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A simple approach for on-line PI tuning using closed-loop setpoint responses

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MOTIVATION

- Desborough and Miller (2001): More than 97% of controllers are PID
- Vast majority of the PID controllers do not use D-action.
- PI controller: Only two adjustable parameters …
  - But still not easy to tune…
  - Many industrial controllers poorly tuned

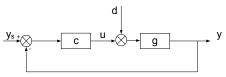
$$c(s)=K_c\left(1+\frac{1}{\tau_I s}\right)$$

- Ziegler-Nichols closed-loop method (1942) is popular, but
  - Requires sustained oscillations
  - Tunings relatively poor

OBJECTIVE

- Find improved & simpler closed-loop alternative to Ziegler-Nichols (1942)
- **Idea:** Derive correlation between "key parameters" of P-control setpoint response and SIMC PI-settings for corresponding process

BASIS: SIMC PI TUNING RULES



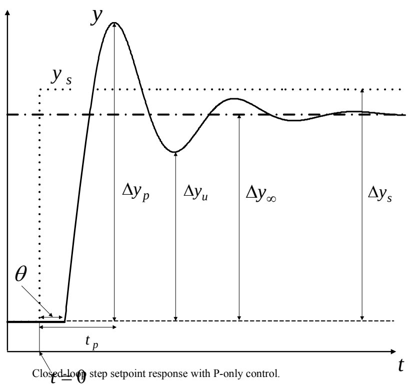
First-order process with time delay: $g(s)=\frac{ke^{-\theta s}}{\tau s+1}$

SIMC PI-settings:

$$K_c=\frac{\tau}{k(\tau_c+\theta)} \qquad \tau_I=\min\{\tau,\ 4(\tau_c+\theta)\}$$

"Fast and robust" setting: $\tau_c=\theta$

CLOSED-LOOP SETPOINT EXPERIMENT



Closed-loop step setpoint response with P-only control.

Procedure:

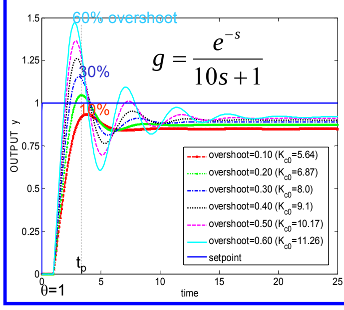
- Switch to P-only mode and make setpoint change
- Adjust controller gain to get overshoot about 0.30 (30%)

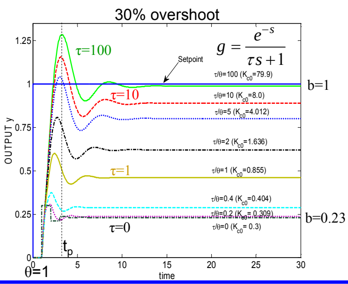
Record "**key parameters**":

1. Controller gain K_{c0}
2. Overshoot = $(\Delta y_p-\Delta y_\infty)/\Delta y_\infty$
3. Time to reach peak (overshoot), t_p
4. Steady state change, b = $\Delta y_\infty/\Delta y_s$.

Estimate of Δy_∞ without waiting:
$\Delta y_\infty = 0.45(\Delta y_p + \Delta y_u)$

Advantages compared to ZN:
* Not at limit to instability
* Works on a simple second-order process.

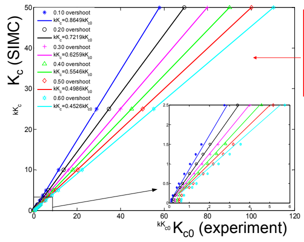




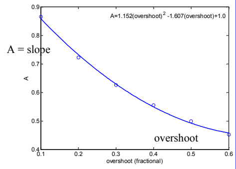
CORRELATION BETWEEN SETPOINT RESPONSE AND SIMC

- Find correlation between SIMC PI-settings and "key parameters" from 90 setpoint experiments.
- Consider range of 15 first-order plus delay processes:
  τ/θ = 0.1, 0.2, 0.4, 0.8, 1, 1.5, 2, 2.5, 3, 5, 7.5, 10, 20, 50, 100
- For each of the 15 processes:
  - Obtain SIMC PI-settings (K_c, τ_I)
  - Generate setpoint responses with 6 different overshoots (0.10, 0.20, 0.30, 0.40, 0.50, 0.60) and record "key parameters"(K_{c0}, overshoot, t_p, b)

1. Controller gain (K_c)



Observation:
For fixed overshoot: slope K_c/K_{c0} = A approx. constant, independent of the value of τ/θ (similar as ZN!)



$$\frac{K_c}{K_{c0}}=A$$

$$A=\left[1.152(\text{overshoot})^2-1.607(\text{overshoot})+1.0\right]$$

2. Integral time (τ_I)

SIMC-rules

- Case 1 (large delay): $\tau_{I1}=\tau$
- Case 2 (small delay): $\tau_{I2}=8\theta$

Case 1 (large delay):

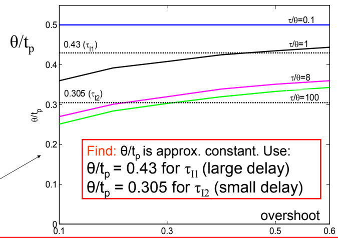
$\tau_{I1}=\tau=2\cdot kK_c\cdot\theta$ (SIMC rule for K_c)

$kK_c=kK_{c0}\cdot K_c/K_{c0}=kK_{c0}\cdot A$

$kK_{c0}=\left|\frac{b}{(1-b)}\right|$ (from steady-state offset)

Conclusion so far: $\tau_{I1}=2A\left|\frac{b}{(1-b)}\right|\theta$

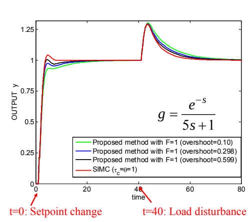
Still missing: Value for θ.
Try correlating with t_p!

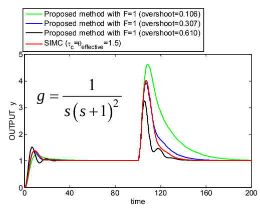


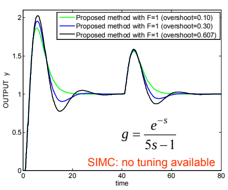
Find: θ/t_p is approx. constant. Use:
θ/t_p = 0.43 for τ_{I1} (large delay)
θ/t_p = 0.305 for τ_{I2} (small delay)

$$\tau_I=\min(\tau_{I1},\tau_{I2})=\min\left(0.86A\left|\frac{b}{(1-b)}\right|t_p,\ 2.44t_p\right)$$

SIMULATION RESULTS







CONCLUSIONS

1. **Setpoint experiment: Record K_{c0}, overshoot, t_p, b**
   - **Adjust K_{c0} to get overshoot around 30%**
2. **Proposed PI settings (including detuning factor F):**

$$K_c=K_{c0}A/F$$

$$A=\left[1.152(\text{overshoot})^2-1.607(\text{overshoot})+1.0\right]$$

$$\tau_I=\min\left(0.86A\left|\frac{b}{(1-b)}\right|t_p,\ 2.44t_pF\right)$$

Choice of detuning factor F:

- **F=1. Good tradeoff between "fast and robust"**
- **F>1:** Smoother control with **more robustness**
- **F<1** to **speed up** the closed-loop response.

"Probably the fastest PI tuning method in the world" ☺

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