Module 3

Process Control

Lesson 17

Special Control Structures: Cascade, Override and Split Range Control

Instructional Objectives

At the end of this lesson, the student should be able to

- State two advantage of using cascade control
- Draw the block diagram representation of cascade control system
- Write down the governing equations for determining the stability of a cascade control system.
- Illustrate with an example the use of override control
- Illustrate with an example the use of split range control.

Introduction

In last two lessons, we have discussed several special control structures those are commonly in use for process control. We shall conclude this part with three more structures. Cascade, override and split range control. Cascade control is widely used for minimizing the effects of certain types of disturbance in the process. On the other hand, override and split range controls are used for controlling certain types of multi variable processes.

Cascade Control

Consider the heat exchange process shown in Fig. 1.Steam is used to heat the water in the heat exchanger. Feedback temperature controller is used to compare the water outlet temperature with the set point and control the steam flow rate by opening or closing the control valve. However due to the change in upstream steam pressure (P_i), the steam flow rate may change, though the control valve is at the same position. This will affect the amount of heat exchanged and the temperature at the water outlet. It will take some time to detect the change in temperature and take subsequent corrective action. In a cascade control, this problem can be overcome by measuring the disturbance (change in flowrate in steam due to upstream pressure variation and a corrective action is taken to maintain constant flowrate of steam. There is an additional controller (flow controller) whose set point is decided by the temperature controller. The schematic arrangement of cascade control is shown in Fig.2. its block diagram is shown in Fig.3. Clearly, there are two control loops – outer and inner, and two controllers. The set point of the inner loop controller is decided by the outer loop primary controller.

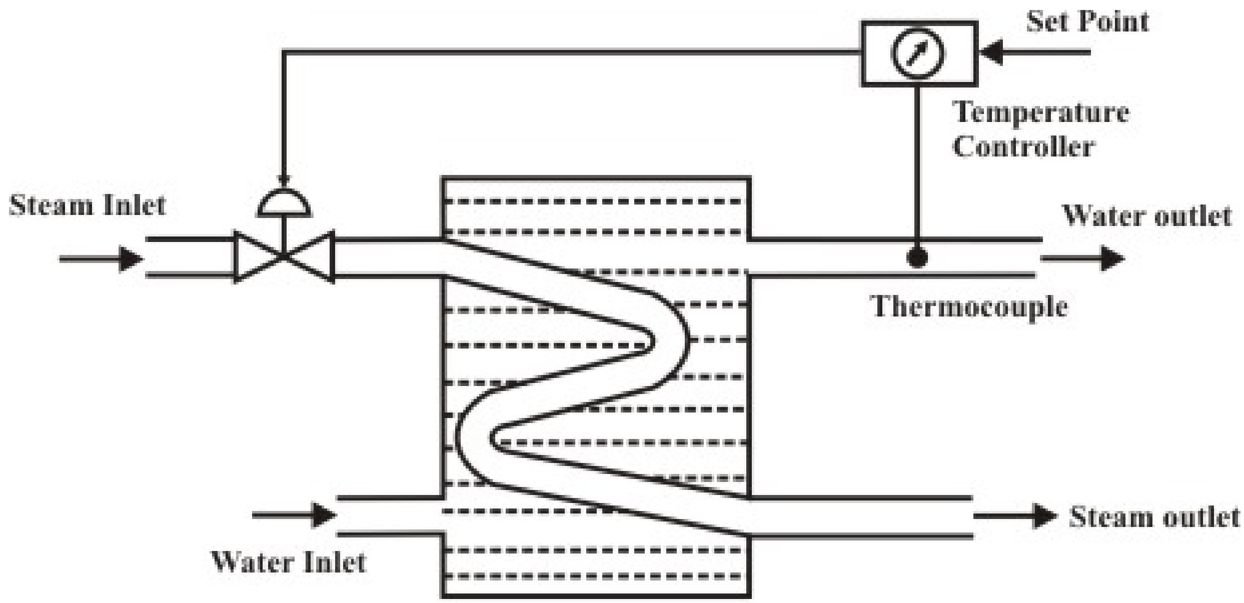

Fig. 1 Feedback temperature control of a heat exchanger

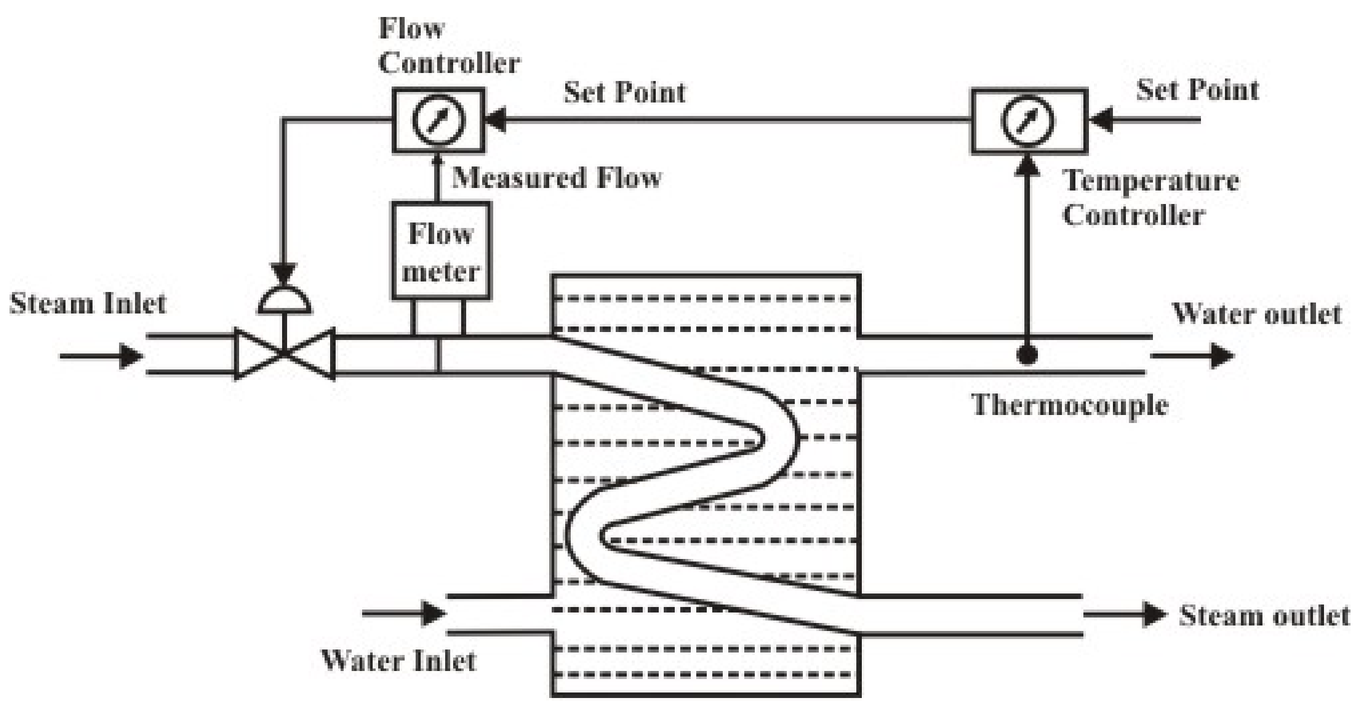

Fig. 2 Cascade Control

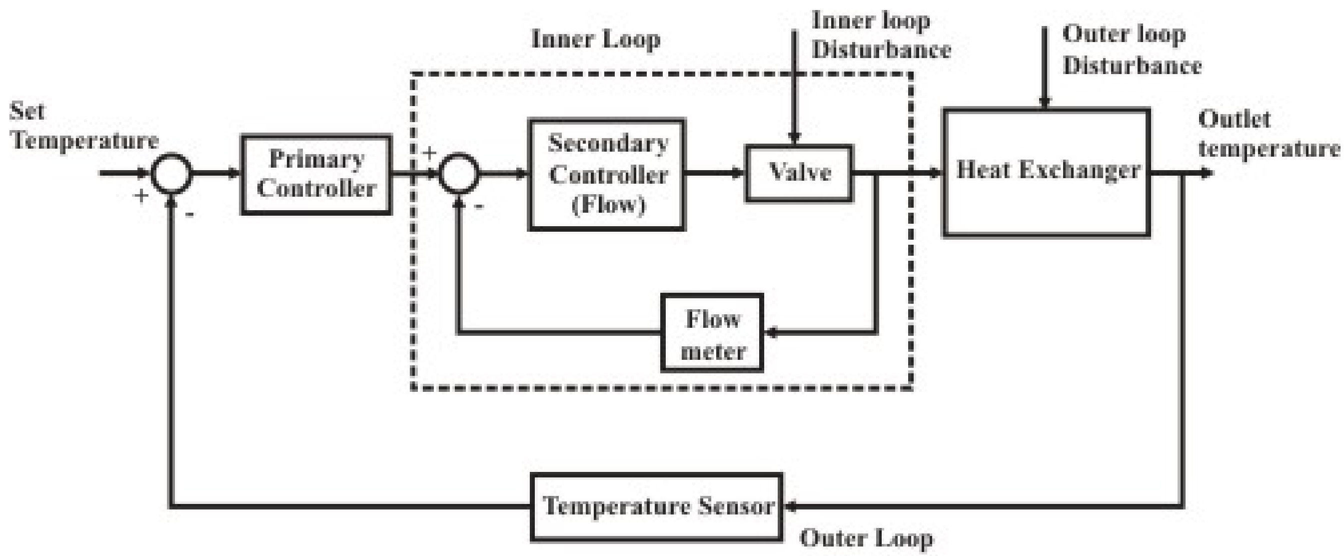

Fig. 3 Block diagram of a Cascade Control System

Broadly speaking, there are two major functions of cascade control: (1) to eliminate the effect of some disturbances, and (2) to improve the dynamic performance of the control loop. It is evident from Fig. 3, that the effect of disturbances arising within the inner loop (or secondary loop, as it is called sometimes) is corrected by the secondary controller, before it can influence the output, and the primary controller takes care of the other disturbances in the outer loop. As a result the transient response of the overall system improves. Fig. 4 depicts typical responses of a closed loop system with (a) simple P-I type feedback controller and (b) cascade with primary P-I controller.

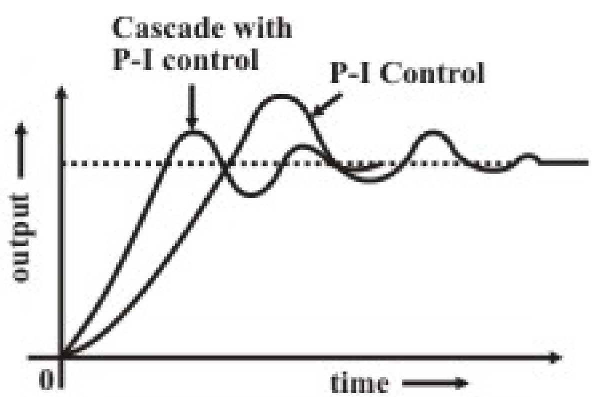

Fig. 4 Comparison of responses between cascade and simple fedback control.

There are few other advantages of cascade control. They can be summarized as:

1. A strong (high gain) inner loop reduces the sensitivity and nonlinearity of the plant in the closed loop. The outer loop therefore experiences less parameter perturbations.
2. Cascading makes the use of feedforward control more systematic. In the heat exchanger example (Fig.2) it is possible to measure the water flow and add feedforward compensation to the flow controller. This would improve the speed of response to fluctuation in water flow, which is a disturbance (refer Lesson 15).

3. Cascade control often makes it possible to use simpler control action than what could be needed for a single controller. Though the number of tunable parameters is more in cascade control, a systematic tuning procedure (inner to outer) is available.

On the other hand the major disadvantages of cascade control are (i) more sensors and transmitters and (ii) more number of controllers.

For proper operation of the cascade control arrangement, the dynamics of the inner loop (control valve in the present case) should be considerably faster than the dynamics of the outer loop process (heat exchanger in the present case). The inner loop secondary controller is normally chosen as a simple P-type controller with high gain, while the outer loop primary controller is a conventional P-I controller.

Due to the presence of two loops in cascade control, the stability of the overall system has to be looked into more carefully. Considering the different elements of the arrangement to be linear, the overall feedback control system can be drawn in terms of the transfer functions as shown in Fig. 5. Here G_{C1} and G_{C2} are the two controllers. G_{P1} is the transfer function of there primary process and G_{P2} is there transfer function of the valve dynamics.

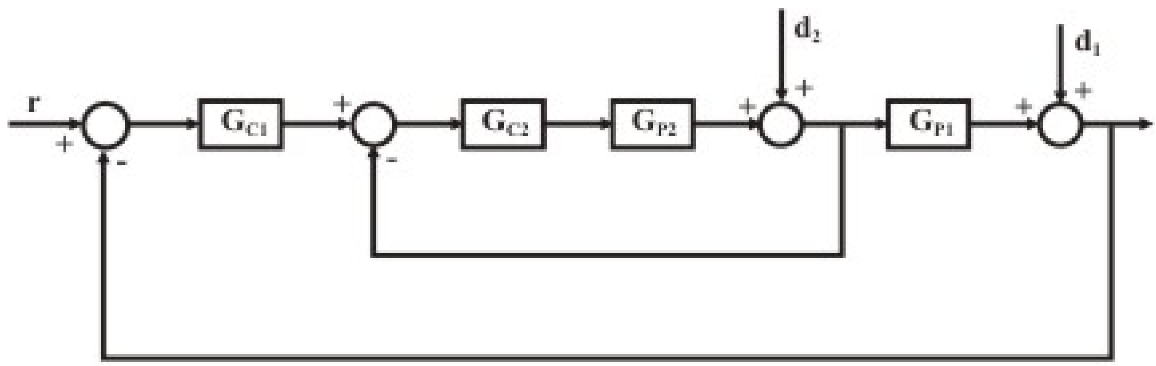

Fig. 5 Block diagram of Cascade Control System

For maintaining stability of the inner loop the roots of the characteristics equation:

$$1+G_{C2}G_{P2}=0 \qquad (1)$$

must be on the left hand side of the s-plane. On the other hand, for maintaining the stability of the primary control loop, the roots of the characteristics equation:

$$1+G_{C1}\left(\frac{G_{C2}G_{P2}}{1+G_{C2}G_{P2}}\right)G_{P1}=0 \qquad (2)$$

must be on the left hand side of the s-plane. It is often advantageous to make the inner loop 3 to 4 times faster than the outer loop.
The cascade control scheme discussed in this scheme is called a *series cascade control*. Besides, there is another scheme called *parallel cascade control*. However, the second one would not been discussed in this lesson.

Override Control

In several processes, there may be a single manipulating variable and several output variables. So the control loop should monitor more than just one control variable. Override control (or a selective control, as it is sometimes called), is a special type of multivariable control, where the manipulating variable is controlled by one output variable at a time. Normally only one of the output variables is controlled; but it has also to be ensured that the other output variables do not cross the safe limits. If it is so, a second controller takes over the controller through a selector switch. This can be achieved by using "High Selector Switch" (HSS) or a "Low Selector Switch" (LSS) as required. HSS is used when it is desired that a variable should not exceed an upper limit. Similarly the LSS.

Let us consider a simple example of override control. Consider a boiler system shown in Fig. 6. Under normal circumstances, the steam pressure of the boiler is controlled by controlling the flow through the discharge line. The pressure is maintained through the pressure transmitter and the pressure controller. But the water level of the boiler should also not fall below a specified lower limit, which is necessary to keep the heating coil immersed in water and thus preventing the burning out. This can be achieved by using override control through the lower limit switch (LSS). Under normal circumstances, the selector switch selects the pressure control loop for control; but as soon as the level of water falls below a set value, the selector switch switches to level control mode and the second loop takes over the control action.

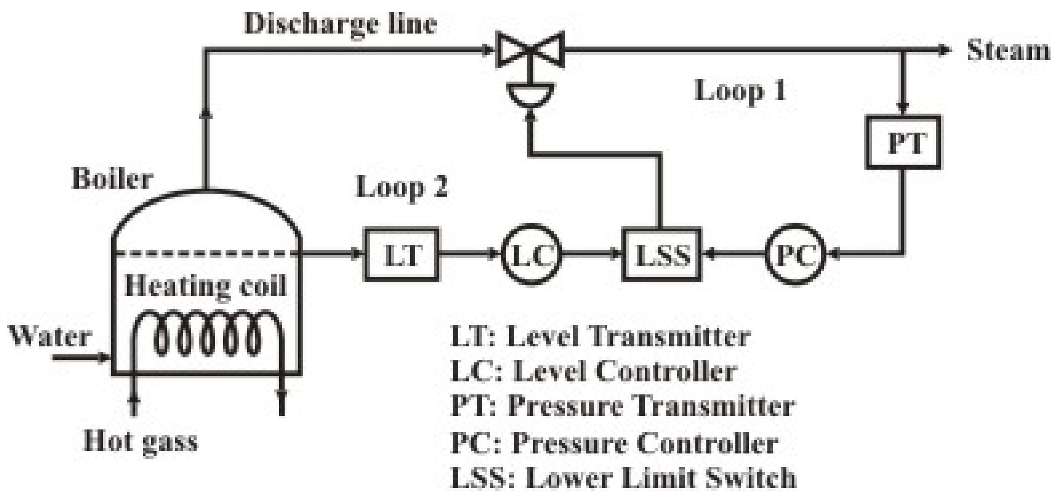

Fig. 6 Override control to protect a boiler system

Split Range Control

This type of control is used, where there are several manipulated variables, but a single output variable. The coordination among different manipulated variables is carried out by using Split Range Control.

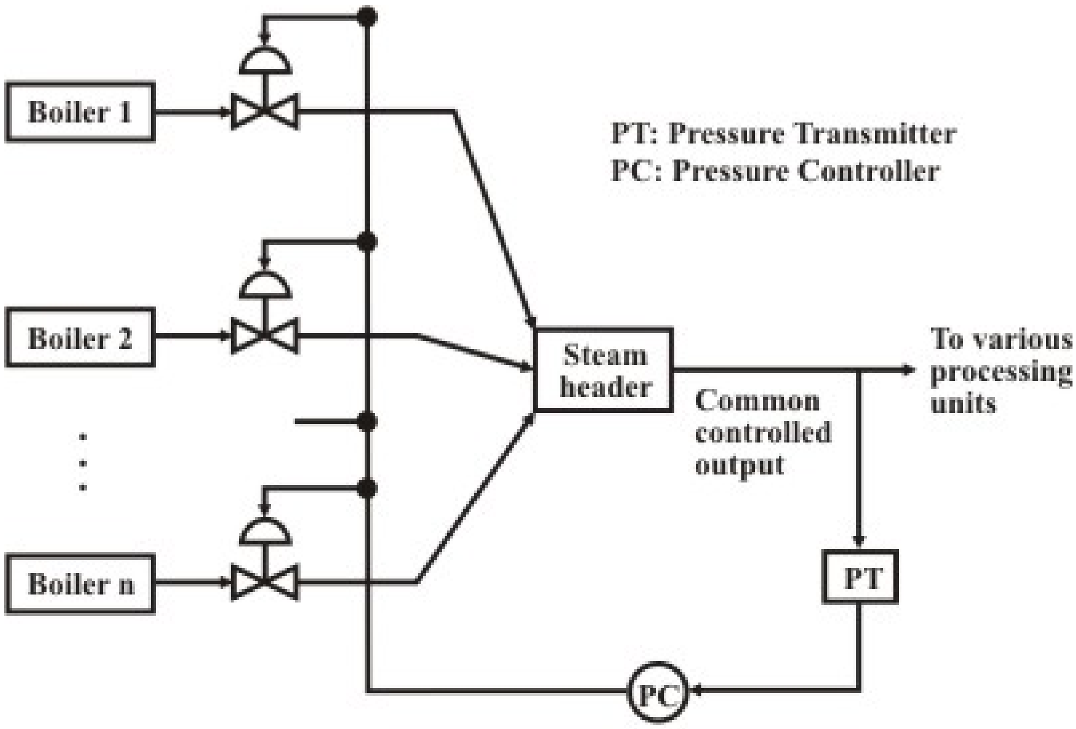

Fig. 7 Steam header with split-range control

Fig. 8 shows an example of a typical split range control scheme. The steam discharges from several boilers are combine at a steam header. Overall steam pressure at the header is to be maintained constant through a pressure control loop. The command from the pressure controller is used for controlling simultaneously the steam flow rates from the boilers in parallel. Clearly, there is a single output variable (steam header pressure) while there are a number of manipulating variables (discharge from different boilers).

References

1. G. Stephanopoulus: Chemical process Control, Prentice Hall of India, New Delhi, 1995.
2. D.R. Coughanowr: Process systems analysis and control (2/e), McgrawHill, NY, 1991.
3. W.L. Luyben and M.L. Luyben: Essentials of Process Control, McgrawHill, NY, 1997.

Review Questions

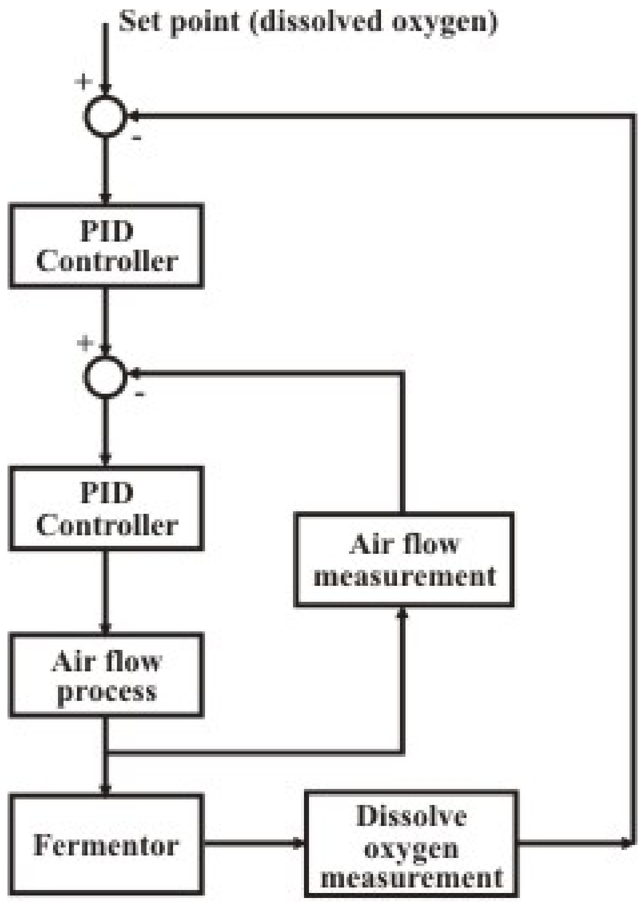

Fig. Q1 Control of a fermentation process

1. Fermentation is a chemical process where sugar, in presence of micro organism breaks down into alcohol and carbon dioxide. Control of fermentation finds wide applications in several industries, e.g. (a) brewing, (b) dairy (c) bakery (d) wine. Fig. Q1 shows a typical control scheme for controlling the dissolved oxygen content in a fermentation process.

    (a) Explain the operation of the control scheme. What type of control is it?

    (b) Identify the inner and outer loops in the control system.

    (c) What types of control would you recommend for the inner and outer loops?

2. Discuss the advantages and disadvantages of using cascade control.
3. Write down the conditions for maintaining stability of a cascade control system.
4. What do you mean by override control? Explain with an example.
5. What do you mean by split range control. Show a schematic arrangement of this type of control.

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