## *Laboratory work 9*

# CASCADE CONTROL

## 1. GOALS

- to design a cascade control loop for a given process
- to compare the advantages and disadvantages of the cascade loop in comparison with the classical mono-loop;

## 2. THEORETICAL BACKGROUND

Cascade control can be used both for dynamic and slow process, with time delays. It is recommended for complex processes, where the transfer function of the process, $H_f(s)$, has a relatively large number of time constants. It this case, in order to avoid complex controller structures, it is recommended to use a cascaded control structure, with more controllers, but with simple forms.

The principle of cascade control is based on dividing the process into sub-processes, by choosing measurable intermediate quantities that are transmitted causally from the input to the output. The cascaded control system is indicated in Fig. 9.1, where the process model has been divided into two subsystems described by the transfer functions $H_{f1}(s)$ and $H_{f2}(s)$, respectively. Hence, apart from the design of the main controller $H_{r1}(s)$ for the main output signal y(t), the design of the secondary controller $H_{r2}(s)$ is required. This secondary controller, of the inner loop, has the main task to limit and control an intermediary output signal x(t).

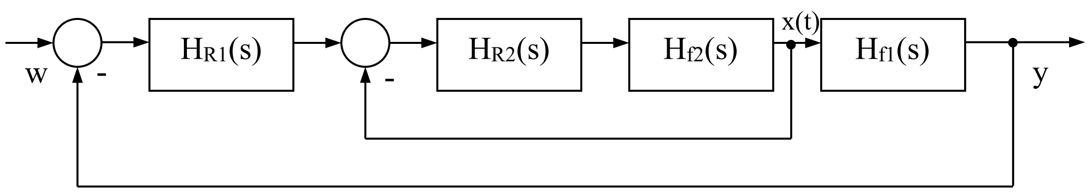


**Figure 9.1.** Cascaded control structure

In order for a cascaded control to be efficient, the intermediary output needs to be easily accessible to allow for additional sensors to be installed for measuring possibilities. At the same time, the intermediary output signal has to be considerably faster than the overall output y(t) in order to handle the inner loop disturbance rejection before this can be sensed at the y(t) output. Then, the intermediary signal is selected such that disturbances are fully or at least partially rejected in the inner loop. Additionally, the process model has to be divided into susbsystem with two time constants at the most, while the inner loop should include those time constants that are significantly smaller compared to the outer loop.

The major issues related to cascaded control system are related to the choice and tuning of the controllers, since the inner loop controllers received their setpoint from the outer loop controllers. It is recommended that the inner loop is faster than the outer loop. Hence, usually a P controller is used in the inner loop, although it doesn't eliminate the steady state error. A PI or a PID controller is usually used in the outer loop. For fast processes, the magnitude and symmetry optimum methods can be used to tune the controllers.

Cascaded control leads to improved closed loop results compared to the classical control structure only if intermediary outputs are properly selected and controllers are properly tuned.

Controller design steps:

Design the inner loop controller $H_{R2}(s)$ to control the intermediary output signal x(t) (as indicated in Fig. 9.1). The design is based on the $H_{f2}(s)$ transfer function and according to the performance criteria set.

Design the outer loop controller $H_{R1}(s)$ for the overall process model, $H_f(s)$ that contains the process transfer functions $H_{f1}(s)$, as well as the closed loop transfer function or the inner loop:

$$H_f(s) = H_{f1}(s)\frac{H_{f2}(s)H_{R2}(s)}{1+H_{f2}(s)H_{R2}(s)} \tag{9.1}$$

3. PROBLEMS

For the process consisting of two sub-systems, described by the transfer functions:

$H_{f1} = \frac{2.4}{(0.5s+1)(50s+1)}$ and $H_{f2} = \frac{8.6}{(0.01s+1)(0.6s+1)}$

Design the two controllers to reject a step disturbance in the inner loop and a ramp disturbance in the outer loop, using the cascade structure (Figure 9.1).

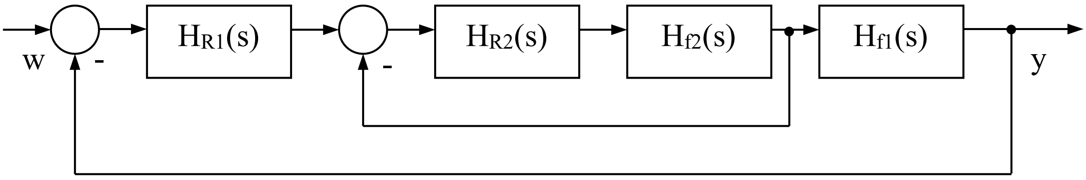


**Figure 9.1.** Cascaded control structure

Compare the closed loop performance with a classical control loop, designed to reject a ramp disturbance (Figure 9.2).

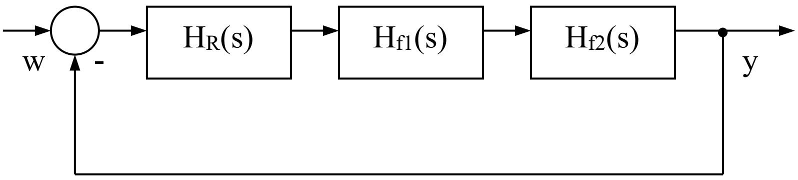


**Figure 9.2**. Mono-loop structure