From:	Sigurd Skogestad
To:	Flore Griet M Ryckeboer
Subject:	RE: questions about lectures process control
Date:	torsdag 31. oktober 2024 20:48:00
Attachments:	image004.png image005.png image006.png image007.png

Hello

See below.
Please ask if you still don't understand

From: Flore Griet M Ryckeboer <fgryckeb@stud.ntnu.no>
Sent: Thursday, October 31, 2024 4:59 PM
To: Sigurd Skogestad <sigurd.skogestad@ntnu.no>
Subject: questions about lectures process control

Dear professor

I have some questions about the lectures.
I listed them in this email. Would it maybe be possible to answer them?

Question 1:
What do you choose for Tc when there is no delay? Sometimes we compare Tau/2, Tau/3, ... but how do you know where to stop? When will the control be too tight?
[]
There is no specific rule for tauc, except that tauc > theta (so theta is the min-value)
Generally, we want tauc as large as possible for robustness, but we want tauc small for performance.

Performance: there may be some requirement on how large changes in y you can accept for disturbances which gives a max value for tauc smaller. I will discuss this 2-3 weeks from now,

Question 2:
I'm a little confused about the formula of the process gain.
For a first order step response, it is defined as k = Δy(∞)/ Δu.
For an integrating process, it is k' = slope = Δy/ (Δt* Δu).
I thought the slope was just Δy/ Δt, without the Δu part.
[] Yes, the slope is what you say, but we are here talking about the slope gain k', and then it must ne normalized by du.

This would mean that k' or process gain equals the slope *** 1/ Δu.** And slope and process gain are then 2 different concepts.
However, in further formulas, we always write k', but does this correspond to Δy/ Δt or Δy/ (Δt *Δu)?
[] k' is always the latter
Another used formula is k'= k/Tau. Does this correspond to Δy/ Δt or to Δy/ (Δt* Δu)?
[] It's again the latter; so always normaize by du.

Question 2:
I don't understand the connection between:
e = ys-y
e = S (ys-Gd*d) with S = sensitivity function

- Shouldn't there be a G*u as well?

[] No, u has been eliminated by u = C(ys-y).
e = ys – y
Define L = GC
Eliminate u to get the closed-loop response
y = T ys + S Gd d, where S = 1/(L+L), T = L/(1+L) . Note that T = 1-S = 1 – 1/(1+L) = L/(1+L)

e = S*ys
These formulas originate from slideshow 5 about transfer functions (slide 28, 29).

Question 3:

I don't really understand what "gain margin" is. In lecture 6 (half rule), we use it in the discussion about tight control. What does gain margin = 3 mean? Is it good or bad?

[] The gain margin should be as large as possible. Because the GM is how much we can multiply Kc*k before we get instability.

What does it say about the control and tuning? What would the gain margin be with smooth control?

[] I recommend GM > 3.

In the same slide show, there is a question about Tau-C (I added screenshots of the concerning slides below). I don't really understand the answer. Why do we want a large value for Tau-C? What will happen if Tau-C is too large?

[] You mean tauc < 1/wd? I didn't cover this yet. It comes 2-3 weeks from now

Queston 4:

I don't understand why the example on slide 21 from advanced control is worse with cascade control.

[] Cascade control is usually better. I think you talk about the setpoint response which is not always better. Yes, there may be a "bump" because the master doesn't know what the slave is doing.

TauC is larger with cascade control, which means smoother control, but isn't that a good thing?

[] Yes, it's better robustness, but not for performance.

What is the explanation of the bump in the plot? Is it because the inner and outer loop "fight", because the time scale separation isn't sufficient?

[] Yes

"Will setpoint tracking for y1 =T be improved with cascade (in this case)?

• No, since there was essentially no dynamics in G2=1/(s+1), it is actually slightly worse (tauc increased from 100 to 105).

• But if G2 was an integrating process, cascade could improve setpoint response" - slide 22 from advanced control

I don't understand what is meant by "no dynamics". ***[]***

[] "No dynamics" is meaning that 1/(s+1) is very fast. In this case cascade may not help so much for the setpoint response, but it helps for disturbances

Question 5:

I don't understand how the transfer functions in this example are build:

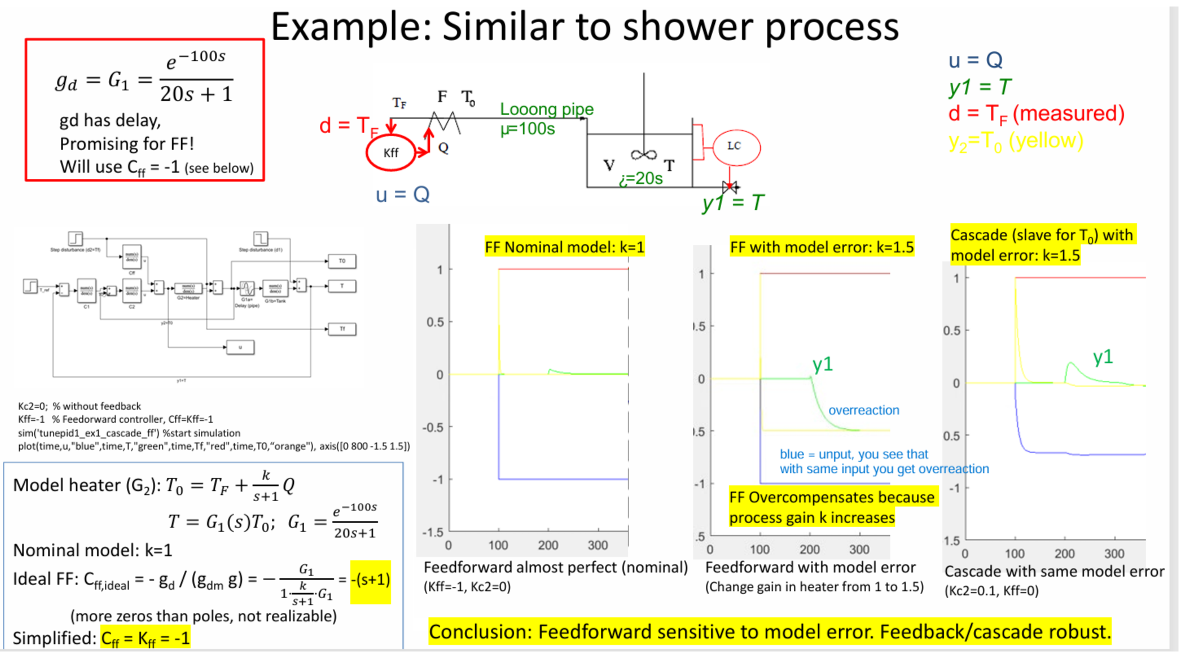
Can you explain how we get the expressions of T0 and T.

I tried it like this:

T0 = Gd * d + G* u = G1*Tf + G*Q

Why is there no Gd on the slides?

[] It's because I have put d where it actually occurs in the block diagram. Putting it at the same place as u is the same as having Gd=G.



Thank you in advance for your help.
Kind regards and have a nice day,
Flore Ryckeboer

Slides corresponding to the other questions:

TIGHT CONTROL

TUNING FOR FAST RESPONSE WITH GOOD ROBUSTNESS

$$\text{SIMC}: \quad \tau_c = \theta \tag{4}$$

Gives:

$$K_c = \frac{0.5}{k}\frac{\tau_1}{\theta} = \frac{0.5}{k'} \cdot \frac{1}{\theta} \tag{5}$$

$$\tau_I = \min\{\tau_1, 8\theta\} \tag{6}$$

$$\tau_D = \tau_2 \tag{7}$$

Gain margin about 3

Process $g(s)$	$\frac{k}{\tau_1 s+1}e^{-\theta s}$	$\frac{k'}{s}e^{-\theta s}$
Controller gain, K_c	$\frac{0.5}{k}\frac{\tau_1}{\theta}$	$\frac{0.5}{k'}\frac{1}{\theta}$
Integral time, τ_I	τ_1	8θ
Gain margin (GM)	3.14	2.96
Phase margin (PM)	61.4°	46.9°
Allowed time delay error, $\Delta\theta/\theta$	2.14	1.59
Sensitivity peak, M_s	1.59	1.70
Complementary sensitivity peak, M_t	1.00	1.30
Phase crossover frequency, $\omega_{180} \cdot \theta$	1.57	1.49
Gain crossover frequency, $\omega_c \cdot \theta$	0.50	0.51

Table 1: Robustness margins for first-order and integrating delay process using SIMC-tunings in (5) and (6) ($\tau_c = \theta$). The same margins apply to second-order processes if we choose $\tau_D = \tau_2$.

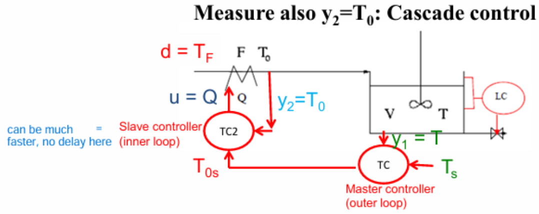
SMOOTH CONTROL

Tuning for smooth control

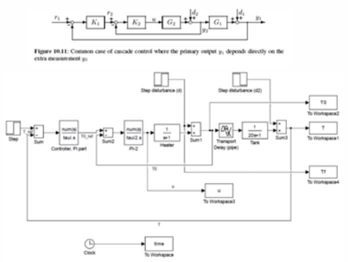
- Tuning parameter: τ_c = desired closed-loop response time
- Selecting τ_c=θ if we need "tight control" of y.
- Other cases: "Smooth control" of y is sufficient, so select τ_c > θ for
  - slower control
  - smoother input usage
    - less disturbing effect on rest of the plant
  - less sensitivity to measurement noise
  - better robustness
- Question: Given that we require some disturbance rejection.
  - What is the largest possible value for τ_c ?
  - ANSWER: $\tau_{c,max} = 1/\omega_d$ (where ω_d is defined as the frequence where $|g_d(j\omega_d)| = y_{max}/d_{max}$)

Proof: S. Skogestad, ``Tuning for smooth PID control with acceptable disturbance rejection", *Ind.Eng.Chem.Res*, **45** (23), 7817-7822 (2006).

Measure also $y_2=T_0$: Cascade control is much better



G_1= exp(-100s)/(20s+1)
G_2=1/(s+1)




```
Kc2=0.1;taui2=1; % inner loop with tauc2=10
Kc=0.119; taui=25; % outer loop with tauc=105
sim('tunepid1_ex1_cascade') %start simulation
plot(time,u,time,T,time,Tf,time,T0), axis([0 800 -1.5 1.5])
```