2A - Automatique

Chapter 5

Control Science (AUT)

Frequency-domain approach, Design Methods, II

September 2019

Romain Bourdais
CentraleSupélec
romain.bourdais@centralesupelec.fr

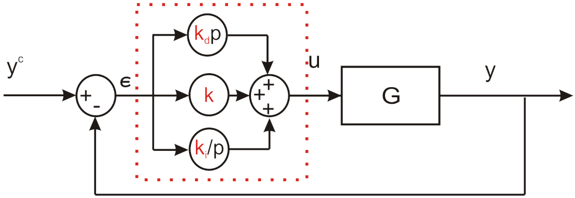
Preamble
About this course

Course Outline

- PID : The most famous control
- Feedforward Control
- Non trivial Feedback
- Parallel compensation

Outline

A few words about PID
Definition



- Parallel compensation, but should be seen as a serial action !
- Three setting parameters : k, k_i, k_d
- (There is a fourth parameter often hidden . . .)

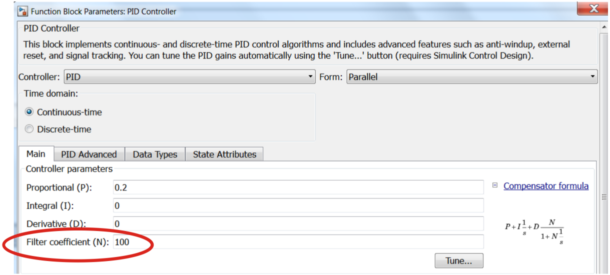
$$C(p) = k + \frac{k_i}{p} + k_d p, \qquad C(p) = K\left(1 + \frac{1}{T_i p} + T_d p\right)$$

A few words about PID

Study according to the values of T_i and T_d

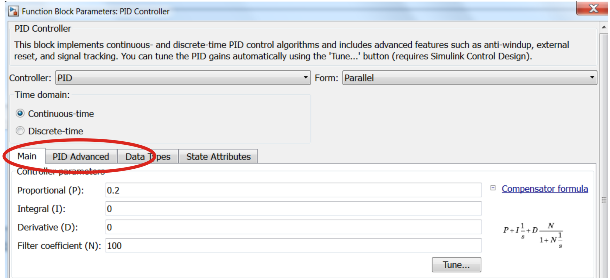
$$C(p) = K\left(1 + \frac{1}{T_i p} + T_d p\right) = K\left(\frac{1 + T_i p + T_i T_d p^2}{T_i p}\right)$$

A few words about PID
Let us have a look in Matlab



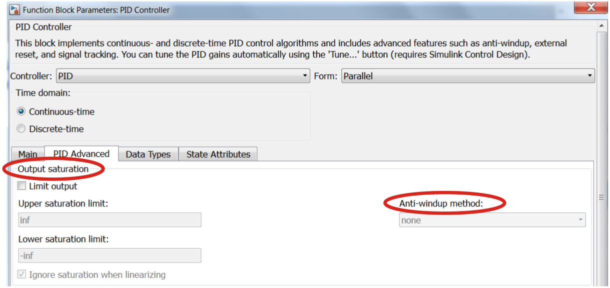
- The fourth parameter is a filter (feasibility of the derived action)

A few words about PID
Let us have a look in Matlab



- There are many advanced settings

A few words about PID
Let us have a look in Matlab



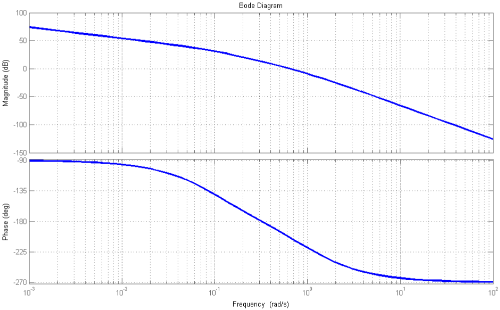
- Importance of saturation : significant performance losses !
- Possibles strategies : anti wind-up, . . .

A few words about PID
The OLD-SCHOOL Zigler-Nichols method (https ://fr.wikipedia.org)

Méthode de Ziegler-Nichols[1]			
Type de contrôle	K_p	K_i	K_d
P	$K_u/2$	-	-
PI	$K_u/2.2$	$K_p/T_u/1.2$	-
PID classique[2]	$0.60K_u$	$2K_p/T_u$	$K_pT_u/8$
Pessen Integral Rule[2]	$0.7K_u$	$2.5K_p/T_u$	$0.15K_pT_u$
quelques dépassements[2]	$0.33K_u$	$2K_p/T_u$	$K_pT_u/3$
pas de dépassement[2]	$0.2K_u$	$2K_p/T_u$	$K_pT_u/3$

- K_u : limit gain for closed-loop stability
- For this limit, oscillating behavior : T_u is the pseudo-period of these oscillations

A few words about PID
The OLD-SCHOOL Zigler-Nichols method : let's try !



- What is the value of the limit gain K_u ?

A few words about PID

The OLD-SCHOOL Zigler-Nichols method : let's see what happens !

A few words about PID
The OLD-SCHOOL Zigler-Nichols method : let's do better !

- Specifications : same rise time, but 20% overshoot.

A few words about PID
Conclusion

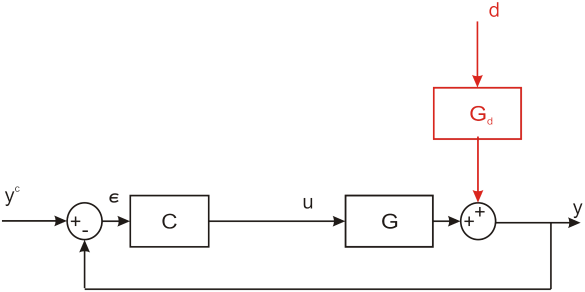
What to remember

- Most used industrial controller
- 3(4) setting parameters
- $T_i = 4T_d$
- Can affect accuracy, speed and stability
- Existence of heuristics for tuning (not necessarily effective)

Outline

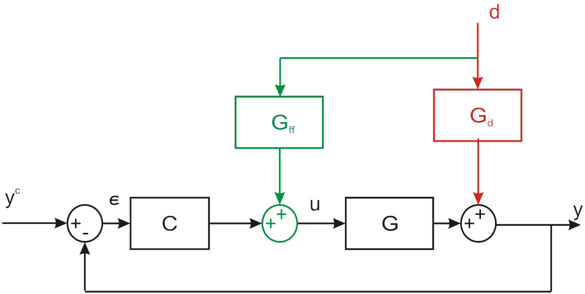
Feedforward
Problem statement - example of a disturbance

- Knowledge of a disturbance, supposedly measured



Feedforward
Problem statement - example of a disturbance

- Construction of a controller to anticipate this disturbance

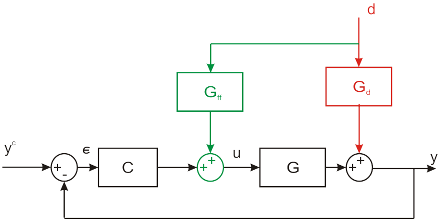


- How to build G_{ff} ?

Feedforward

Problem statement - example of a disturbance

- How to build G_{ff} ?



- We have

$$Y(p) = G(p)U(p) + G_d(p)D(p)$$

- Which leads to :

$$G_{ff} = -\frac{G_d}{G}$$

Feedforward

Problem statement - example of a disturbance

$$G_{ff} = -\frac{G_d}{G}$$

1st remark : feasibility

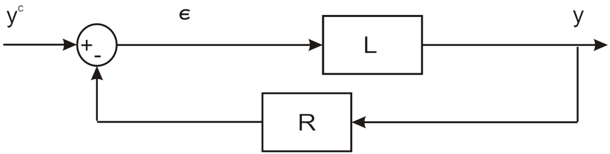
- Be careful about the feasibility of the controller !
- Add filters if necessary

2nd remark : stability

- Be careful with the stability of the corrector !
- Do not add unstable poles
- Beware of the zeros of $G(p)$!

Outline

Non trivial Feedback
Closed-loop diagram

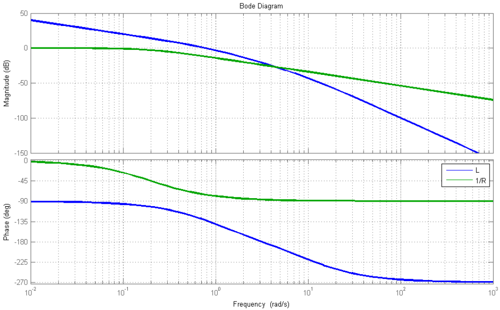


- In closed-loop, the transfer is :

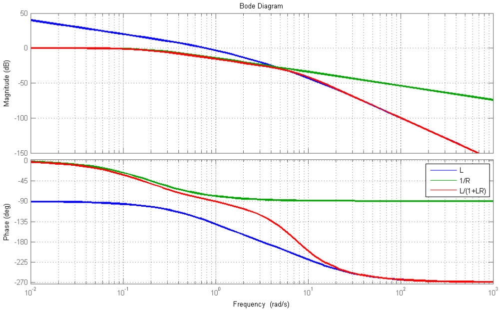
$$\frac{Y}{Y^C} = \frac{L}{1+RL} = \frac{\frac{L}{R}}{\frac{1}{R}+L}$$

- How to use « THE APPROXIMATION » ?

Non trivial Feedback
Example in Matlab



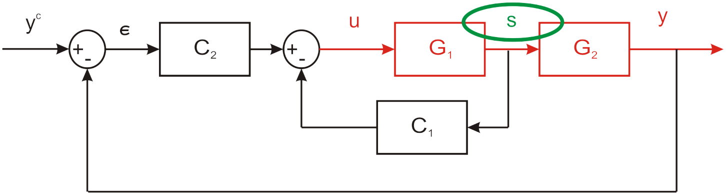
Non trivial Feedback
Example in Matlab



- This is a generalization of the unit case !
- For stability analysis : Analysis with RL

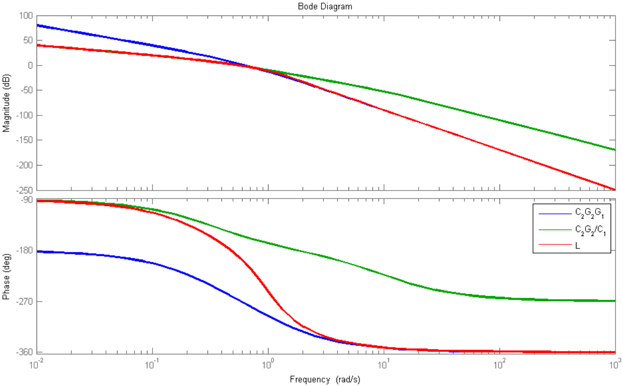
Outline

Parallel compensation
A cascading structure : example



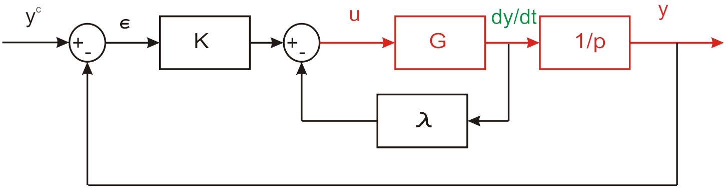
- Requires additional sensors
- Case-by-case approach

Parallel compensation
A cascading structure : example

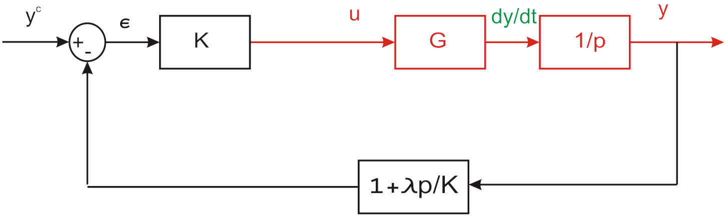


- Intersection points : $|C_1 G_1| = 1$

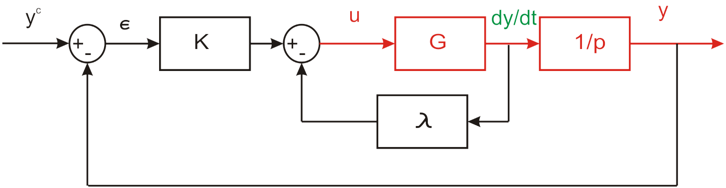
Parallel compensation
Tachometric feedback



- Remark : equivalence with



Parallel compensation
Tachometric feedback

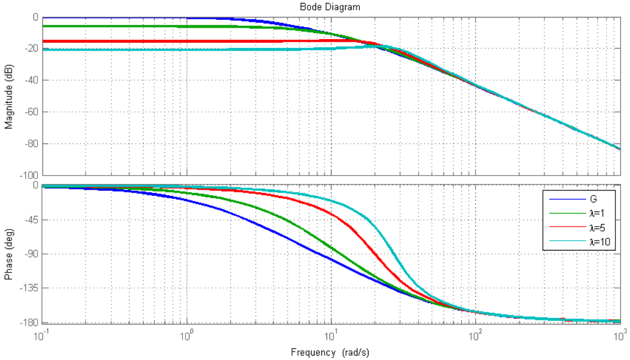


- Example :

$$G = \frac{1}{(1+\tau_1 p)(1+\tau_2 p)}$$

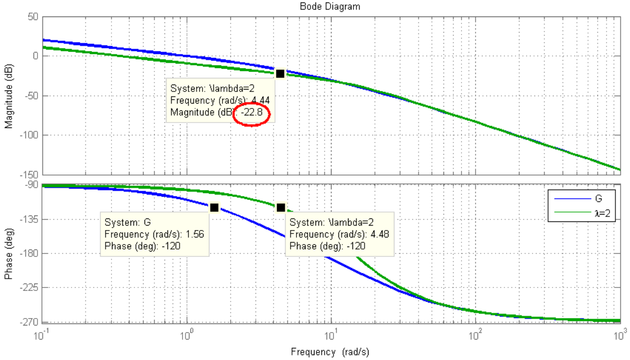
- Specifications : 10% overshoot, cut-off pulsation at 0dB : 20 $\mathrm{rad.s}^{-1}$

Parallel compensation
Tachometric feedback



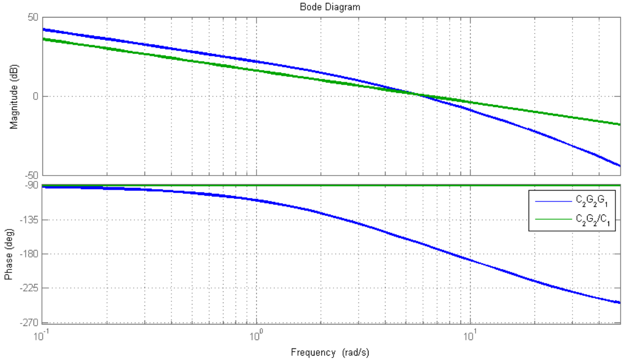
- Effect of λ : phase shift

Parallel compensation
Tachometric feedback



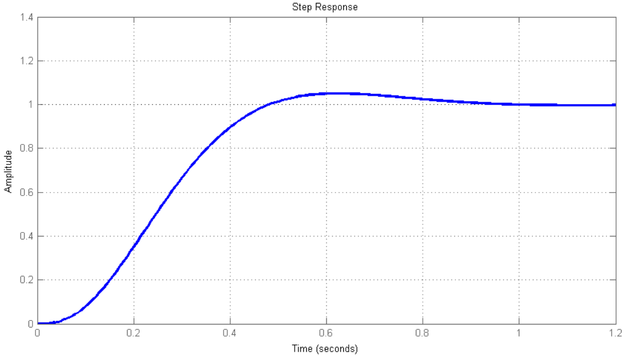
- Determination of λ to have the desired phase margin at the desired pulse
- Then, adjustment of the gain k to get the right bandwidth

Parallel compensation
Tachometric feedback



- Remark : it is just a particular case of parallel control

Parallel compensation
Tachometric feedback



- The temporal behavior looks nice !

Outline

Conclusion
At the end of this course

Expected skills

- Understand the PID, its settings, the effect of the parameters
- Do not limit yourself to the single feedback : Tachometric feedback feedback, Feedforward
- Have the basics to analysis any type of correction