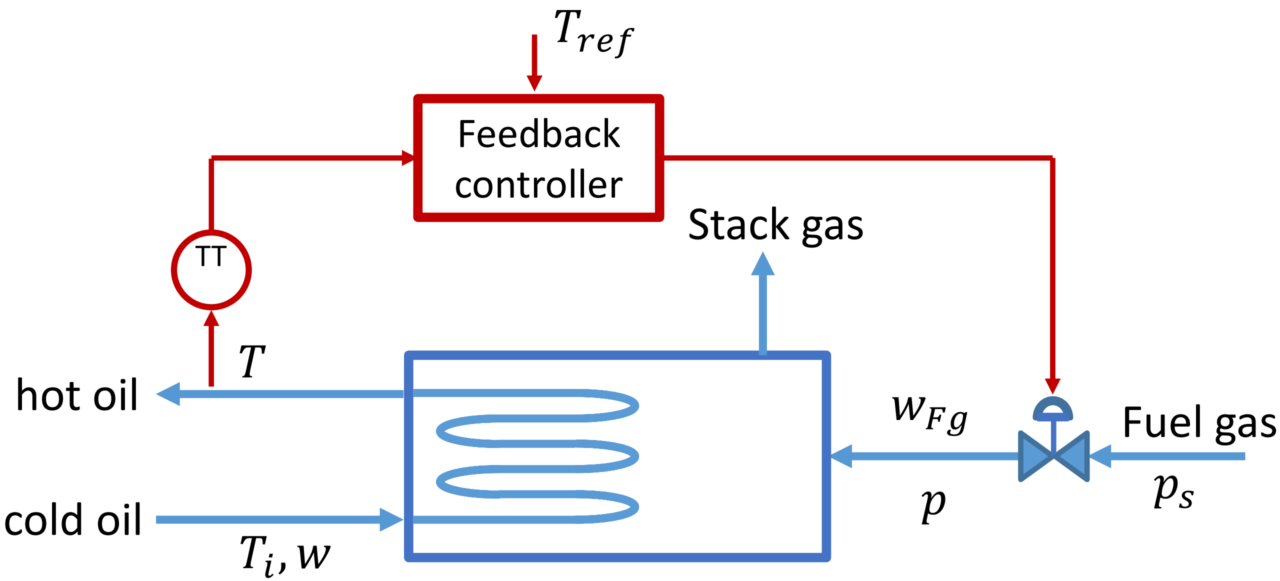
Cascade control

Furnace temperature control



- Feedback controller will correct all perturbations in the system

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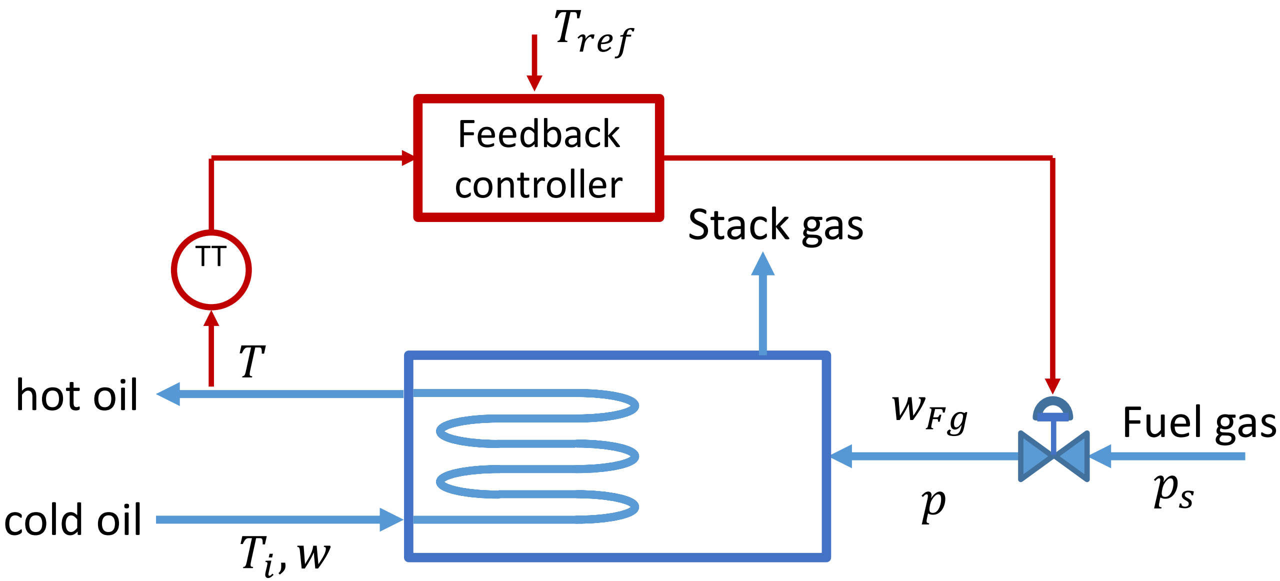

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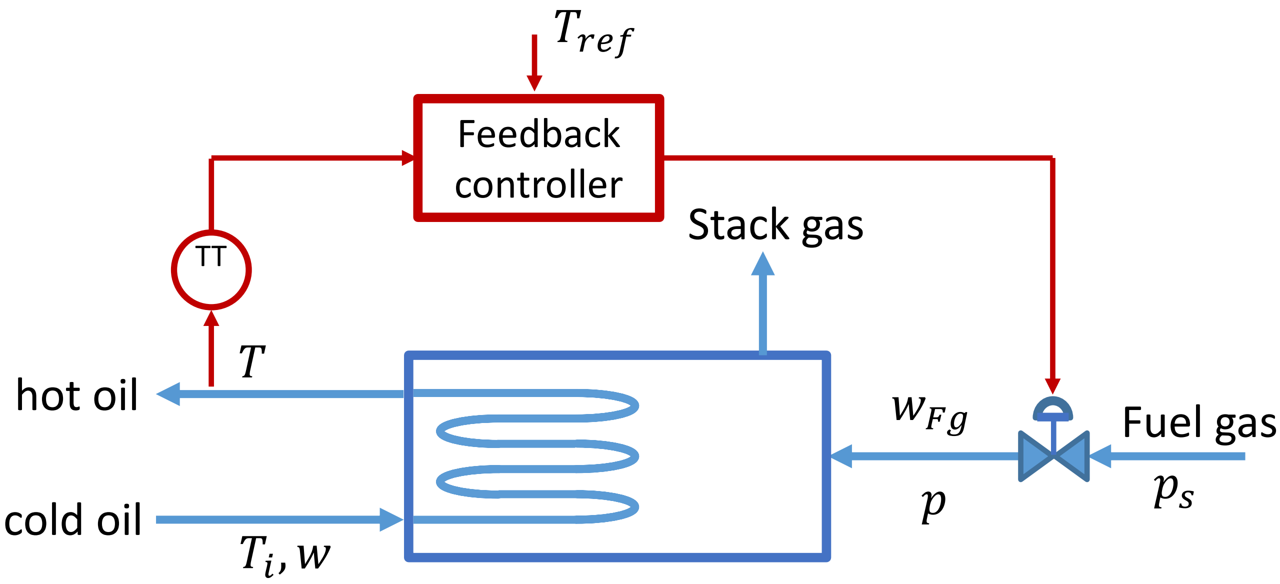

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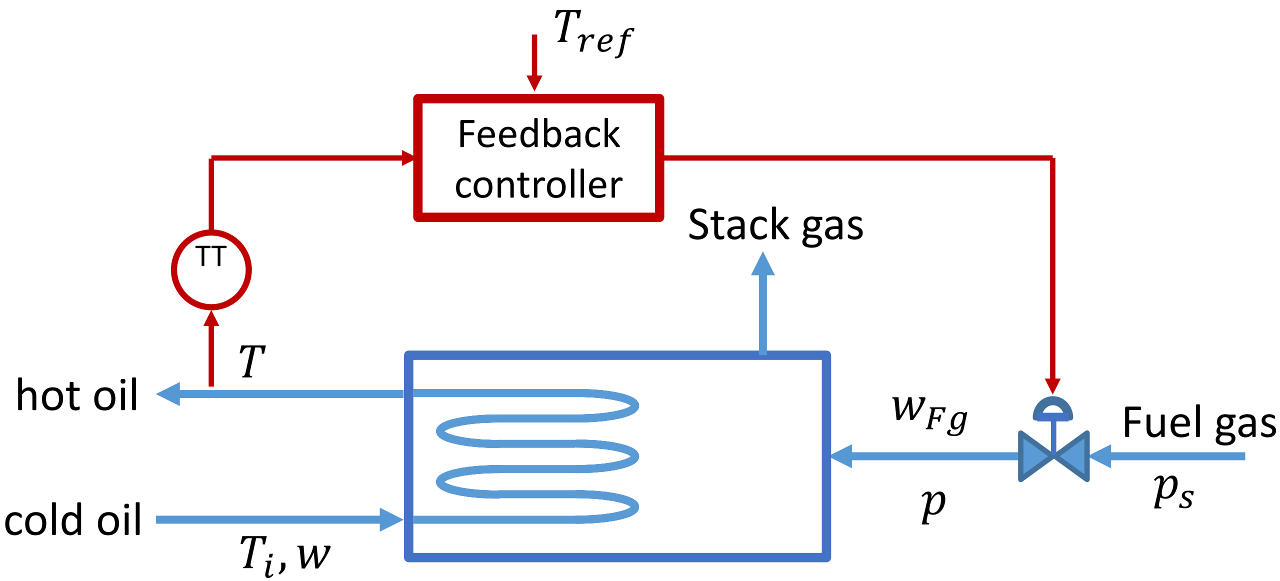
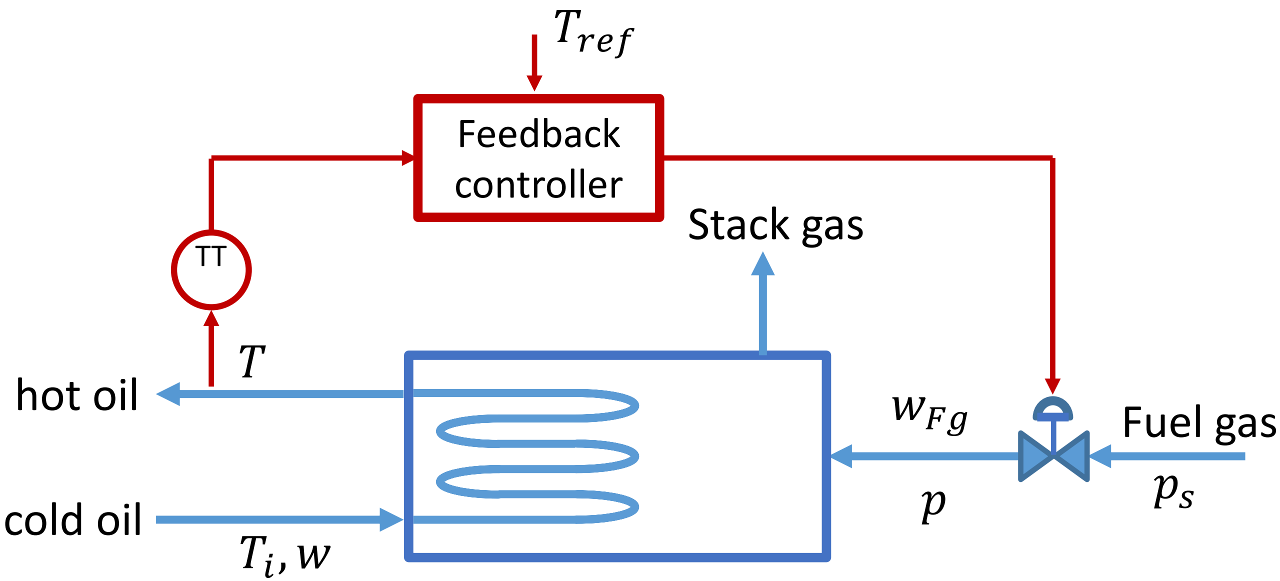


- Feedback controller will correct all perturbations in the system
- However its correcting action starts only after the effect of the disturbance appears at the controlled output
- Consider a disturbance in the fuel gas supply pressure
  - a sluggish response of the output T to the changes in the gas pressure
  - the disturbance is associated with the manipulated variable

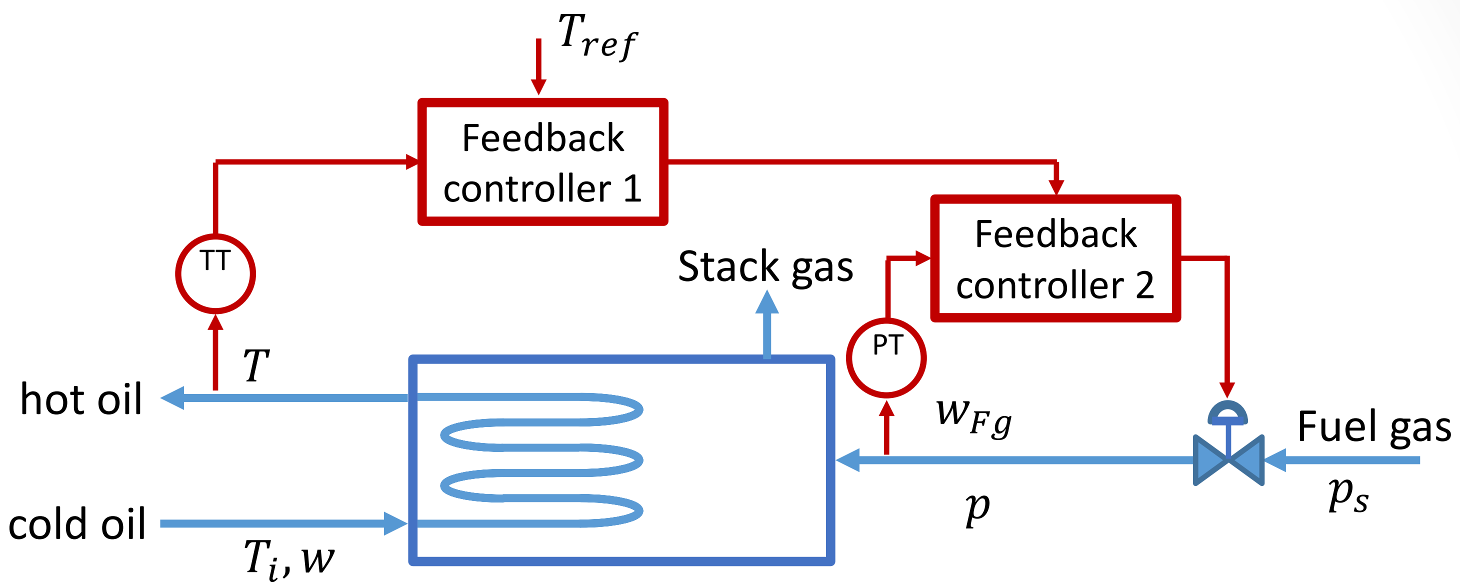
Furnace temperature control



- Change in $p_s \to p \to w_{Fg} \to T$
- Instead of waiting to observe the effect of the disturbance at the output T:

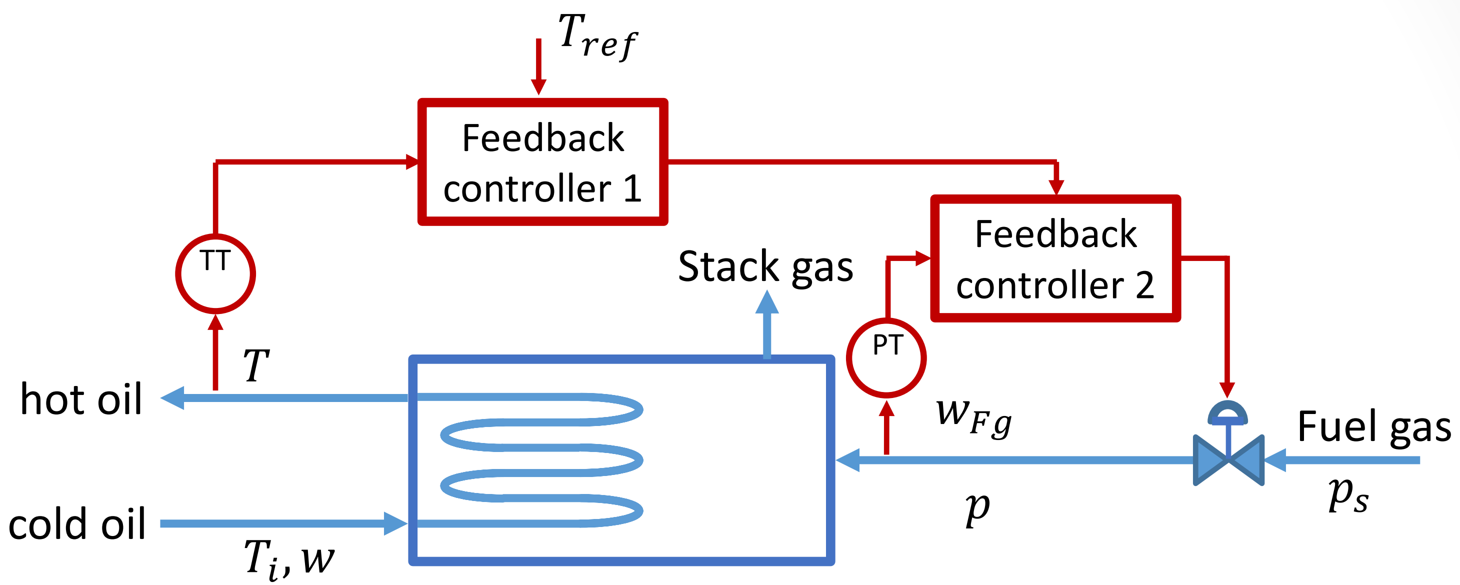
  Can we measure an additional variable in the systems to react immediately???

Furnace temperature control



- Cascade control with two loops
  - Internal loop controlling the fuel gas pressure
  - External loop controlling the oil temperature

Furnace temperature control



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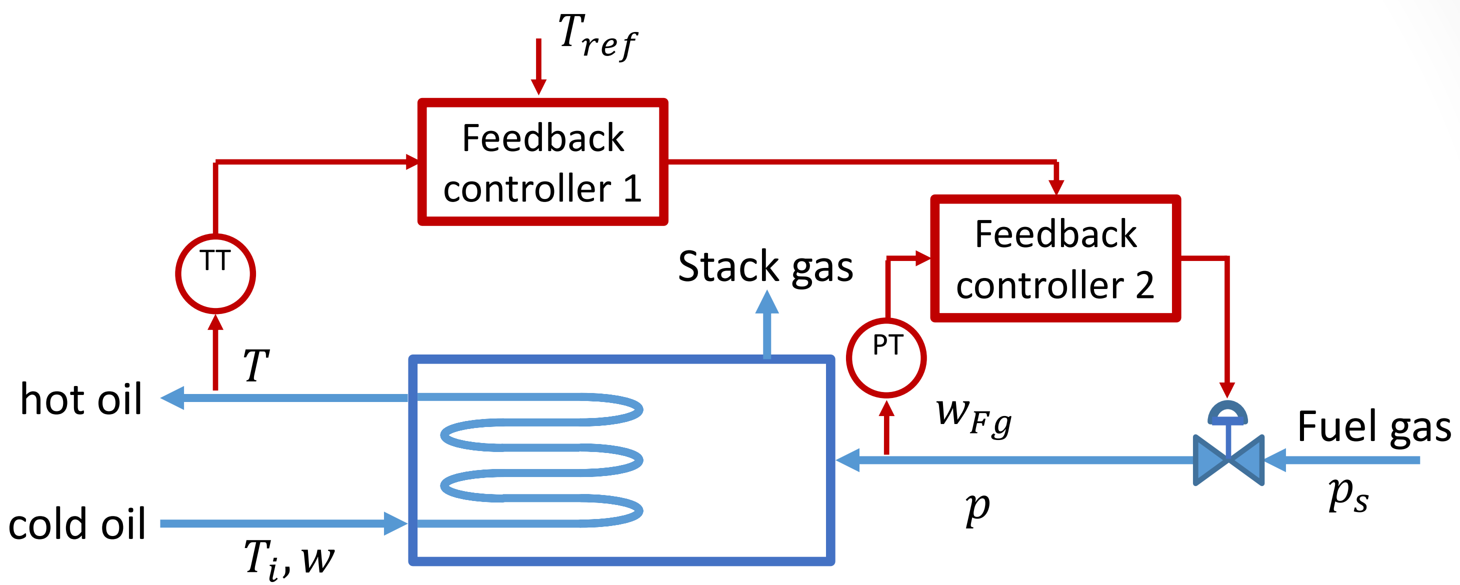
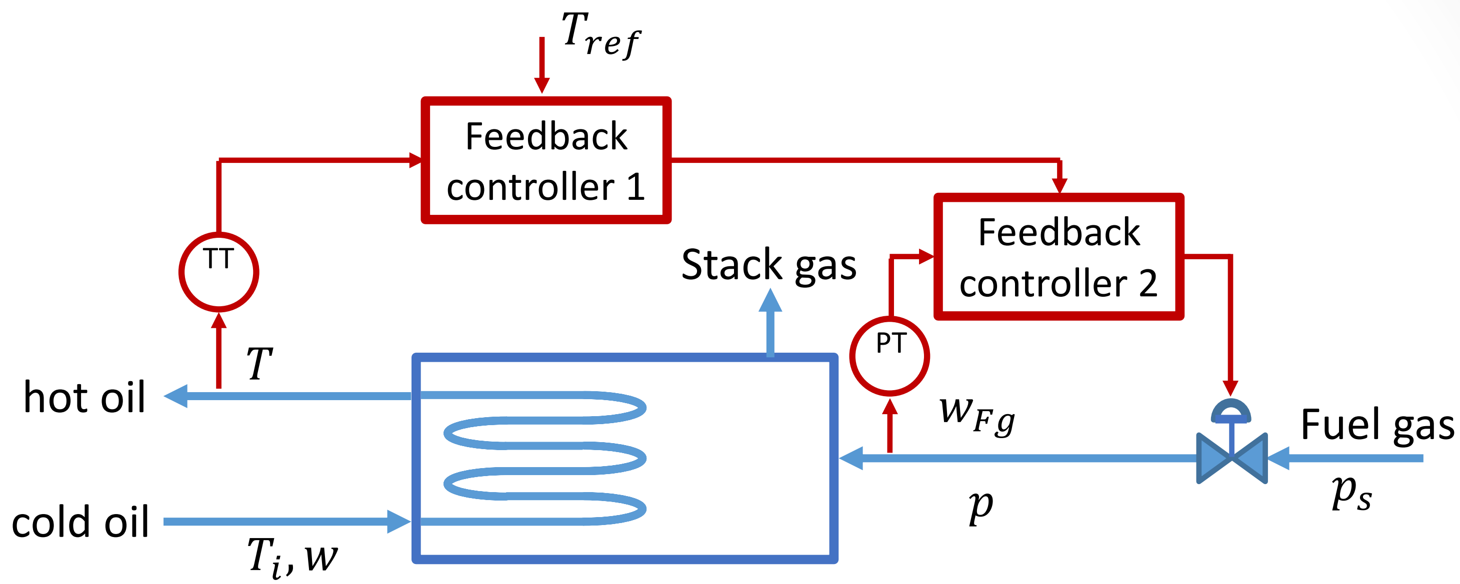
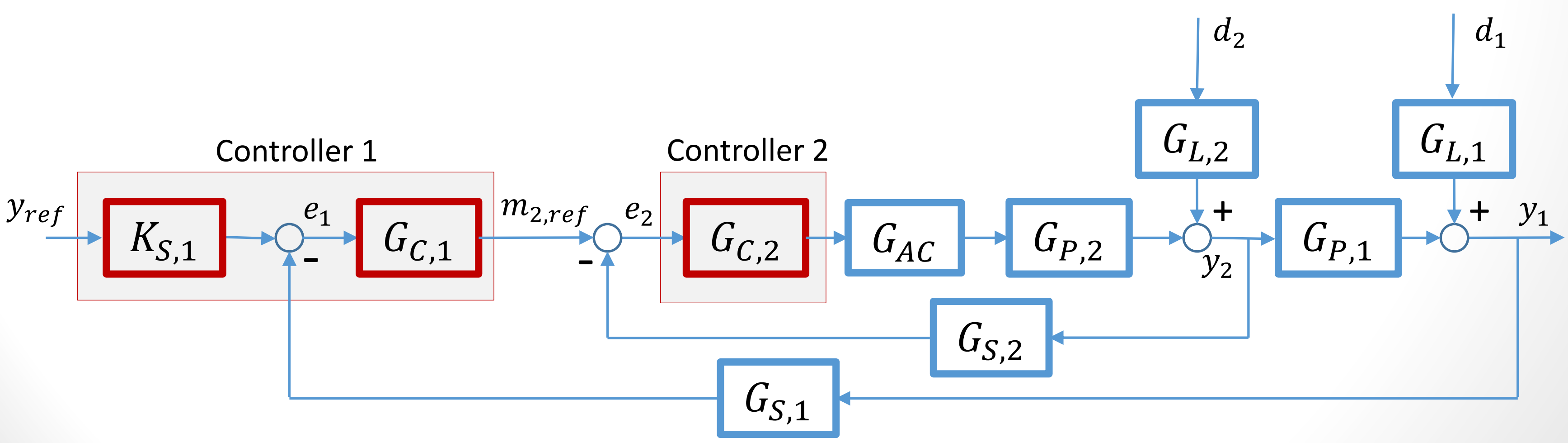


- Cascade control with two loops
  - Internal loop controlling the fuel gas pressure
  - External loop controlling the oil temperature
- Internal controller reacts quickly to the disturbances in the gas pressure thus improving the performance of the control system
- External loop provides the set point for the internal controller

Cascade control scheme



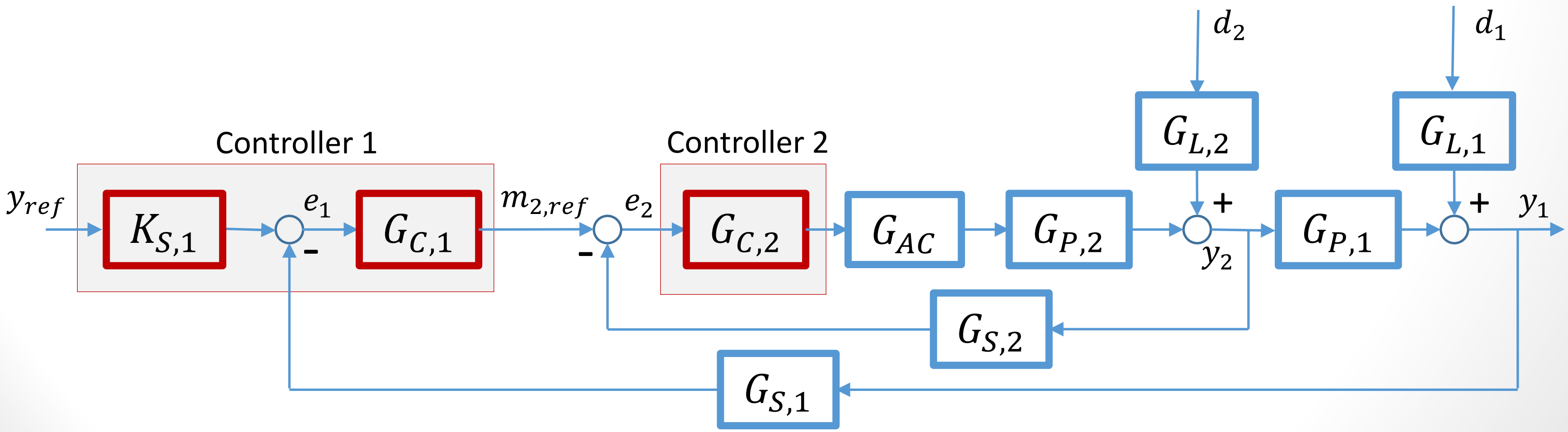


Cascade dynamics

- Consider the transfer function between external controller output $m_{2,ref}$ and gas pressure (y_2) in two cases:

    a) Single loop: $\frac{Y_2}{M_{2,ref}} = G_{AC}G_{P,2}$

    b) Cascade control: $\frac{Y_2}{M_{2,ref}} = \frac{G_{C,2}G_{AC}G_{P,2}}{1+G_{C,2}G_{AC}G_{P,2}G_{S,2}}$



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Cascade dynamics

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Example:

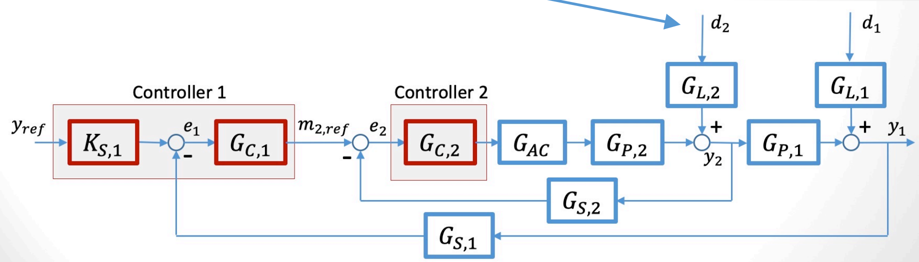
$$G_{AC} = \frac{2}{0.2s+1} \quad G_{C,2} = 10 \quad G_{S,2} = 0.5 \quad G_{P,2} = \frac{0.5}{s+1}$$

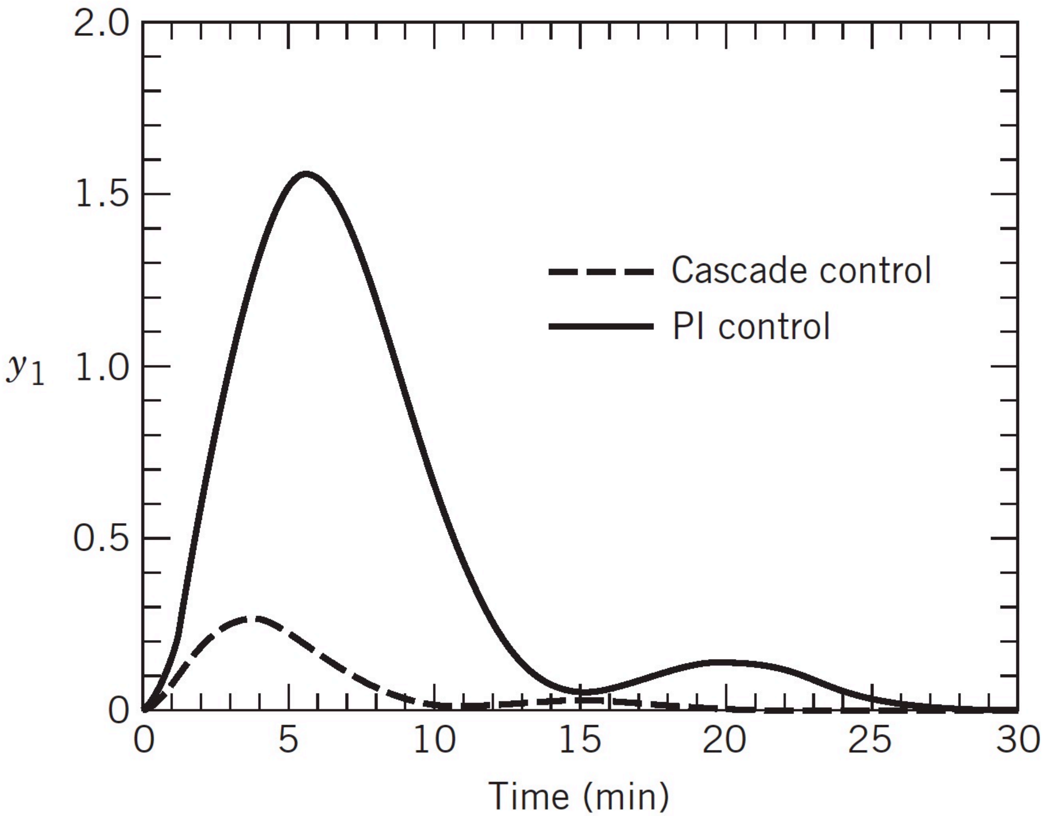
a) Single loop: $\frac{Y_2}{M_{2,ref}} = G_{AC} G_{P,2} = \frac{2}{0.2s+1}\frac{0.5}{s+1} \cong \frac{1}{s+1}$

b) Cascade control: $\frac{Y_2}{M_{2,ref}} = \frac{G_{C,2} G_{AC} G_{P,2}}{1+G_{C,2} G_{AC} G_{P,2} G_{S,2}} = \frac{10\frac{2}{0.2s+1}\frac{0.5}{s+1}}{1+10\frac{2}{0.2s+1}\frac{0.5}{s+1}} \cong \frac{1.67}{0.167s+1}$

Cascade vs Feedback controller

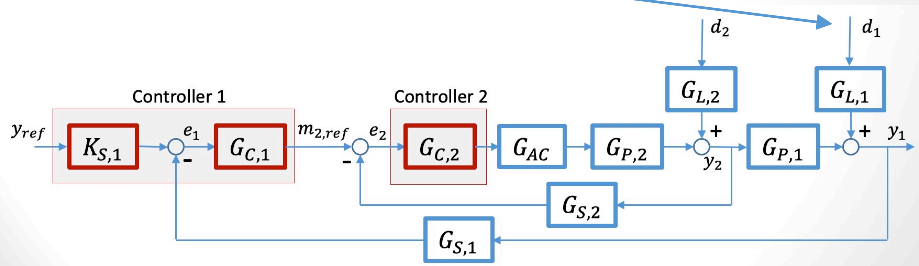
- Responses obtained upon a step disturbance in d_2

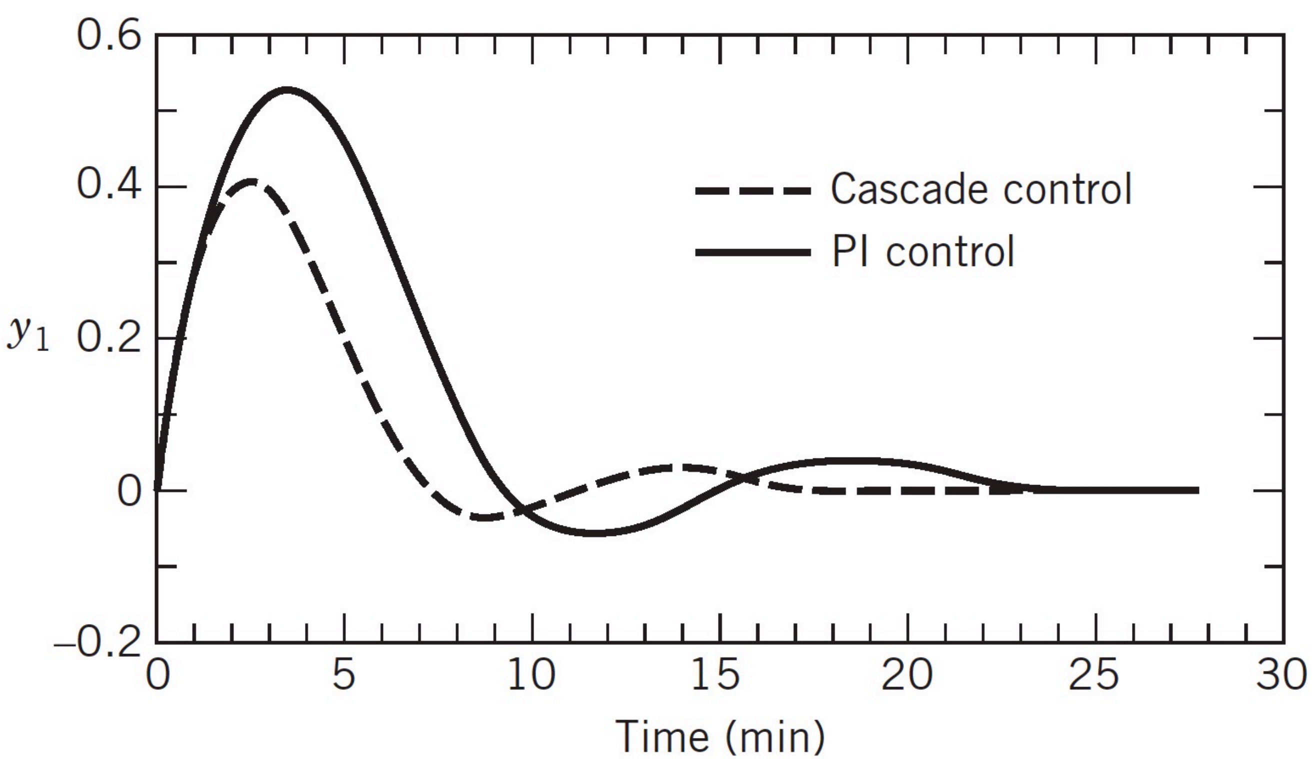




Cascade vs Feedback controller

- Responses obtained upon a step disturbance in d_1





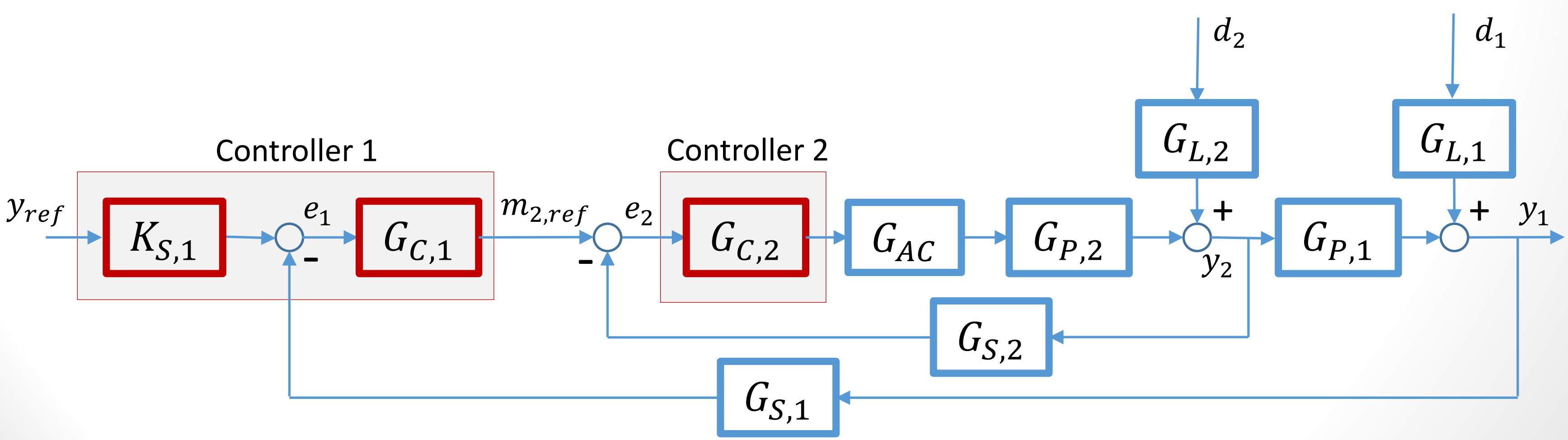
Cascade control characteristics

- Two feedback controllers (and two sensors) but only a single actuator controlling the output
- Two feedback control loops are nested with the internal-loop control loop inside the external control loop.
- Output signal of the external-loop controller is the set-point for the internal-loop controller
- Can be extended to multiple nested loops

Alternative terminology (in the literature)
- inner/outer
- slave/master
- secondary/primary

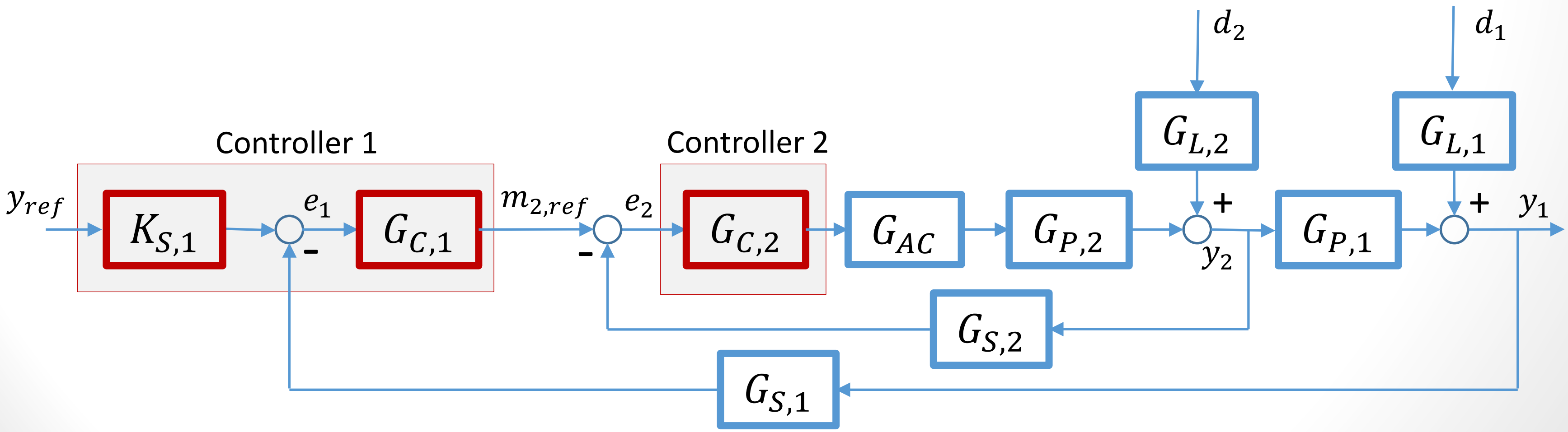
Cascade control is recommended

- when the disturbance d_2 affects the measured output y_2 sooner than the controlled output y_1



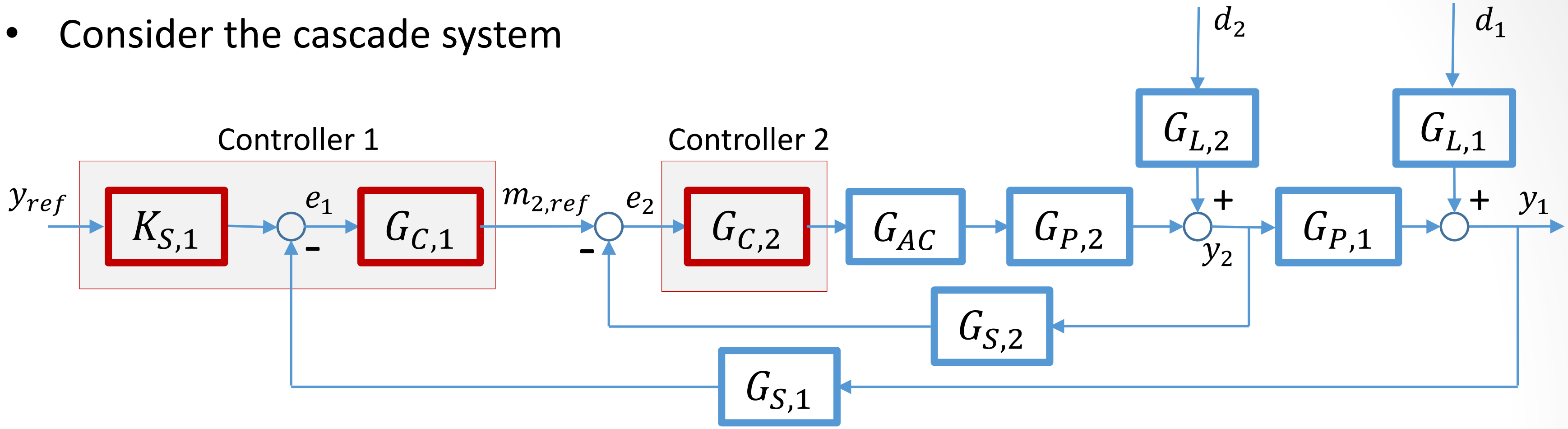
Cascade control is recommended

- when the disturbance d_2 affects the measured output y_2 sooner than the controlled output y_1
- when the internal loop (secondary loop) is faster than the external (primary) one



Example

- Consider the cascade system



with $G_{AC} = \frac{5}{s+1}$, $G_{P,2} = 1$, $G_{P,1} = \frac{4}{(4s+1)(2s+1)}$, $G_{L,2} = 1$, $G_{L,1} = \frac{1}{3s+1}$, $G_{S,1} = 0.05$,

$G_{S,2} = 0.2$

Assuming that $K_{R,2} = 4$

a) Determine stability limits for conventional proportional controller as well as for a cascade control system with two proportional controllers

b) For the two cases from a) calculate the offset error (steady-state error) in the output y_1 for a unit step change in d_2

Cascade control – Wrap up

Properties

1. Rapid rejection of the perturbations affecting the internal loop (as soon as y_2 changes the internal loop reacts
2. Also improves the disturbance rejections of the external loop (d_1)
3. A faster response of the internal loop improves the stability margin of the system and reduces the steady-state error at y_1

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Design (one of multiple ways)

1. Set the external loop in the manual mode and design the internal controller, $G_{C,2}$ using, e.g., Ziegler-Nichols method
2. Then, with the designed $G_{C,2}$ in operation, design the external controller $G_{C,1}$

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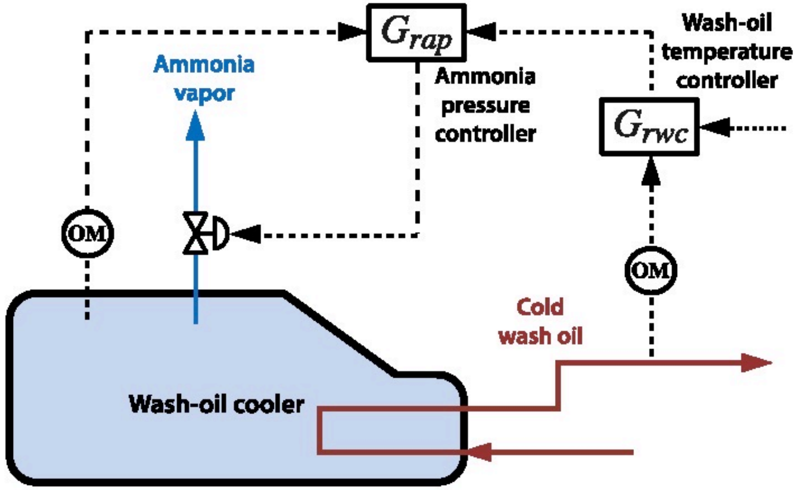
Comments

1. The internal loop has to be faster than the external loop. A small stead—state error in the internal loop is admissible because the ultimate objective is to control the output y_1. Very often, P controllers are used.
2. In contrast, the external controllers are often PI or PID to ensure that the steady-state error at the output y_1 is eliminated.

Example (January 2019)

5) **(20 points)** A cascade control system of the wash oil temperature is considered due to a sticky valve. It was observed that ammonia pressure responded much quicker to changes in valve position than the wash oil temperature. The set point of the wash oil temperature is controlled by an operator.



a) Draw the block-scheme of the control system. Identify the variables in the system (inputs, outputs, disturbances). Discuss briefly the dynamical properties of the inner and outer loops and the complexity of the corresponding controllers.

b) For the given transfer functions $\frac{T_{wo}(s)}{P_{av}(s)} = \frac{e^{-2s}}{s}$ and $\frac{P_{av}(s)}{q_{av}(s)} = \frac{s-2/3}{s^2+11s+10}$, where T_{wo} denotes the wash-oil temperature at the output, P_{av} the pressure of the ammonia vapor and q_{av} the flow of the ammonia vapor controlled by the valve:

   i) Find a P controller that ensures the stability of the inner loop such that the value of its parameter is in the middle of the allowed range.

   ii) Find the parameters of the simplest PID-like controller (K_R or K_R, τ_D or K_R, τ_I or K_R, τ_I, τ_D) for the outer loop such that it ensures the zero steady-state error of a step response (use the 1st order Padé approximation to approximate the delay).

Process Control