Identification of dynamical systems

-

A case study with the QUBE servo 2

Hugues GARNIER

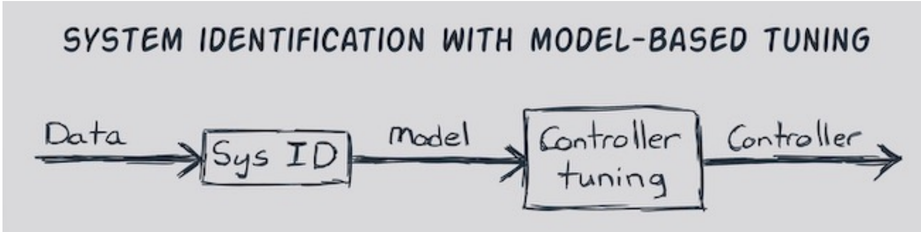
hugues.garnier@univ-lorraine.fr

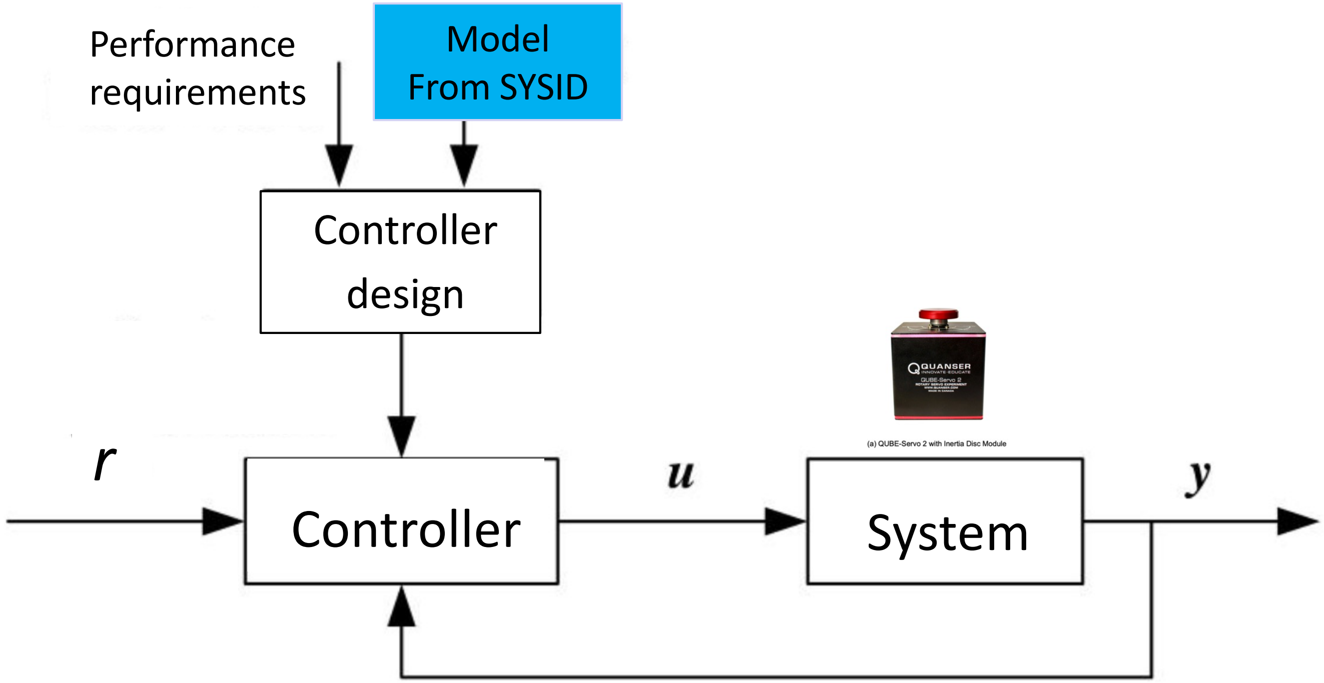
Qube-Servo 2


Inertia disc module
Encoder & tachometer
QUANSER
INNOVATE·EDUCATE
QUBE-Servo 2
ROTARY SERVO EXPERIMENT
WWW.QUANSER.COM
MADE IN CANADA

Model identification for control
What is it all about?

*Exploit a **model-based approach** for control design*





Model-based control design
Case study: Rotary speed control of the QUBE servo 2

(a) QUBE-Servo 2 with Inertia Disc Module

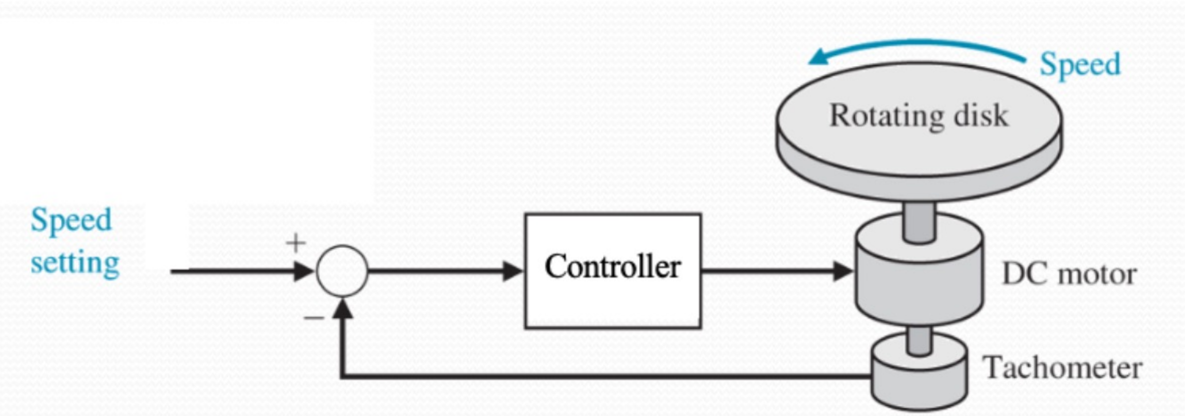
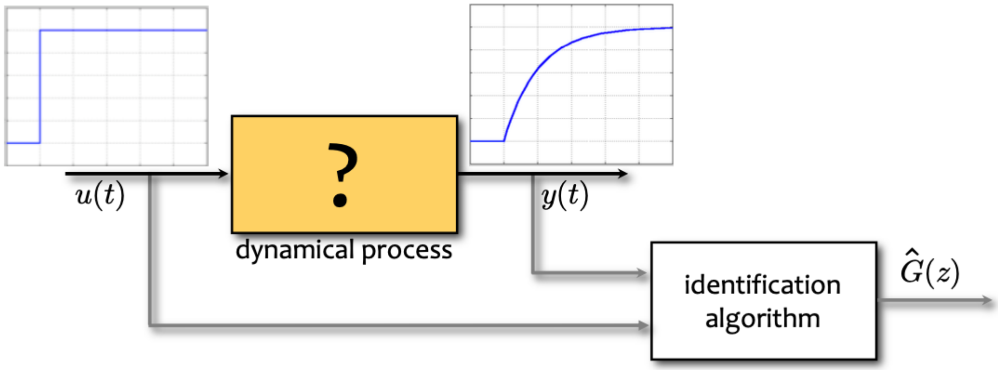


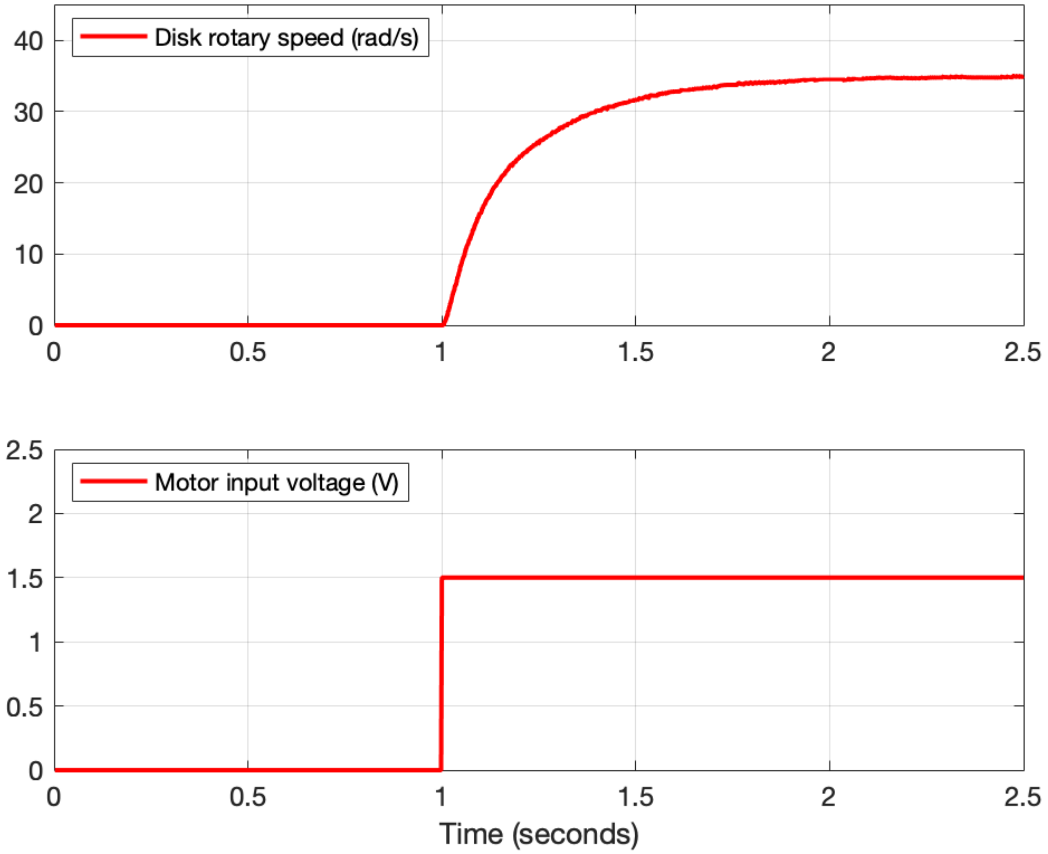
Figure 1.2: Schematic of the feedback speed control of the rotating disk

Basic system identification method
Step response-based model identification



- Excite the process with a step $u(t)$, record output response $y(t)$
- Observe the shape of $y(t)$
  (1st-order response ? 2nd-order undamped response ? Any delay ? ...)

Start with a simple step response

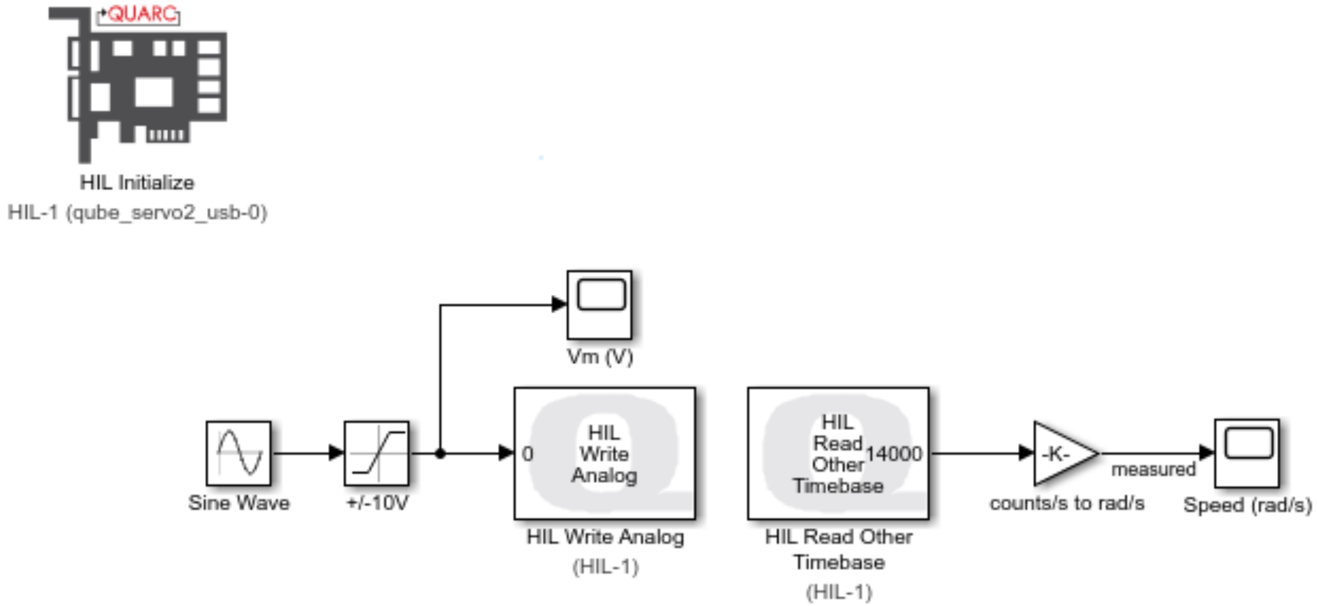


(a) QUBE-Servo 2 with Inertia Disc Module

Input voltage-to-angular velocity transfer function

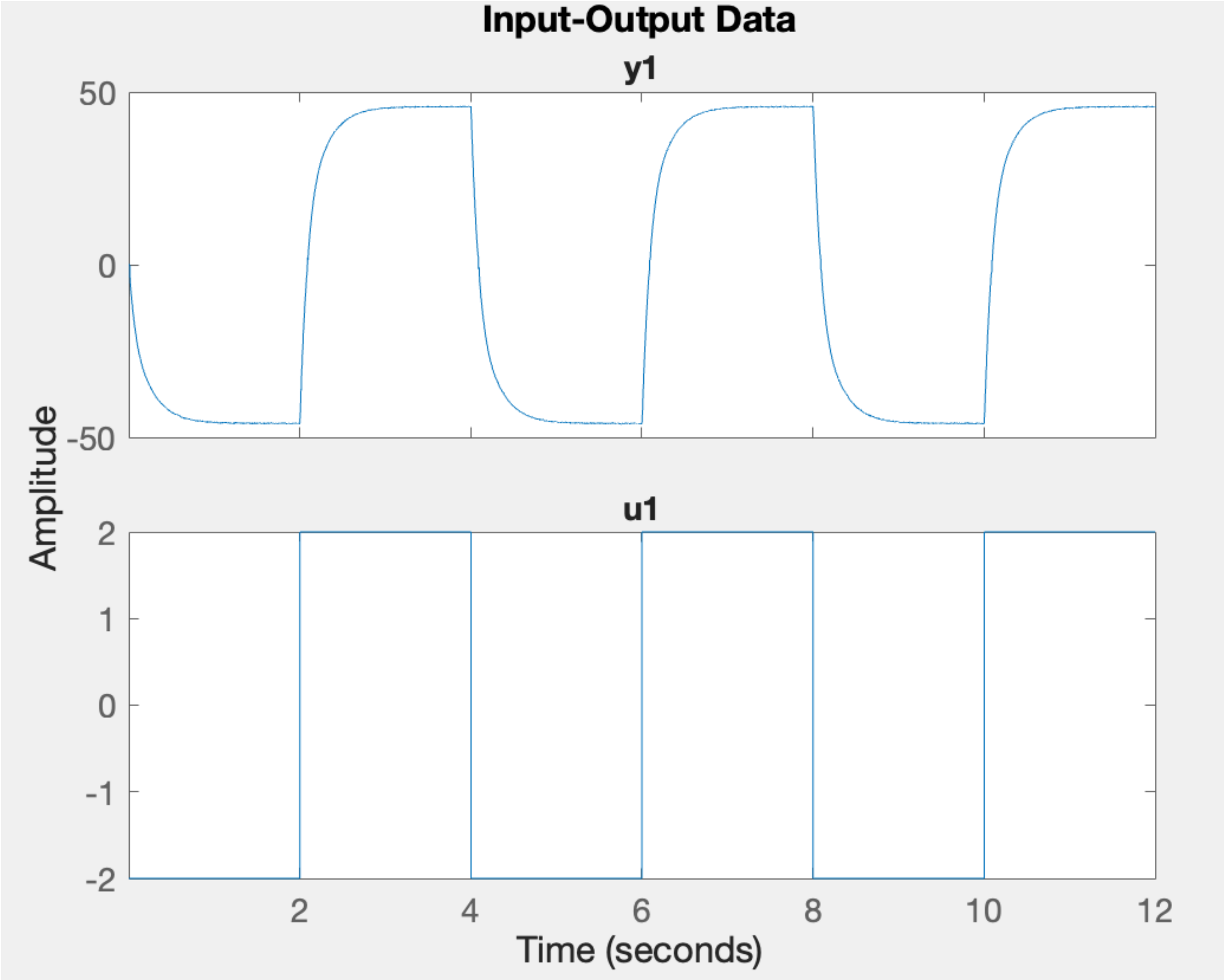
$$\frac{\Omega_m(s)}{V_m(s)} = G(s) = \frac{K}{Ts+1}$$

Choose an excitation signal (square wave, ...)
Measure the open-loop response of the speed via the tachometer



H. Garnier

Apply a richer excitation signal: a square wave for example



Example: Model identification of the QUBE servo 2 by using the PROCSRIVC routine from the CONTSID toolbox

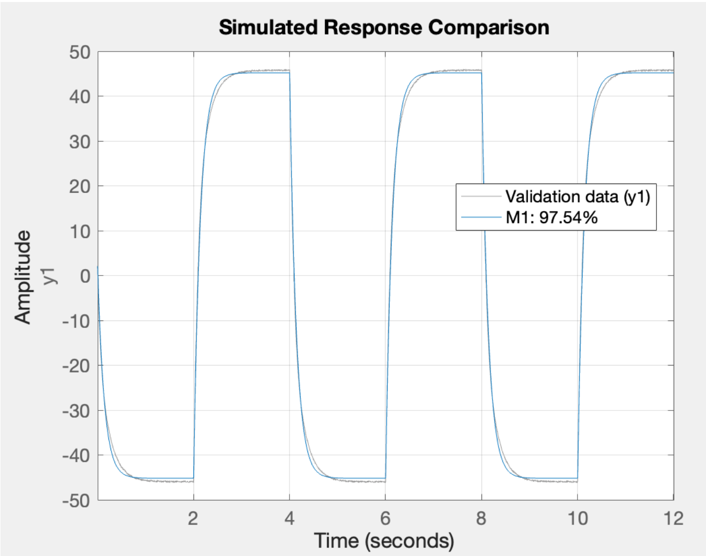
(a) QUBE-Servo 2 with Inertia Disc Module

```
load data_step_Qube_speed
t=speed_data(1,:)'; % time-instants
y=speed_data(2,:)'; % rotary speed in rad/sec
u=speed_data(3,:)'; % motor input voltage in V
Ts=t(2)-t(1);       % Sampling period in sec

data=iddata(y,u,Ts);
idplot(data)

Model_type=idproc('P1'); % Simple first-order model
M=procsrivc(data,Model_type)
Process model with transfer function:
              Kp
  G(s) = ----------
           1+Tp1*s

        Kp = 22. 598
       Tp1 = 0.13845
```



H. Garnier

PI SPEED CONTROL

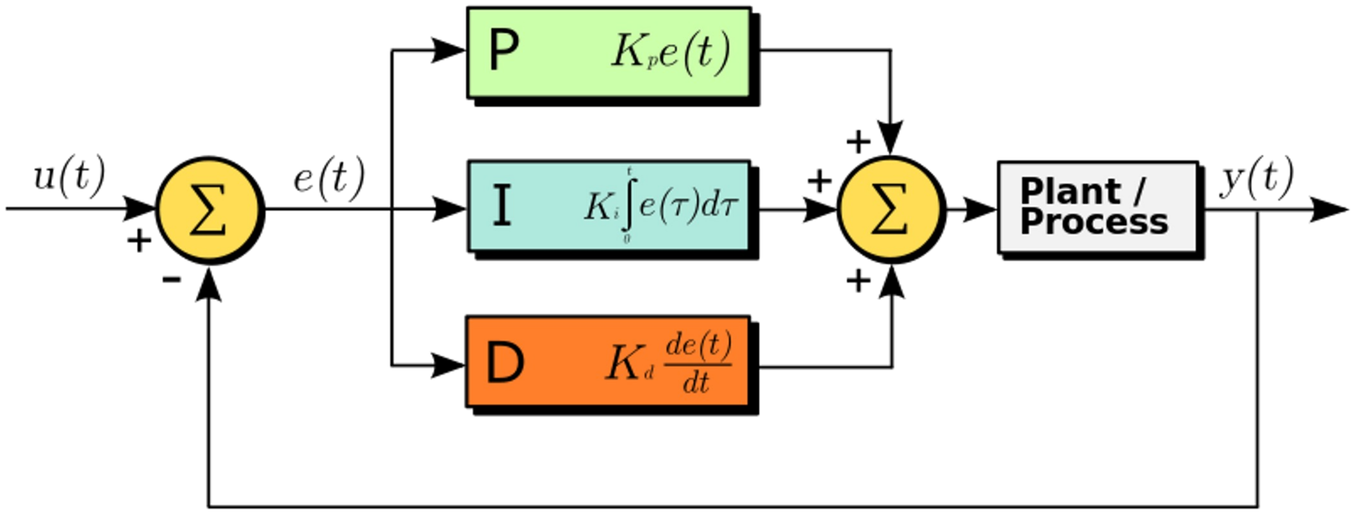
PID overview

Tuning PI speed controller

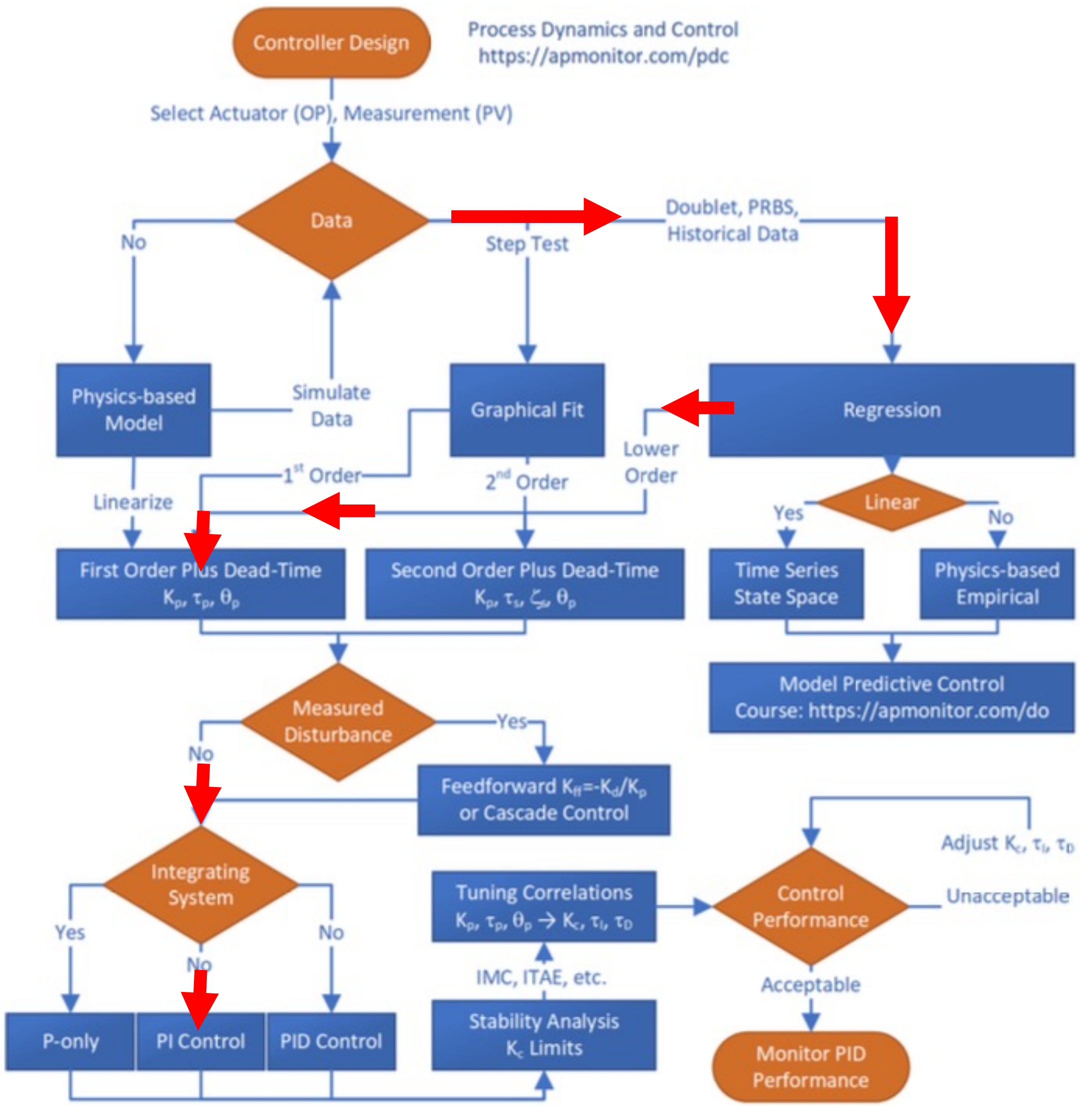
PI control design

PID Control

- Common control used in feedback loop for single-input single output systems
- PID = Proportional-Integral-Derivative



Why PI control when *G(s)* is a simple first order transfer function ?



H. Garnier

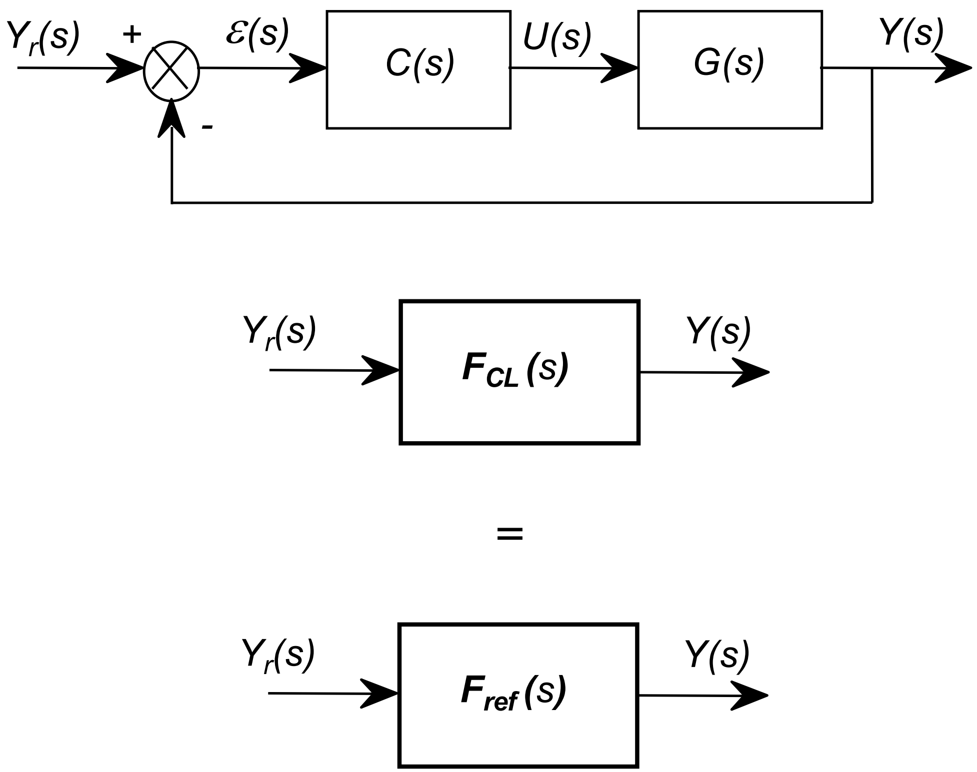
Why no D?

- Derivative term does not provide much benefit when performing speed tracking control

- Makes designing for control specifications more difficult

PID tuning by the reference model method

We want to select and tune $C(s)$ such that $F_{CL}(s)$ behaves like a reference model $F_{ref}(s)$ which takes, usually, the form of a standard second-order transfer function model



Standard 2nd Order System for the reference model

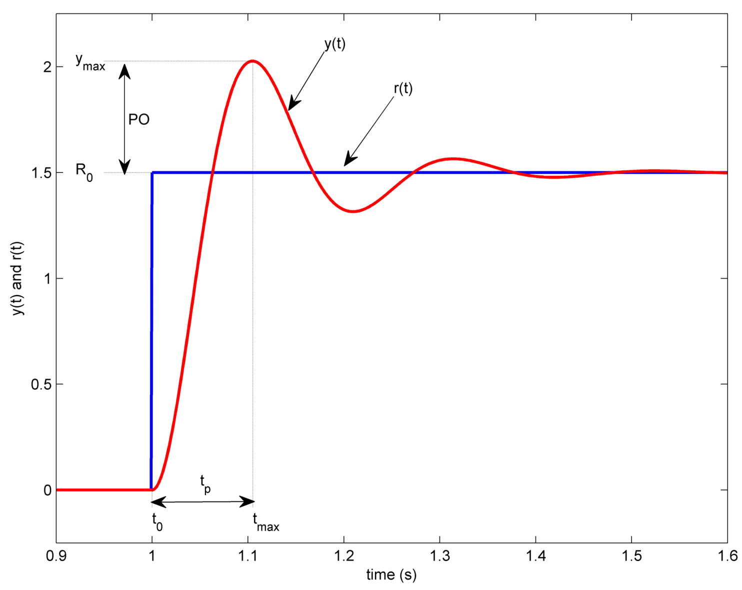
- Recall the 2nd-order transfer function of the reference model:

$$F_{ref}(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n + \omega_n^2}$$

➢ ω_n is the natural frequency

➢ ζ is the damping ratio

Step response of 2nd order system



H. Garnier

Finding natural frequency and damping coefficient from desired percent overshoot and settling time

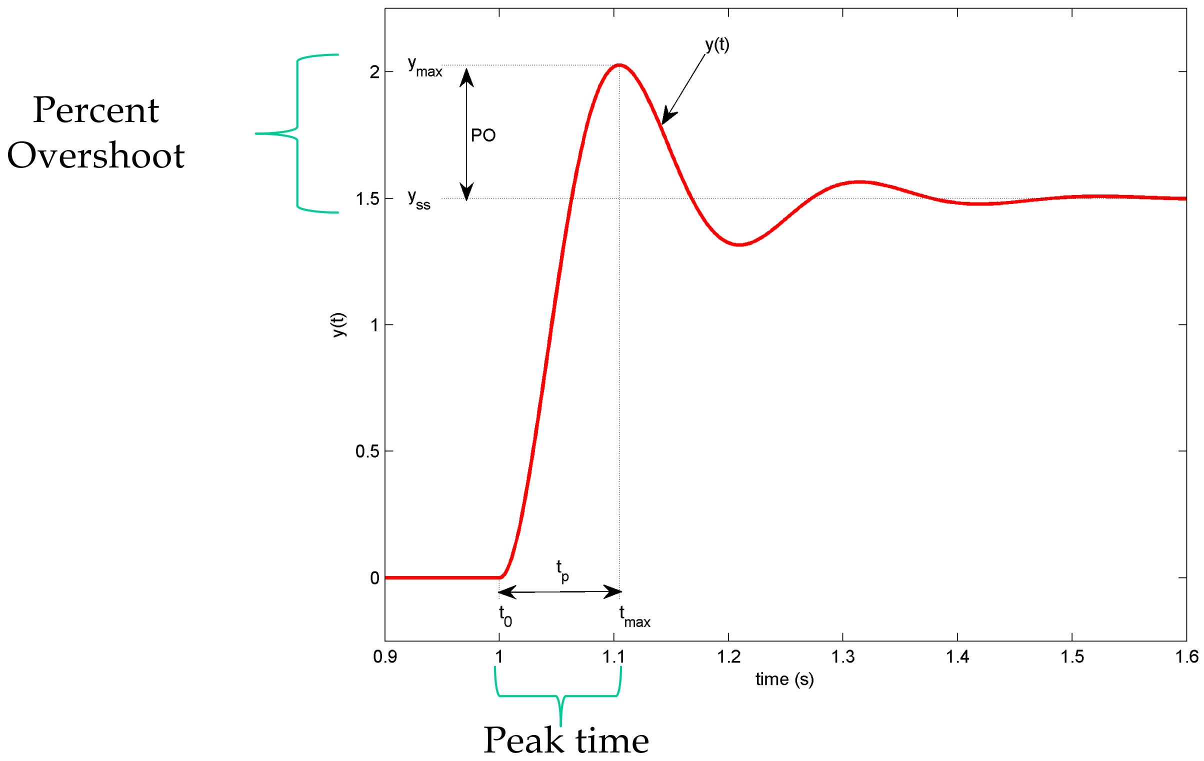
- From desired percent overshoot PO and settling time $t_s^{5\%}$ given in the specification requirements, determine:
  - Percent overshoot

$$\zeta = \sqrt{\frac{(\ln(PO/100))^2}{\pi^2 + (\ln(PO/100))^2}}$$

  - Natural frequency

$$\omega_n = \frac{3}{t_s^{5\%}} \quad when \quad \zeta = 0{,}707$$

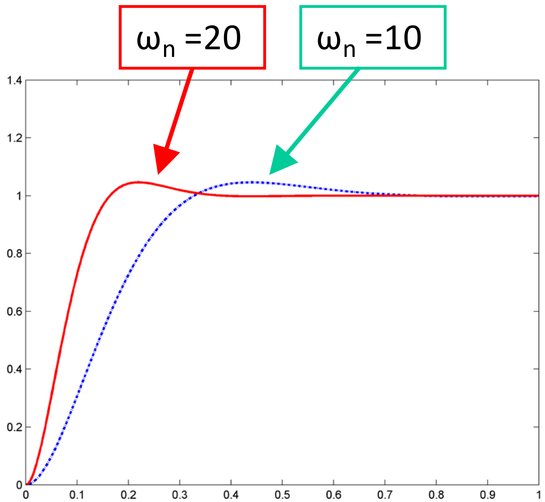
Peak time/settling time and percent overshoot



H. Garnier

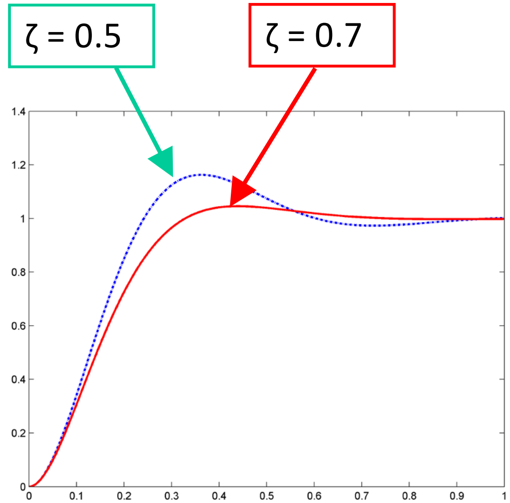
Effect on the step response?

Natural frequency effects the response speed



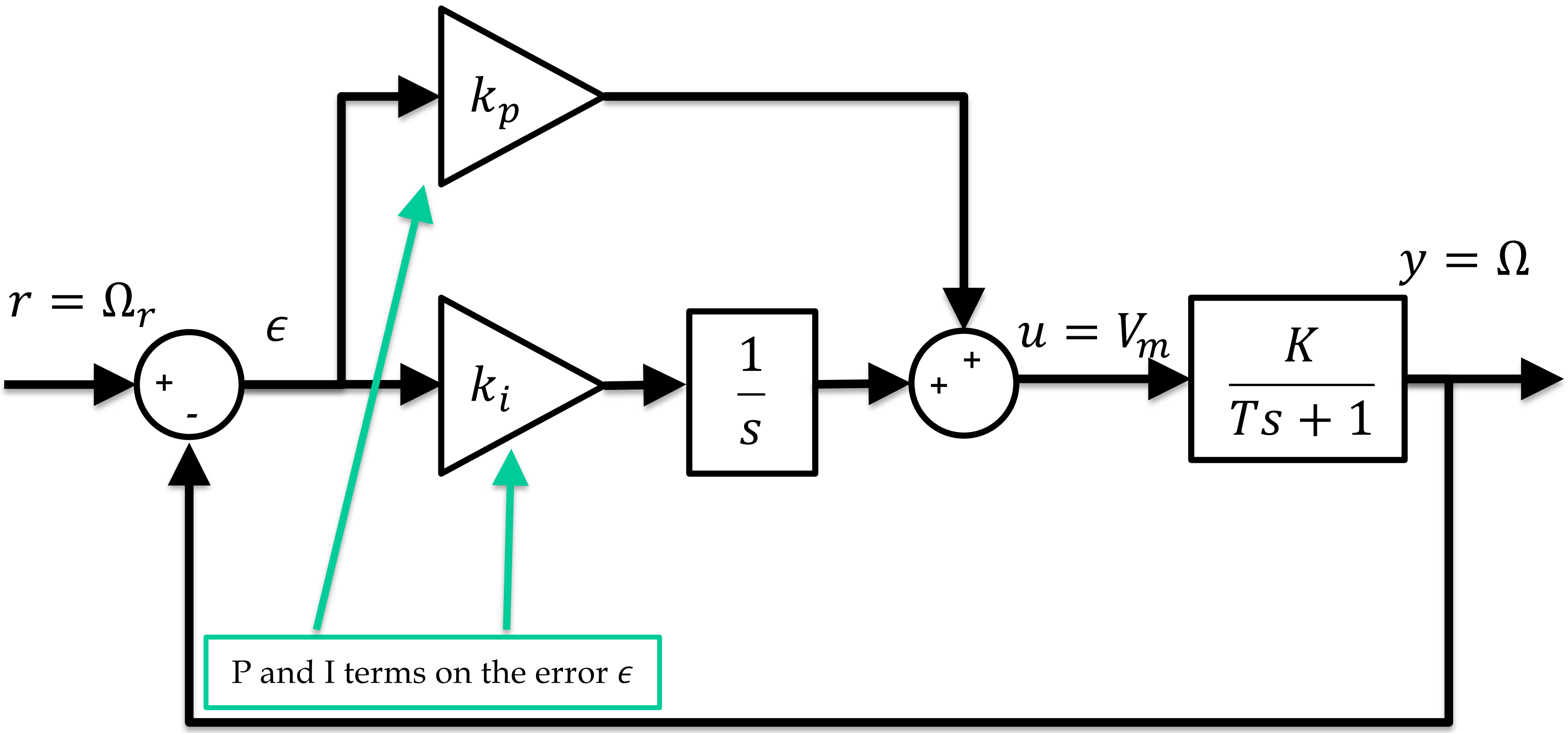
Increasing the natural frequency makes the response faster

Damping ratio effects the response shape



System is known as being **critically damped** when $\zeta = 1$; there is *no overshoot*

PI Control for DC Servo Motor
Both P and I terms applied to the error



Closed-loop transfer function with standard PI controller

- Plant model

$$G(s) = \frac{\Omega(s)}{U(s)} = \frac{K}{Ts + 1}$$

- PI controller

$$C(s) = \frac{U(s)}{\epsilon(s)} = k_p + \frac{k_i}{s}$$

- Find closed-loop transfer function

$$F_{CL}(s) = \frac{K(k_p s + k_i)/T}{s^2 + \frac{(1 + Kk_p)s}{T} + \frac{Kk_i}{T}}$$

H. Garnier

Closed-loop transfer function with standard PI controller

Numerators does not match !

Closed-loop transfer function with standard PI controller

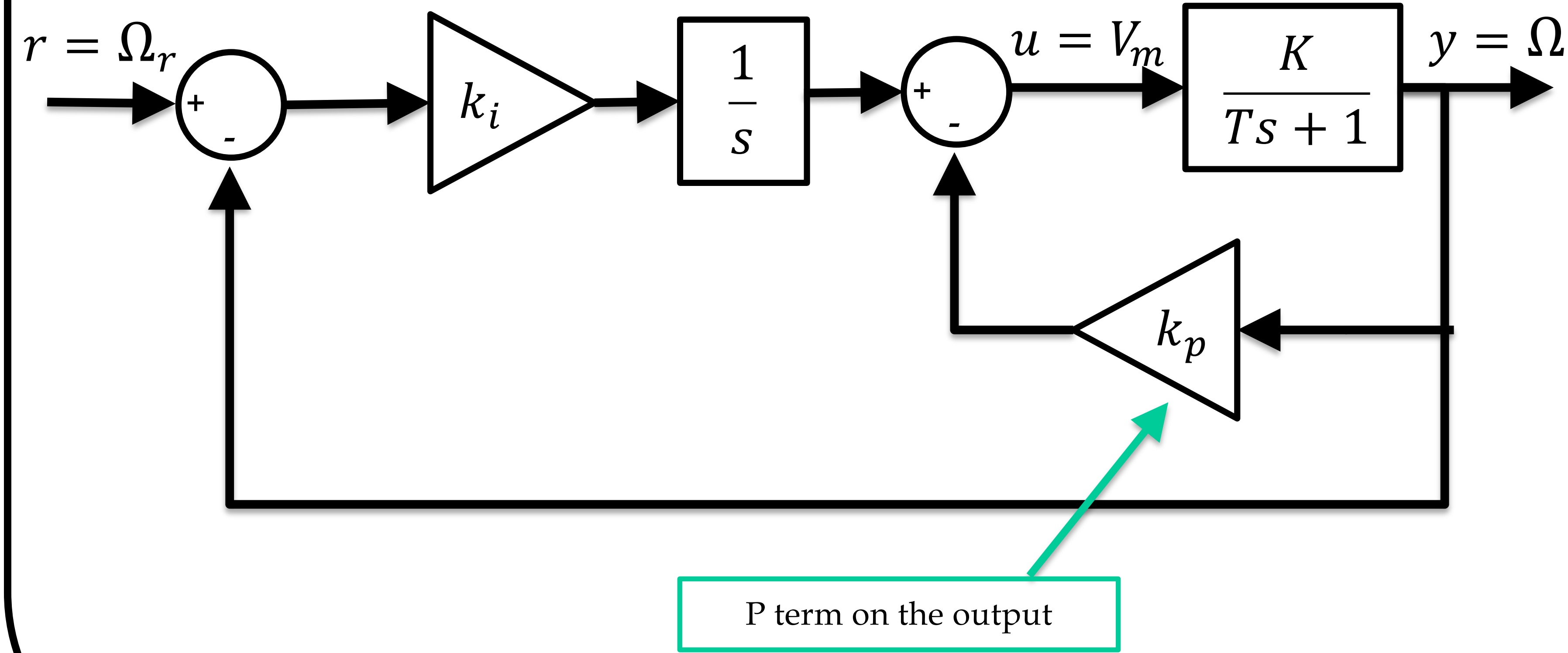
$$F_{CL}(s) = \frac{K(k_p s + k_i)/T}{s^2 + \frac{(1 + K k_p)s}{T} + \frac{K k_i}{T}}$$

2nd-order transfer function of the reference model

$$F_{ref}(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Denominator match

PI Control with P term on the output



PI Control with P on the output

Closed-loop transfer function
with PI controller (P term on the output)

$$F_{CL}(s) = \frac{Kk_i/T}{s^2 + \frac{(1+Kk_p)s}{T} + \frac{Kk_i}{T}}$$

2nd-order transfer function
of the reference model

$$F_{ref}(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$\omega_n^2 = \frac{Kk_i}{T}$$

$$2\zeta\omega_n = \frac{1+Kk_p}{T}$$

$$k_p = \frac{2\zeta\omega_n T - 1}{K}$$

$$k_i = \frac{\omega_n^2 T}{K}$$

Both numerator and denominator match. Transient response of the closed-loop PI control should be close to the desired response of the reference model

UNIVERSITÉ DE LORRAINE

POLYTECH NANCY

Summary
PI tuning for a given (ζ , ω_n) when P term on the output

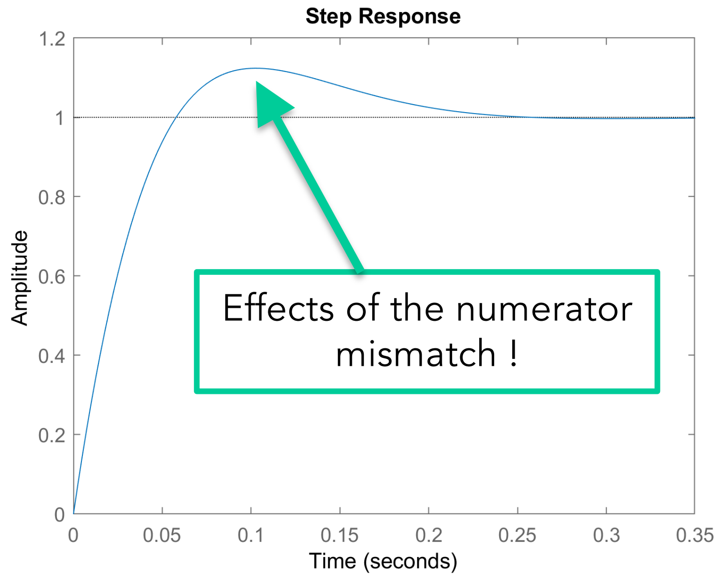
1. Based on required settling time and overshoot → get ζ and ω_n

2. Given ω_n and ζ, what the PI gains k_p and k_i should be set as

$$\boxed{\begin{aligned} k_p &= \frac{2\zeta\omega_n T - 1}{K} \\ k_i &= \frac{\omega_n^2 T}{K} \end{aligned}}$$

Closed-loop response of the two possible PI controller implementation

Standard PI
P and I on the error



Recommended PI
with P on the output