Quality of a Control Loop

Histograms of the controlled variable

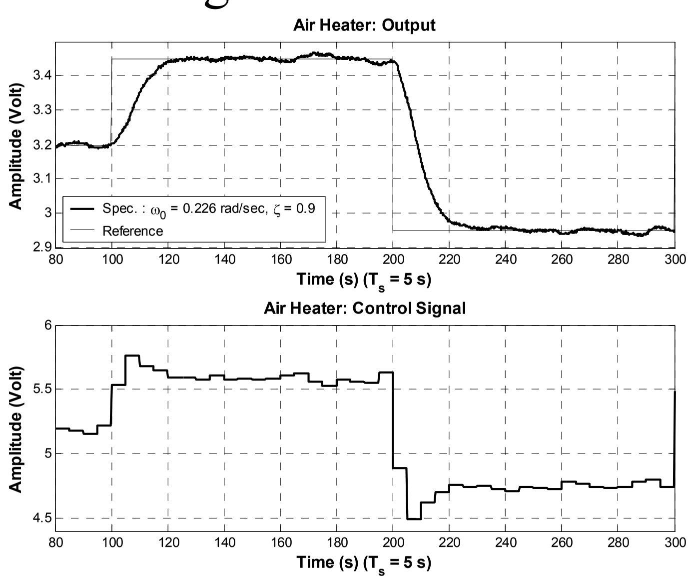


For details see book pg. 328 - 330

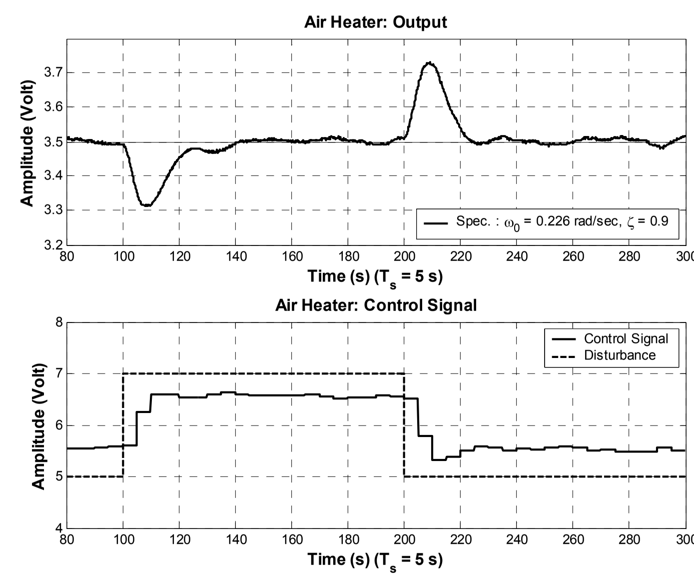
Digital Control of an Air Heater



Tracking



Regulation



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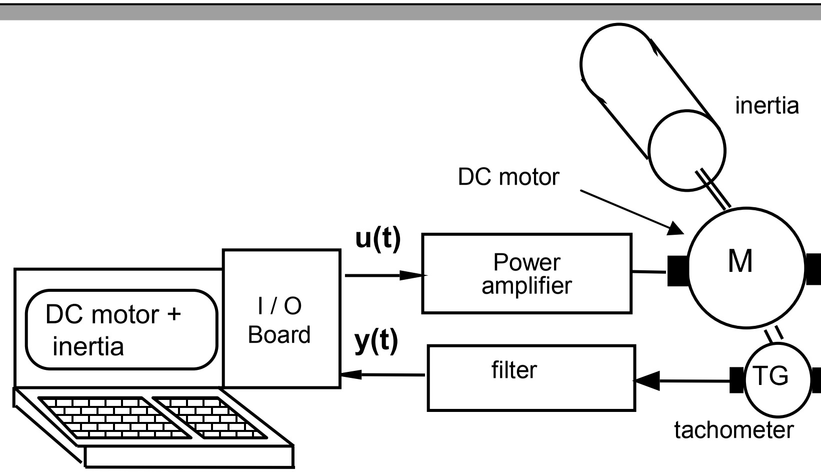
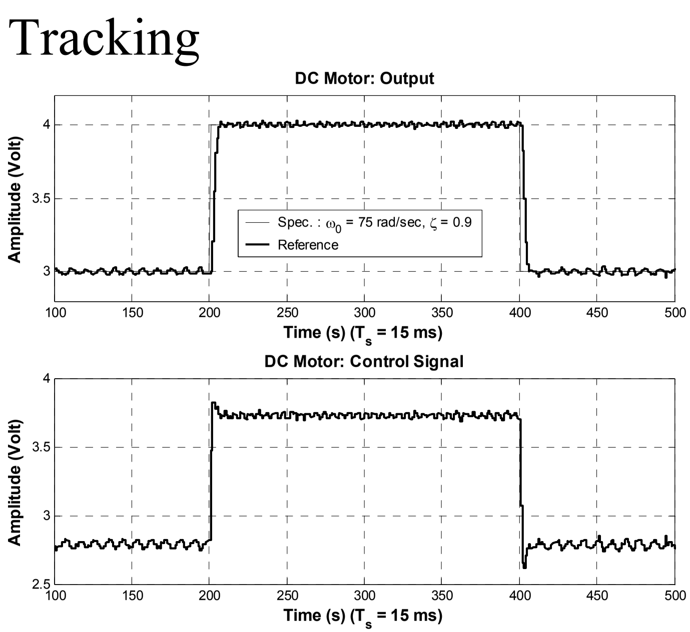
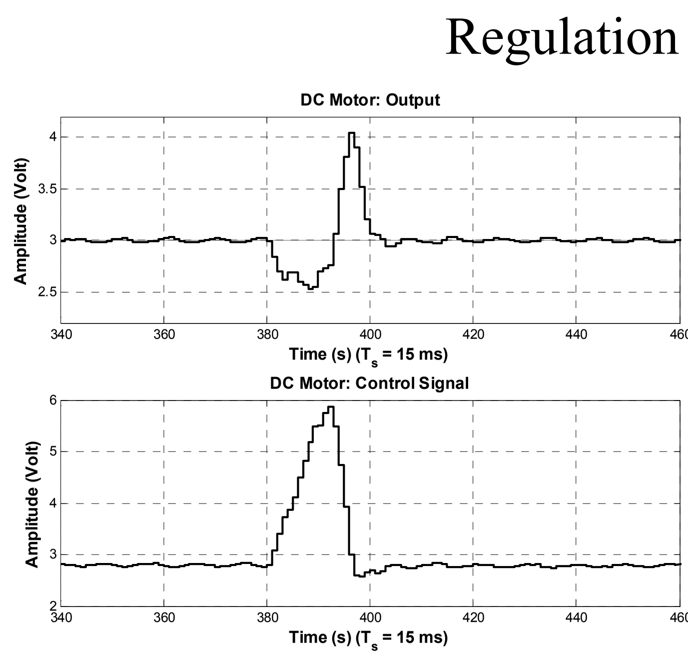
Digital Speed Control of a DC Motor







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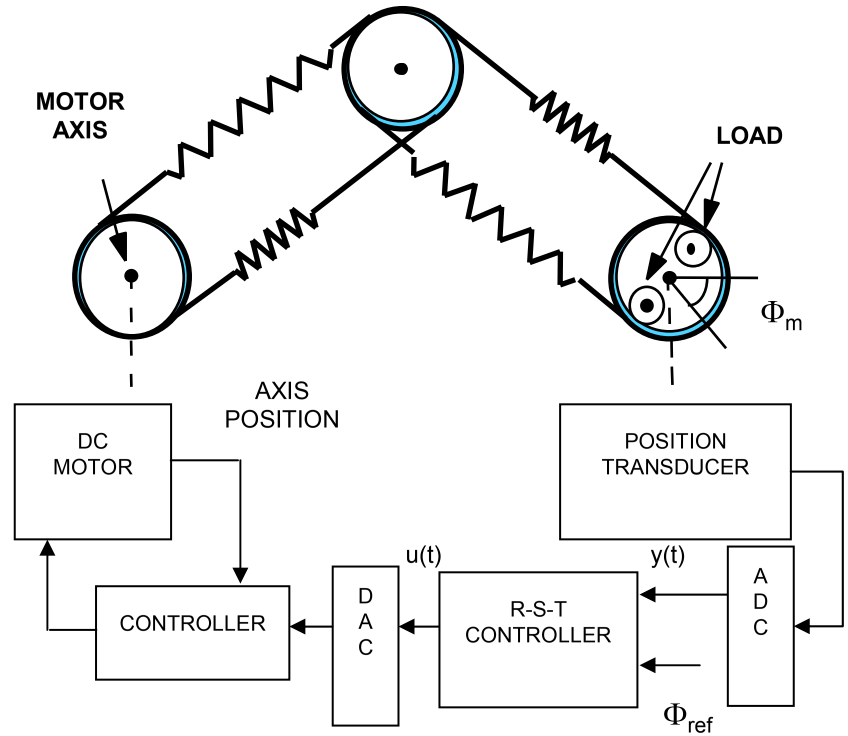
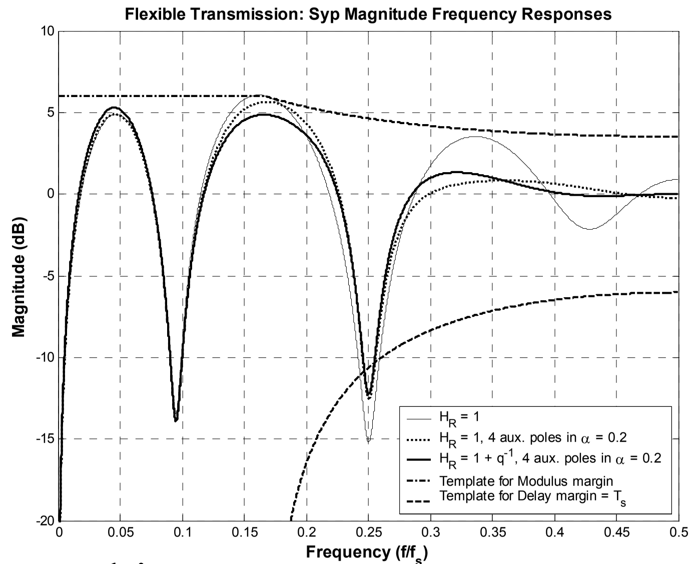
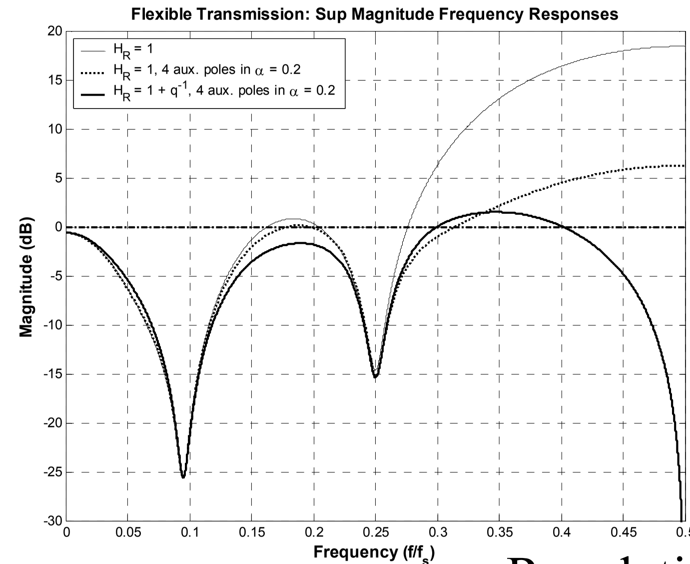
Position Control by means of a Flexible Transmission



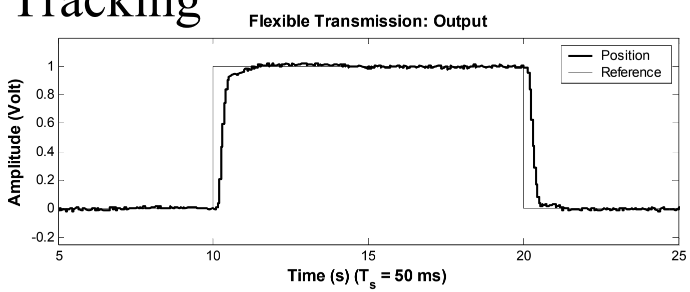
For details see next slide and book pg. 352 - 358

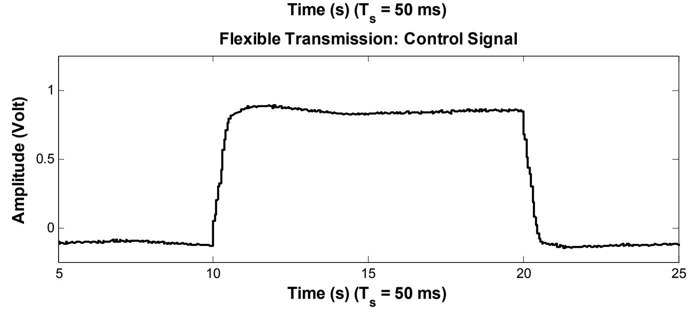
Position Control by means of a Flexible Transmission



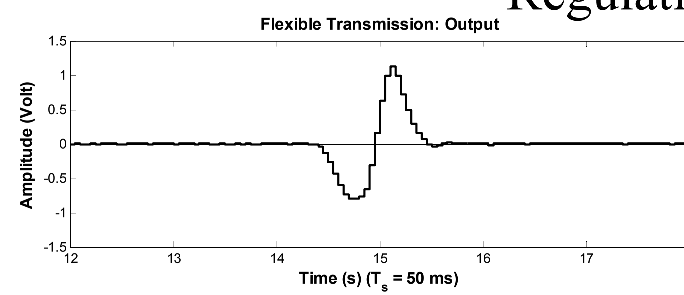


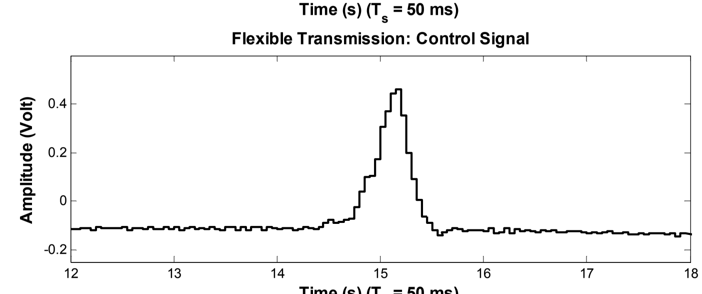
Tracking



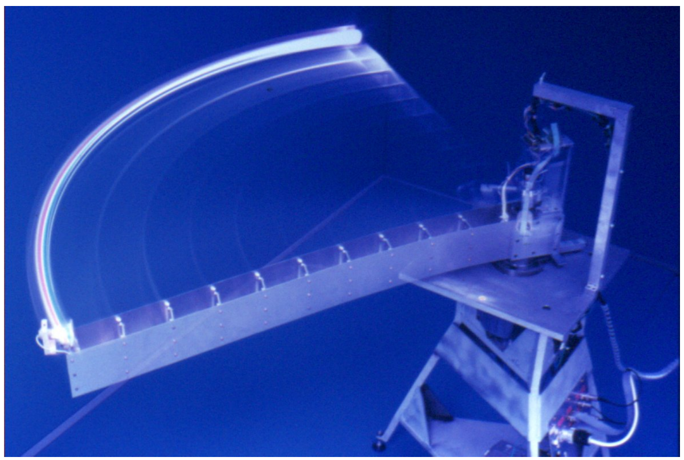


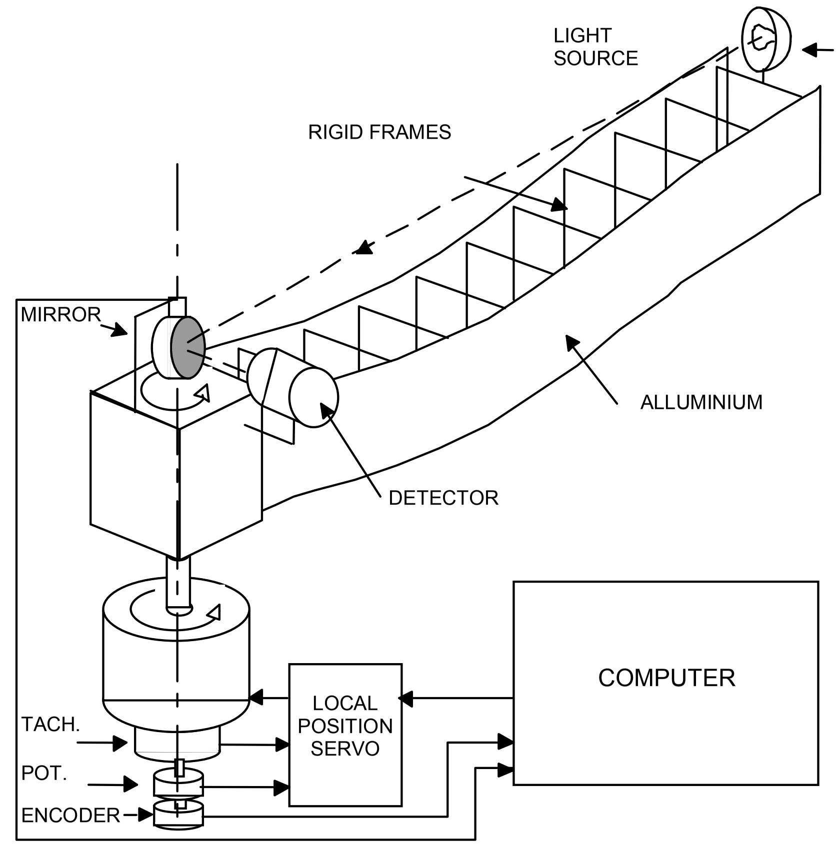
Regulation





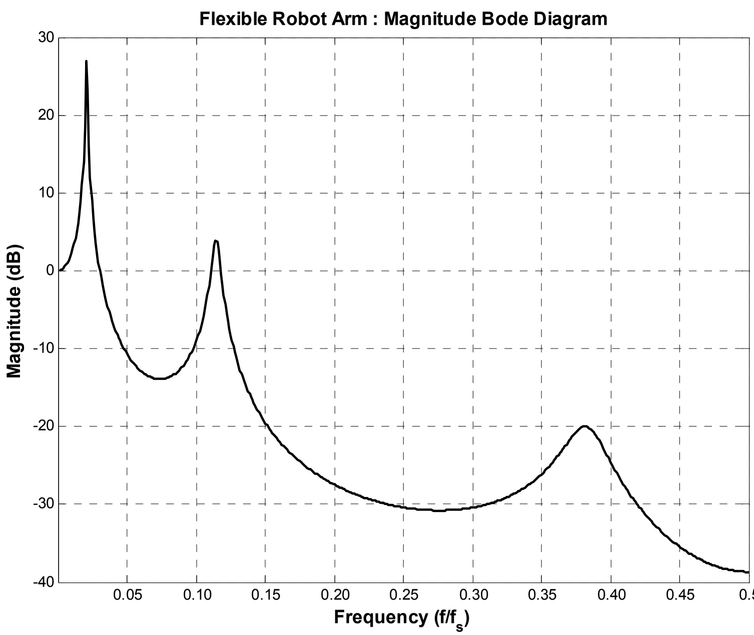
Control of a 360° Flexible Robot Arm



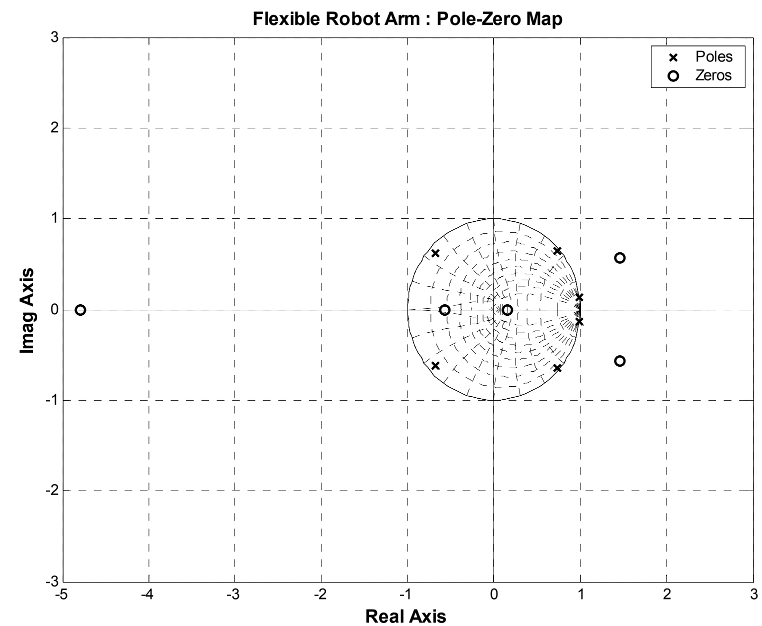


Control of a 360° Flexible Robot Arm

Identified model



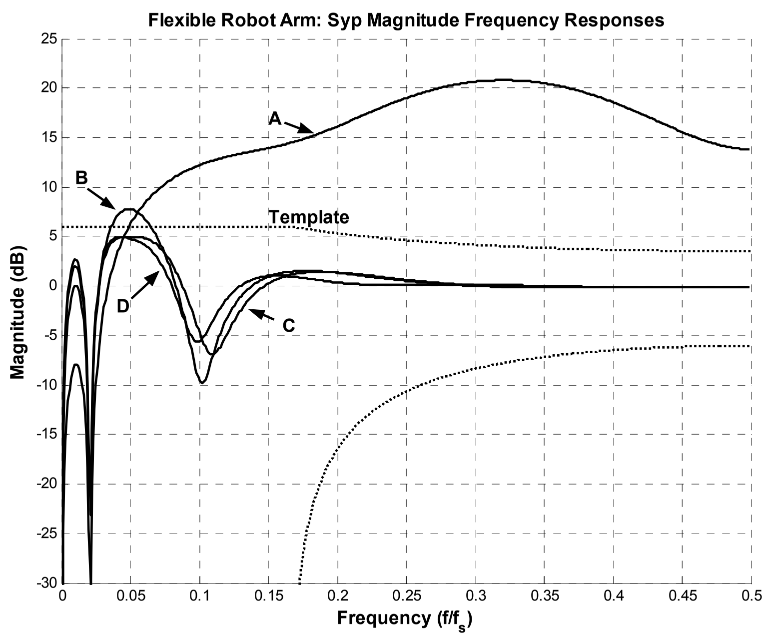
Plant frequency characteristic



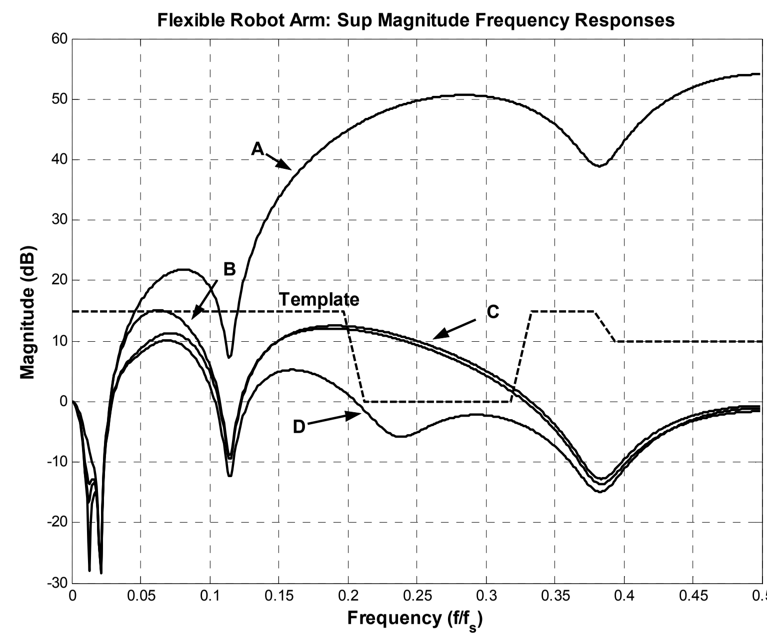
Plant pole-zero map

Control of a 360° Flexible Robot Arm

Controller design
Pole placement with sensitivity functions shaping



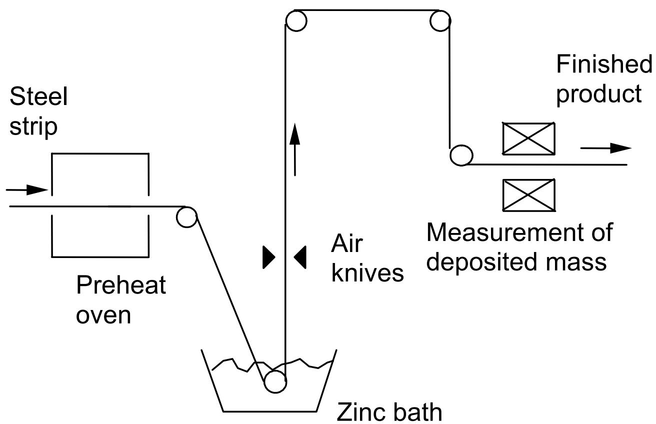
Output sensitivity function

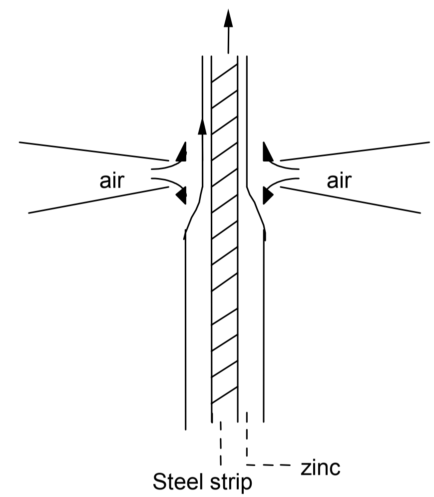


Input sensitivity function

For details see book pg. 358 - 364

Control of Deposited Zinc in Hot Dip Galvanizing Sollac-Florange





Pressure variation $\rightarrow$ mass variation of the deposited zinc

$$H(s) = \frac{Ge^{-s\tau}}{1+sT} \quad ; \quad \tau = \frac{L}{V}$$

L – distance between the air knives and the transducers

V – strip speed

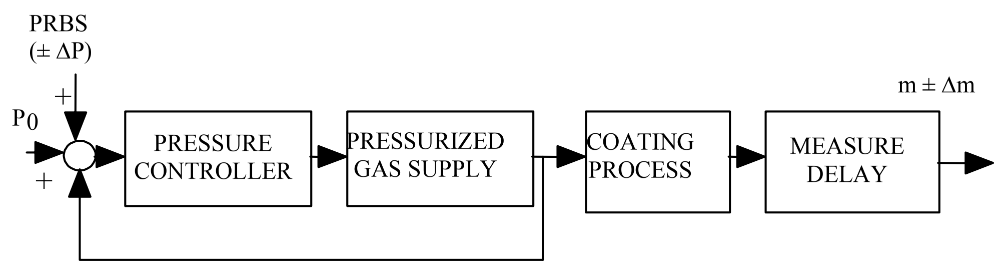
$$H(q^{-1}) = \frac{q^{-d}(b_1 q^{-1})}{1+a_1 q^{-1}}$$

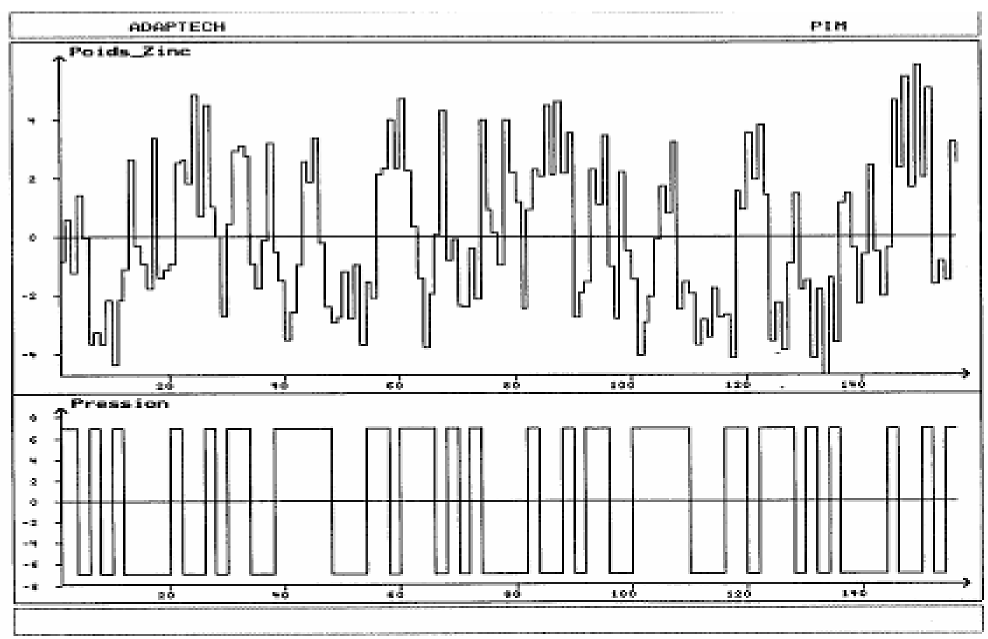
Sampling period (depends on the speed)

$$T_s = \frac{\left(\frac{L}{V}+\delta\right)}{d} \quad ; \quad d = \text{integer}$$

Control of Deposited Zinc in Hot Dip Galvanizing Sollac-Florange

System Identification

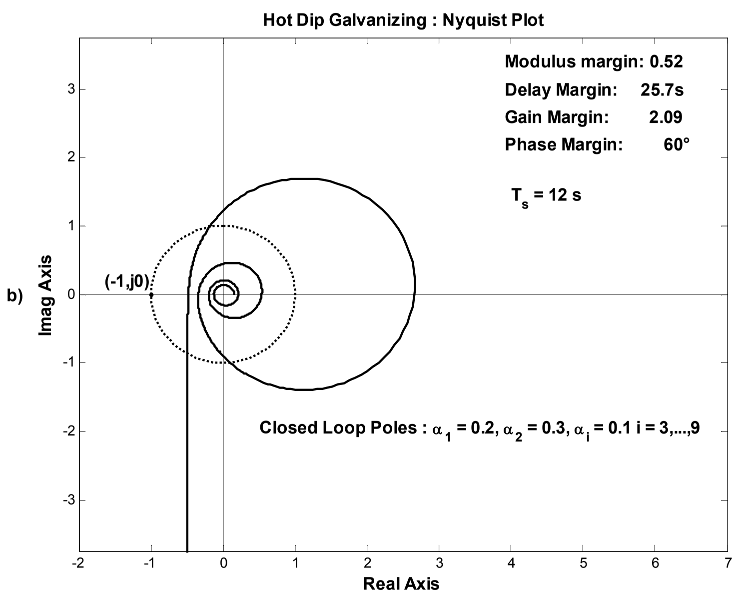


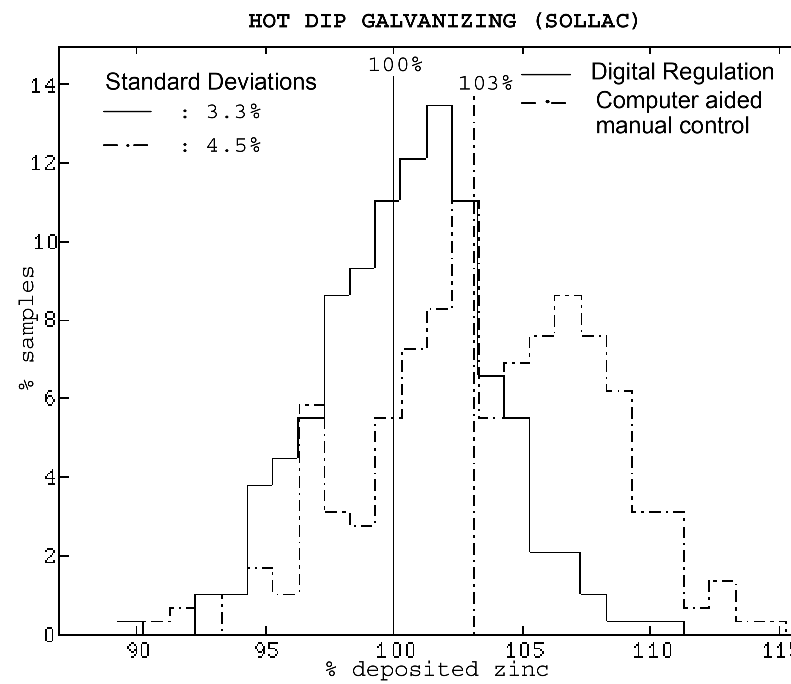


Control of Deposited Zinc in Hot Dip Galvanizing Sollac-Florange

Control Design

Pole-placement with shaping of the sensitivity functions





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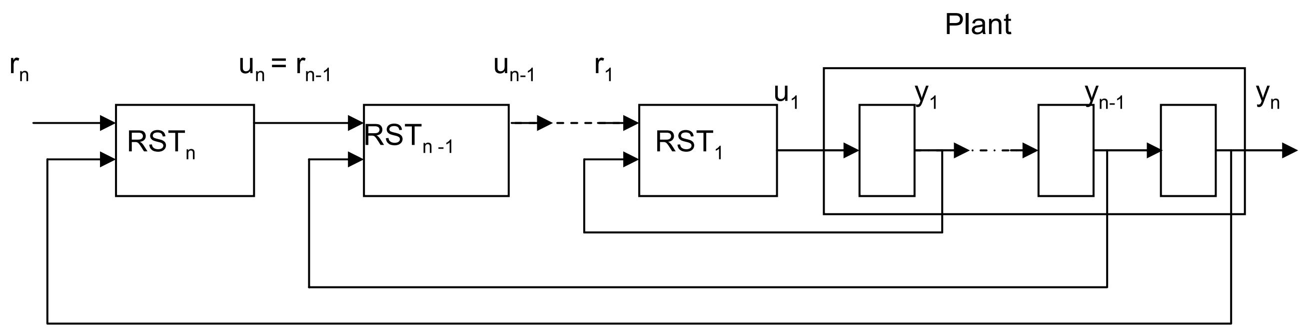
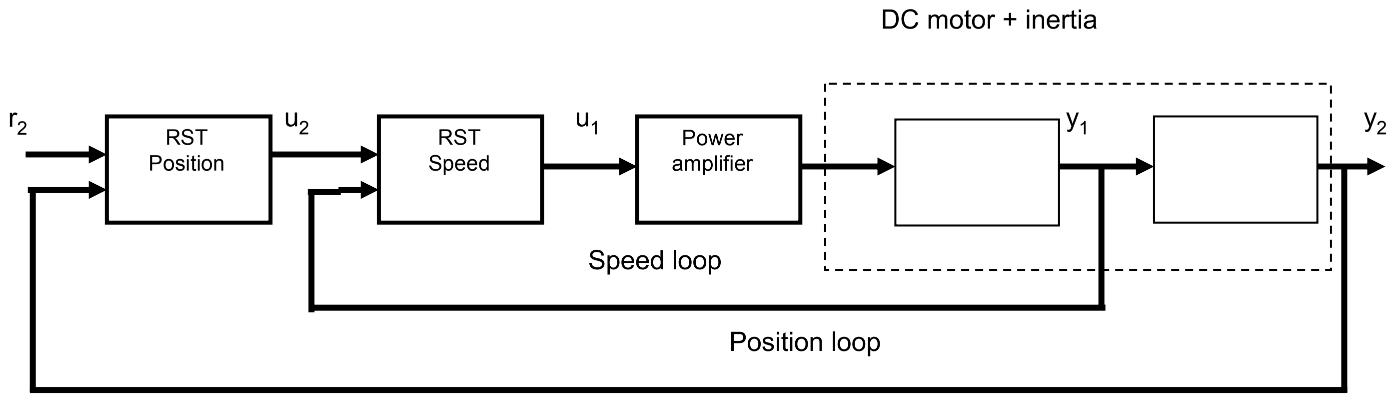
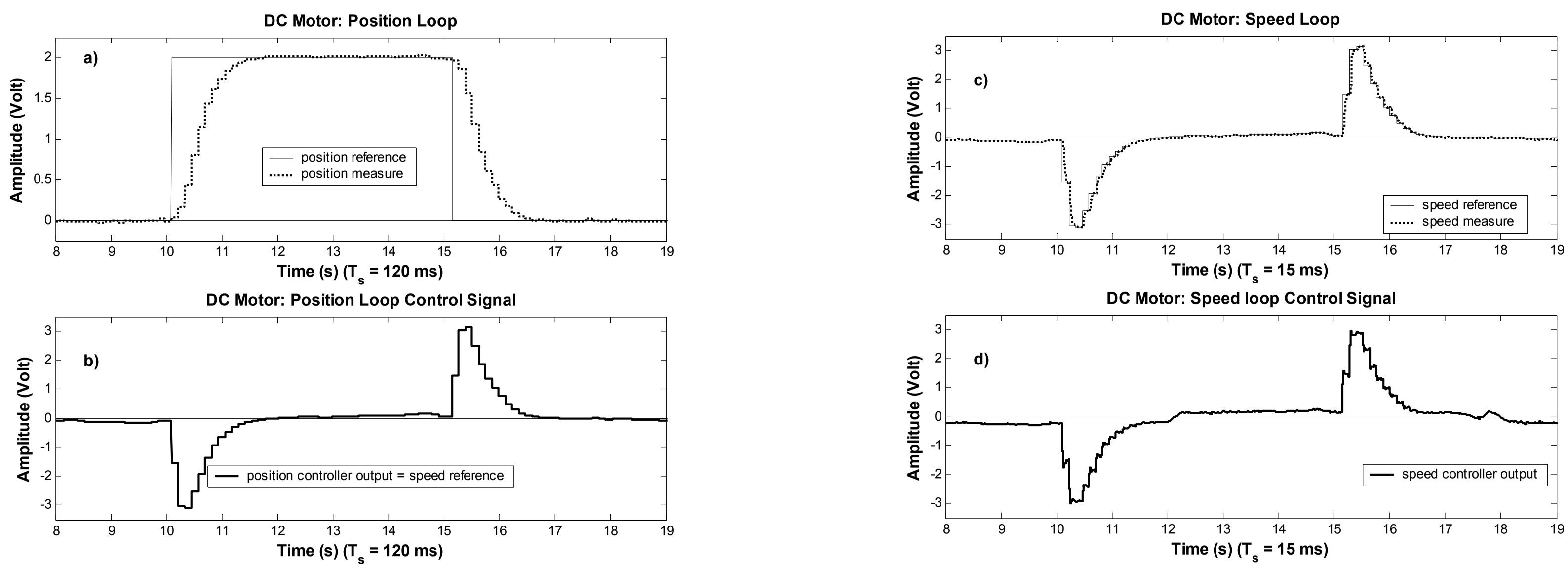
Digital cascade control



- The dynamics of the internal loops become more and more rapid as we approach the actuator
- This has to be taken in account for selection of the sampling frequency for each loop
- The sampling frequency of a loop k is an integer under multiple (or equal) of the sampling frequency of the loop k-1

Cascade Position Control of a DC Motor Axis





For details see book pg. 344 - 352

A few concluding remarks

Digital controllers can be implemented on a large variety of hardware

One has to pay attention to:

- specification of the desired performances taking into account the actuator power and band pass, the time response of the plant in open loop and the desired robustness margins
- computational delay and to the quantization effect of D/A converter
- introduction of anti-windup schemes to avoid problems with saturation
- implementation of a bumpless transfer procedure from open loop operation to closed loop operation
- sensitivity functions validation before the controller implementation

A helpful support:

C++ routines available on the book website

Adaptech : *Guide to the RST controllers implementation on programmable devices.(www.adaptech.com)*