Telemark University College/Finn Haugen

Solution to exam in Course PEF3006 Process Control

Exam date: 17. December 2013. Duration: 4 hours. Exam aids: None.
Weight: 100% of course grade.

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1. (10% weight) Figure 1 shows a block diagram of a feedback control system.

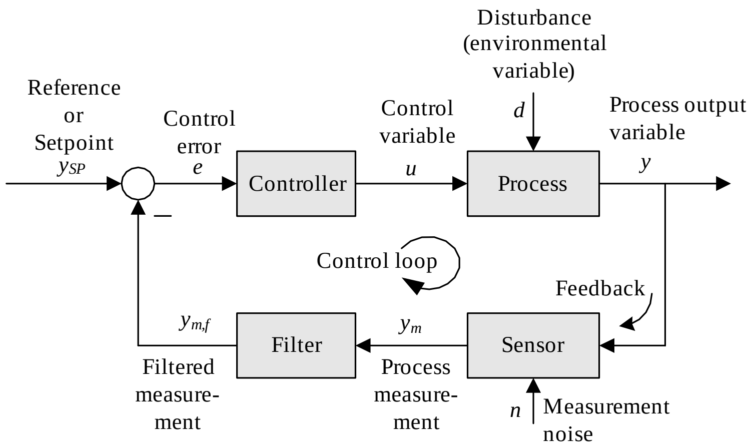

Figure 1: Block diagram of an error-driven control system

Blocks:

- Process is the physical system to be controlled.
- Sensor measures the process output variable to be controlled.
- Filter attenuates the measurement noise.
- Controller manipulates the process via the actuator.

Signals:

- The control variable or the manipulating variable is the variable which the controller uses to control or manipulate the process.
- The disturbance is a non–controlled input variable to the process which affects the process output variable.
- The setpoint or the reference is the desired or specified value of the process output variable.
- The measurement signal is the output signal from the sensor which measures the process variable.

- The measurement noise is typically a random component in the measurement signal.
- The control error is the difference between the setpoint and the process output variable:

2. (10%) Figure 2 shows a P&I Diagram of the level control system of a wood-chip tank. The control systems works as follows: Assume that

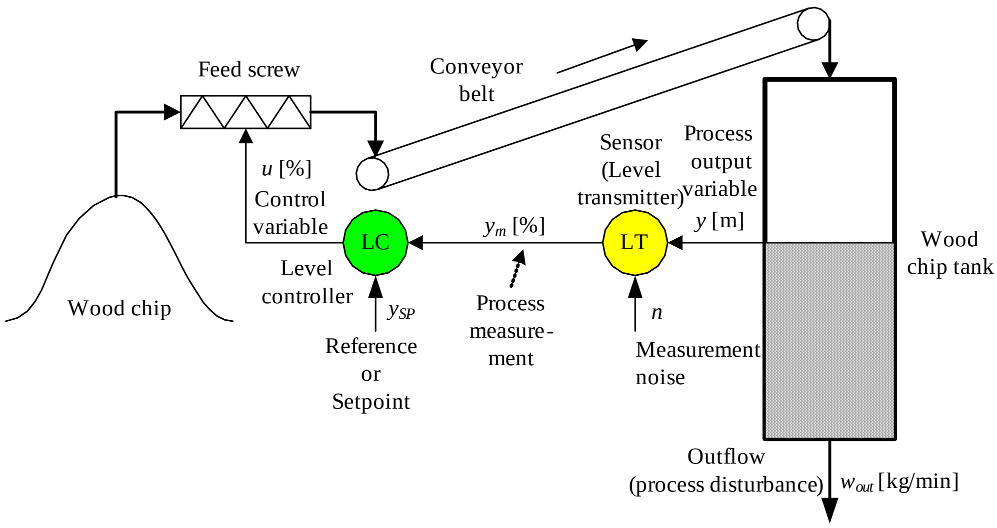

Figure 2:

initially the level is at its setpoint, i.e. the control error is zero. Assume that there is an increase in the outflow from the tank, i.e. a change in the process disturbance. This will cause the level to decrease, thereby increasing the control error. This increase makes the controller increase the control signal acting on the actuator which is the feed screw. This in turn increases the chip inflow to the belt, and eventually (after the transportation time on the belt is passed) in to the tank, causing the level to increase and come closer to the setpoint. This control action will continue until the level is back at its setpoint, and thereafter the control signal will be constant until a new disturbance happens or until the setpoint is changed.

3. (5%) Taking the Laplace-transform of both sides of the given differential equation and ignoring the initial state:

$$asy(s) = be^{-\tau s}u(s) - y(s) + cd(s) \tag{1}$$

Solving for the output variable:

$$y(s) = \underbrace{\frac{be^{-\tau s}}{as+1}}_{H(s)} u(s) + \frac{c}{as+1} d(s) \quad (2)$$

where $H(s)$ is the transfer function from u to y.

4. (5%) The P (proportional) control function is

$$u_p = u_0 + K_p e \quad (3)$$

Assume that u_0, which is constant when the controller is in automatic mode, does not have a perfect (correct) value, i.e. the steady-state error, e_s, is non-zero. Therefore, a non-zero change in u is needed to obtain $e_s = 0$. The change in u is $K_p e_s$, which can be non-zero only if e_s is non-zero. Consequently, typically, a non-zero e_s can not be obtained with a P controller.

5. (5%)

    - *On-off control*: Benefit: Simple to implement and to tune (virtually no tuning is needed except selecting the control signal in *on* and *off* states). Drawback: Sustained oscillations in the control system.
    - *PI control*: Benefits: Smooth control, and zero steady-state control error. Drawback: Must be tuned properly to fit the process dynamics.

6. (5%) A measurement filter is needed in most practical control systems to attenuate the noise contents of the process measurement signal, thereby reducing the propagation of the noise through the controller, thereby obtaining a smoother control signal, thereby reducing the actuator wear.

7. (10%) The Ziegler-Nichols method for PI controller tuning: First, bring the process to or close to the normal or specified operation point by adjusting the nominal control signal u_0 (with the controller in manual mode). Then, ensure that the controller is a P controller, i.e. set $T_i = \infty$ (or very large) and $T_d = 0$, with $K_p = 0$. Then, with the controller in automatic mode, increase K_p by trial-and-error to the the value K_{p_u} which causes the the control loop to become marginally stable, i.e. there are sustained oscillations in any signal in the loop. From these oscillations, read off the period, P_u. Then, calculate proper PI settings as $K_p = 0.45 K_{p_u}$ and $T_i = P_u/1.2$ to be applied in the controller.

8. (10%) The PI controller is tuned assuming the process dynamics is "integrator with time-delay" with time-delay $\tau = 5$ s and integral gain

$$K_i = \frac{20\ \%/\text{s}}{10\ \%} = 2\ \text{s}^{-1} \tag{4}$$

Skogestad PI tuning gives, with $T_C = \tau$ and $c = 2$,

$$K_p = \frac{1}{K_i\,(T_C + \tau)} = \frac{1}{2K_i\tau} = \frac{1}{2 \cdot 2\ \text{s}^{-1} \cdot 5\ \text{s}} = 0.05 \tag{5}$$

$$T_i = c\,(T_C + \tau) = 4\tau = 4 \cdot 5\ \text{s} = 20\ \text{s} \tag{6}$$

9. (10%) Cascade control: Usually, the most important reason for using cascade control is to obtain faster (better) disturbance compensation comparing with single-loop control. In a cascade control system there is one or more control loops inside the primary loop, and the controllers are in cascade, see Figure 3. The control signal calculated

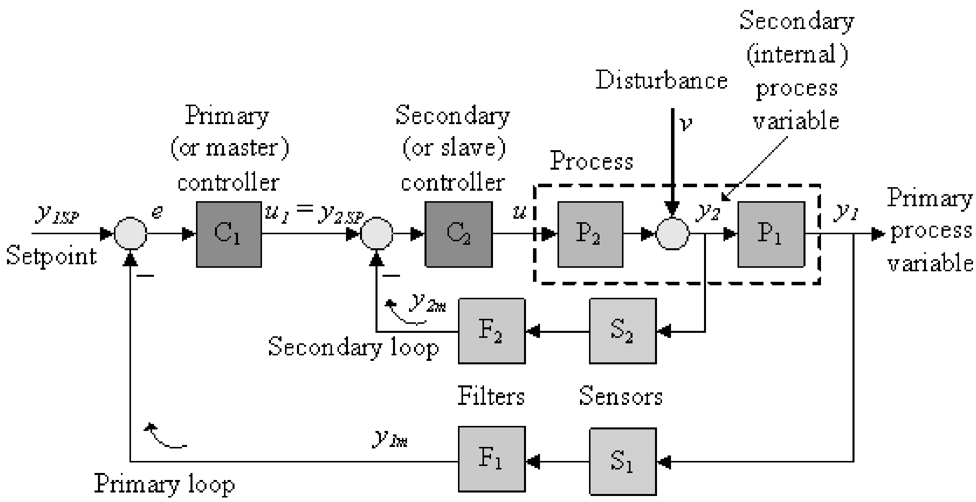

Figure 3: Cascade control system

by the primary controller is used as the setpoint of the secondary controller. The secondary control loop compansates quickly for the disturbance so that the disturbance does not influence the primary process output variable.

Example: Level control system of a wood chip tank, see Figure 4. The primary loop performs level control. The secondary loop is a mass control loop. The purpose of the secondary loop is to give a quick compensation for disturbances, d, in the input chip flow. With ordinary single-loop level control compensations for d will be

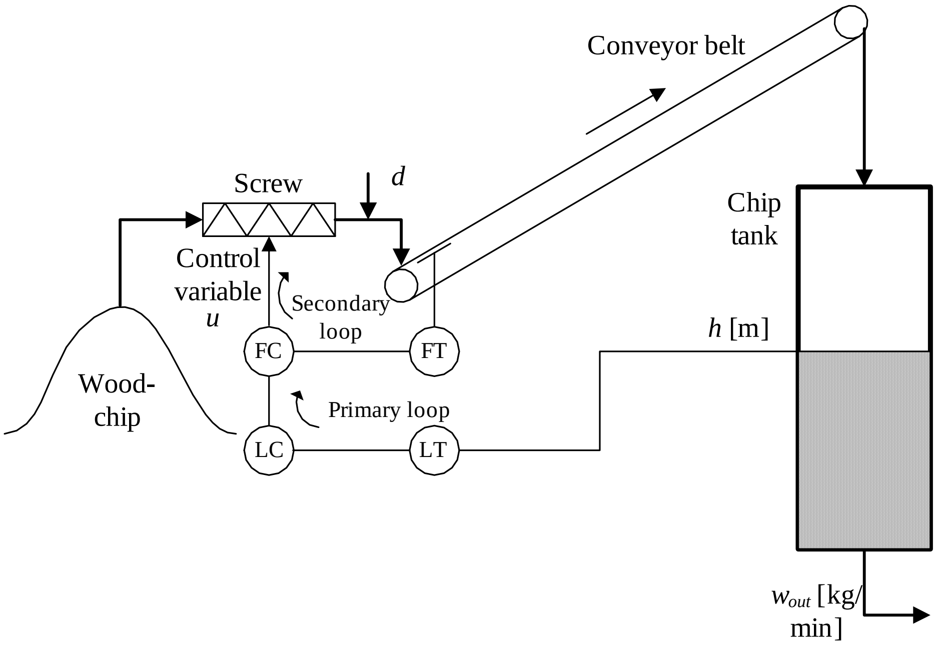

Figure 4:

accomplished only by the level control loop, cause larger variations in the level that with cascade control.

10. (5%) Assume that the process measurement is equal to the setpoint initially, and that for any reason the process measurement increases to become *larger* than the setpoint (this change may for example have been caused by a change of the process disturbance). If the controller must *decrease* the control signal to bring the *increased* process measurement back to the setpoint, the controller shall have *Reverse action mode*. If the controller must *increase* the control signal to bring the *increased* process measurement back to the setpoint, the controller shall have *Direct action mode*.

    Example: Figure 5 shows the control system. It is assumed that the valve is a Fail Closed valve, i.e. when the control signal is reduced, the valve opening is reduced, and, hence the flow is reduced – and vice versa. Assume that the level is at the setpoint initially, and that the level then (for any reason) *increases*. How should the control signal acting on the pump be adjusted to get the level back to the setpoint? The outflow must be increased. With the given valve, increased flow is obtained with an *increased* control signal. Hence, this case is an "up-up" case, and therefore the controller must have *direct action*.

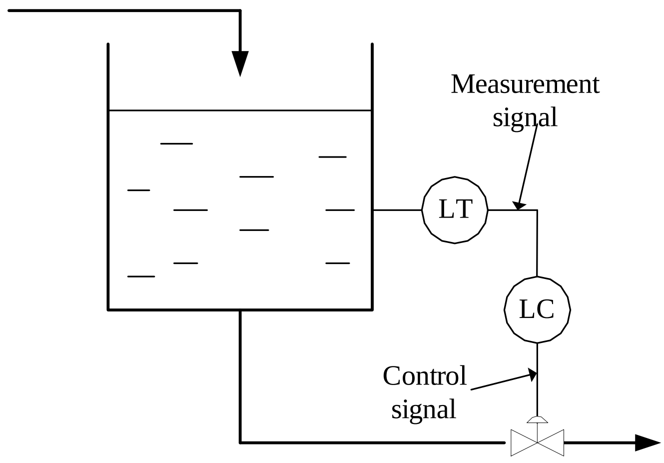

Figure 5:

The consequence of selecting wrong among direct and reverse action mode is that the control system becomes *unstable*.

11. (5%) Split range control is feedback control with one controller (typically a PID controller) where the the control signal is used to manipulate more than one actuator. The total control signal is splitted onto each of these actuators.

    Example: See Figure 6 which shows a temperature control system of a process (e.g. a reactor) with split-range control. Two valves are controlled by the single temperature controller – one for cooling and one for heating. For example, the temperature controller controls

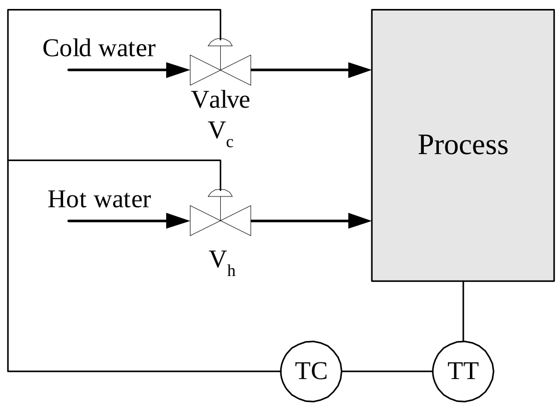

Figure 6:

may control the cold water valve actively when the control signal is in the range 0 – 50 % and the hot water valve for control signals is in the range 50 – 100 %, see Figure 7.

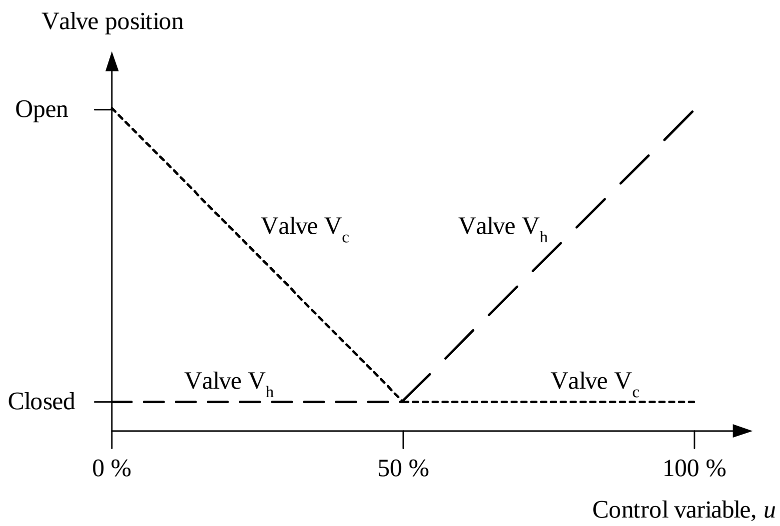

Figure 7:

12. (10%) Substituting y by its setpoint, y_{SP}, and solving for u gives the feedforward control function:

$$u_{ff}(t) = \frac{\dot{y}_{SP}(t) - a\sqrt{y_{SP}(t)} - cd(t)}{b} \tag{7}$$

All of the quantities at the right side of eq. (7) must have known values to make the feedforward control function implementable, i.e. y_{SP}, from which $\dot{y}_{SP}$ can be calculated, disturbance d, and parameters a, b and c.

13. (10%) Reducing the measurement span (range) of a sensor increases the sensor gain, and hence, increases the control loop gain, which causes reduced control system stability.