Module 3

Process Control

Lesson
15
Special Control Structures: Feedforward and Ratio Control

Instructional Objectives

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

- Justify the use of feedforward controller in addition to conventional feedback controller.
- Draw the block diagram of a feedforward-feedback controller.
- Find the transfer function of the feedforward controller for complete disturbance rejection.
- Write down three typical applications of ratio control
- Give two possible arrangements for achieving ratio control

Introduction

In the last few lessons we have discussed about the different aspects of PID controllers, their tuning, implementation etc. In all the cases the control action considered was feedback type; i.e. the output was fed back and compared with the set point and the error was fed to the controller. The output from the controller was used to control the manipulating variable. However there are several cases, where apart from the feedback action few other control structures are incorporated in order to satisfy certain requirements. In this lesson we would take up two such special control structures: feedforward and ratio control.

Feedforward Control

When the disturbance is measurable, feedforward control is an effective means for cancelling the effects of disturbance on the system output. This is advantageous, since in a simple feedback system, the corrective action starts after the effect of disturbance is reflected at the output. On the other hand, in feedforward control the change in disturbance signal is measured and the corrective action takes place immediately. As a result, the speed and performance of the overall system improves, if feedforward control, together with feedback action is employed.

In order to illustrate the effect of feedforward control, let us consider the heat exchange process shown in Fig.1. The cold water comes from a tank and flows to the heat exchanger. The flow rate of cold water can be considered as a disturbance. The change in input flow line may occur due to the change in water level in the tank. Suppose, the feedforward line is not connected, and the controller acts as a feedback control only. If the water inlet flow rate increases, the temperature of the outlet hot water flow will decrease. This will be sensed by the temperature sensor that will compare with the set point temperature and the temperature controller will send signal to open the control valve to allow more steam at the steam inlet. The whole operation is a time consuming and as a result the response of the controller due to the disturbance (inlet water flow rate) is normally slow. But if we measure the change in inlet flow rate by a flowmeter and feed this information to the controller, the controller can immediately take the correcting action anticipating the change in outlet temperature. This will improve the speed of response. Thus feedforward action, in addition to the feedback control improves the performance of the system, but provided, the disturbance is measurable.

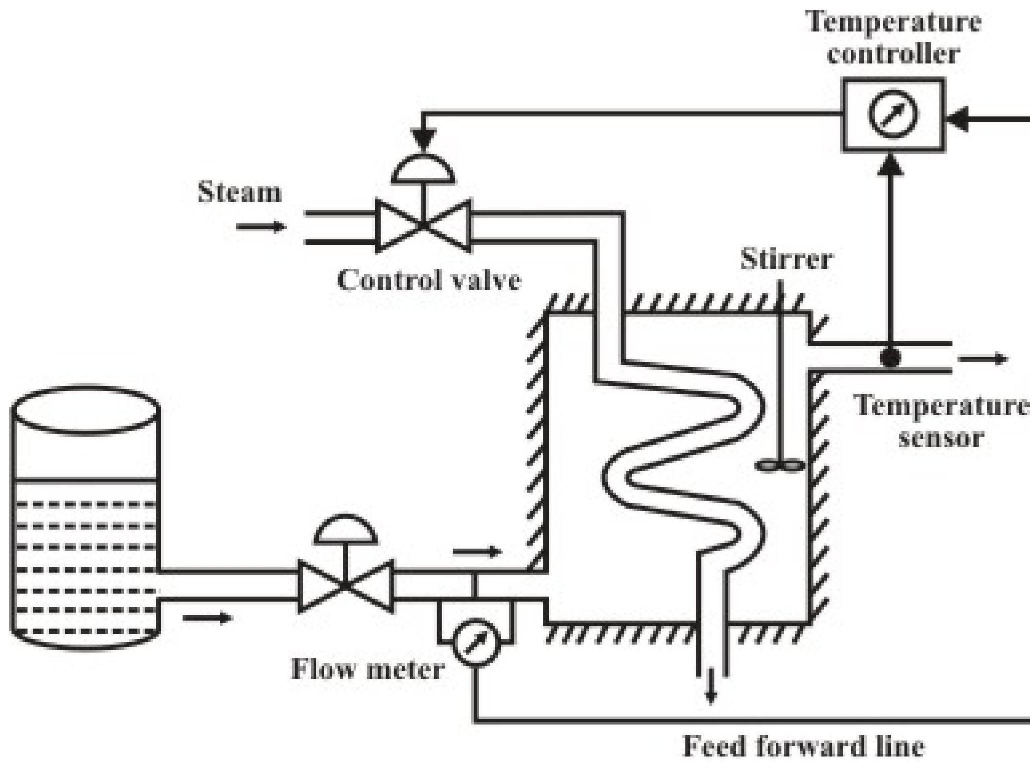


Fig. 1 Feed forward control action in a heat exchange.

Let us now draw the block diagram of the overall control operation of the system shown in Fig. 1. The block diagram representation is shown in Fig. 2.

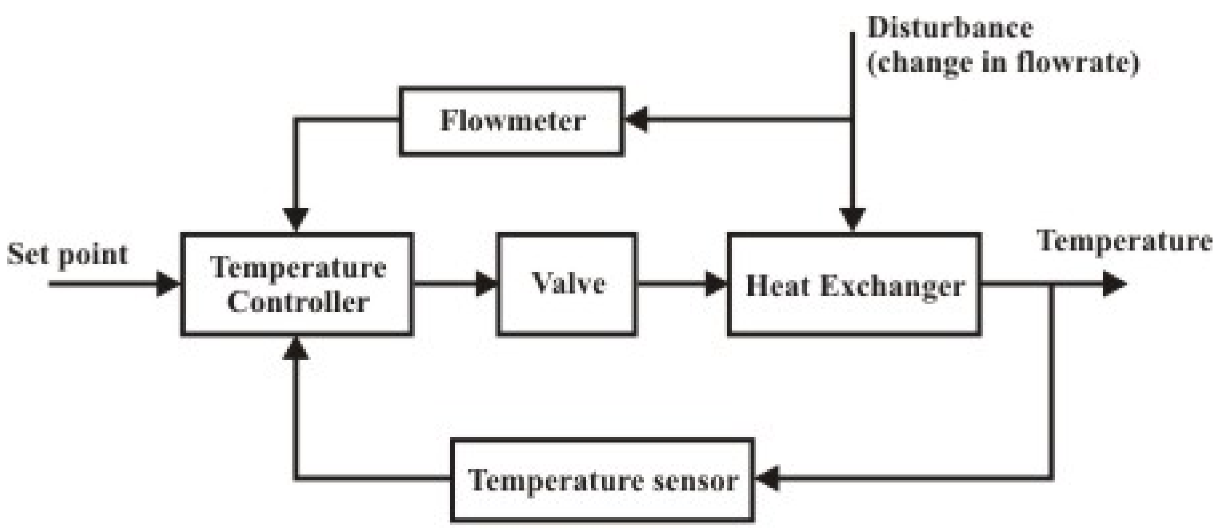


Fig. 2 Block diagram representation of the control action shown in Fig. 1

In general, the structure of the feedforward-feedback action in terms of the block diagram of transfer functions can be represented as shown in Fig. 3. Where,

$G(s)$ = Transfer function of the process (manipulating variable to output)

$G_n(s)$ = Disturbance transfer function (disturbance to output)

$G_c(s)$ = Transfer function of feedback controller

$G_f(s)$ = Transfer function of the feedforward controller

So there are two controllers, one is the conventional feedback controller $G_c(s)$, while the other is the feedforward controller that is intended to nullify the effect of disturbance at the output. From Fig. 3, the overall output is:

$$
\begin{aligned}
C(s) &= G_c(s)G(s)E(s) + G_n(s)N(s) \\
&= G_c(s)G(s)\left[R(s) - C(s) + G_f N(s)\right] + G_n(s)N(s) \\
&= G_c(s)G(s)\left[R(s) - C(s)\right] + \left[G_c(s)G(s)G_f(s) + G_n(s)\right]N(s)
\end{aligned}
$$

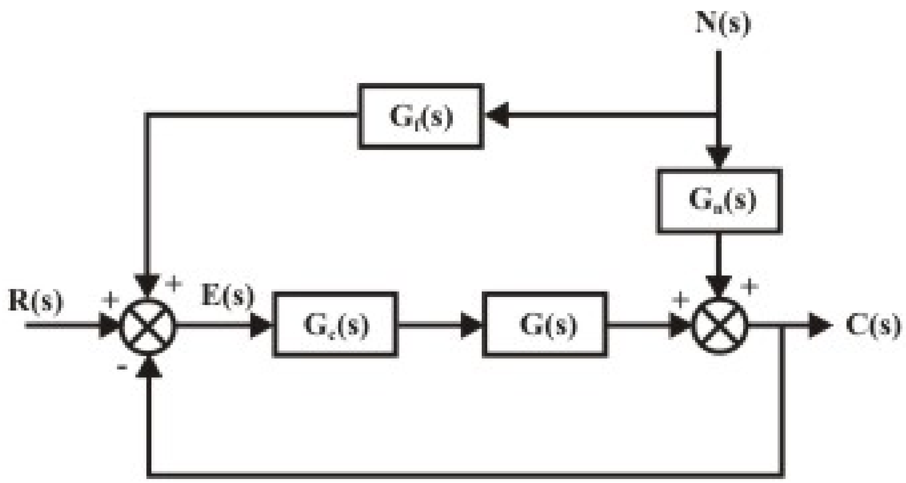


Fig. 3 Transfer function representation of the feedforward-feedback control action

If we want to select the feedforard transfer function, such that, the effect of disturbance at the output is zero, then we require the co-efficient of N(s) in above equation to be set to zero. Thus,

$$G_c(s)G(s)G_f(s) + G_n(s) = 0$$

or, $$G_f(s) = -\frac{G_n(s)}{G_c(s)G(s)} \qquad (1)$$

It is to be noted that complete disturbance rejection can be obtained if the transfer functions $G_p(s)$ and $G_n(s)$ are known accurately, which is not possible in actual situation. As a result, the performance of the feedforward controller will deteriorate and complete disturbance rejection can not be achieved, through the effect can be reduced considerably. However the feedback controller would reduce the residual error due to imperfect feedforward control and at the output, the effect of imperfect cancellation may not be felt.

Example -1

Consider the composition control system of a certain reagent. The block diagram of the feedforward-feedback control system is shown in Fig.4. Here we are using a P-I controller for feedback action. C_i is the disturbance signal. Compared to Fig.3, the feedforward controller output in the present case is added after the feedback controller. Suppose, the plant transfer function and the disturbance transfer function are given by:

$$G_p(s) = \frac{1}{(s+1)^3}$$

$$G_n(s) = \frac{1}{(5s+1)(s+1)^3}$$

With a little calculation using eqn.(1), we obtain the transfer function of the feedforward controller as:

$$G_f(s) = -\frac{1}{5s+1}$$

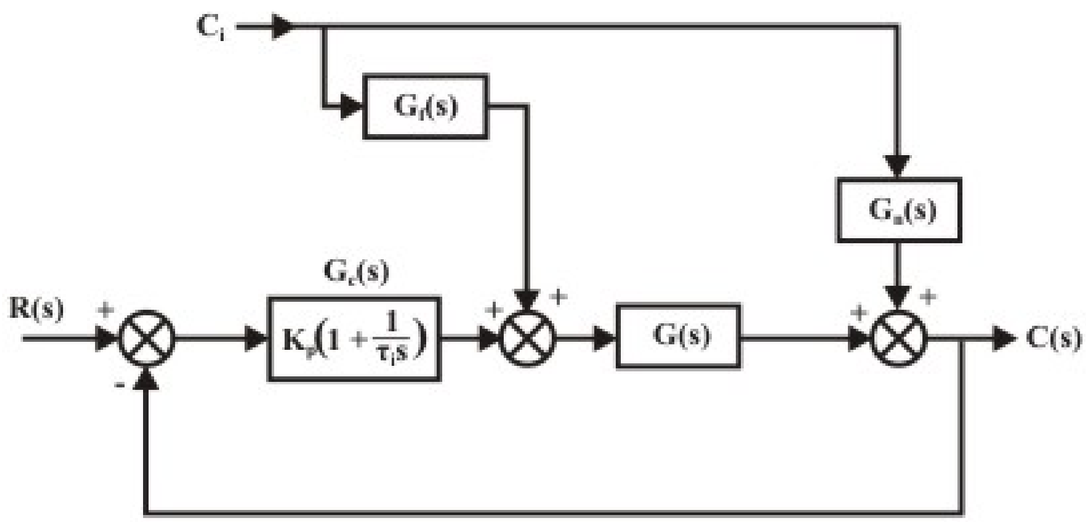


Fig. 4 Block diagram of a feedforward-feedback control of a composition control system

But in many cases, practical implementation of the feedforward controller as obtained from eqn.(1) is difficult. It can be easily seen in the above example if the disturbance transfer function is :

$$G_n(s) = \frac{1}{(s+1)^2}$$

In this case, the feedforward controller transfer function becomes:

$$G_f(s) = -(s+1)$$

But since the above transfer function is not a proper one, practical realization of this transfer function is difficult. In these cases, the transfer function of the feedforward controller is chosen in the form of a lag-lead compensator as:

$$G_f(s) = -\frac{K_f(1+T_1 s)}{(1+T_2 s)}, \text{ with } T_2 << T_1 \text{ and } K_f \text{ is a constant.}$$

In the present case the transfer function $G_f(s) = -(s+1)$ can be realized by approximating as:

$$G_f(s) = -\frac{s+1}{0.1s+1}.$$

In normal case, the transfer function of the process is not known exactly. So the question is how to tune the parameters of the feedforward controller for optimum performance. This can be carried out by performing some experimentation for tuning the controller. The details of the tuning procedure for feedforward controllers can be found in [2].

Ratio Control

Ratio control is a special type of feedforward control where the disturbance is measured and the ratio of the process output and the disturbance is held constant. It is mostly used to control the ratio of flow rates of two streams. Flow rates of both the stream are measured, but only one of them is controlled. There can be many examples of application of ratio control. Few examples are:

1. fuel-air ratio control in burners,
2. control of ratio of two reactants entering a reactor at a desired ratio,
3. maintaining the ratio of two blended streams constant in order to maintain the composition of the blend at the desired value.

There can be two schemes for achieving ratio control. The first scheme is shown in Fig. 5. In this configuration the ratio of flow rates of two streams is measured and compared with the desired ratio. The error is fed to the controller and the controller output is used to control the flow rate of stream B.

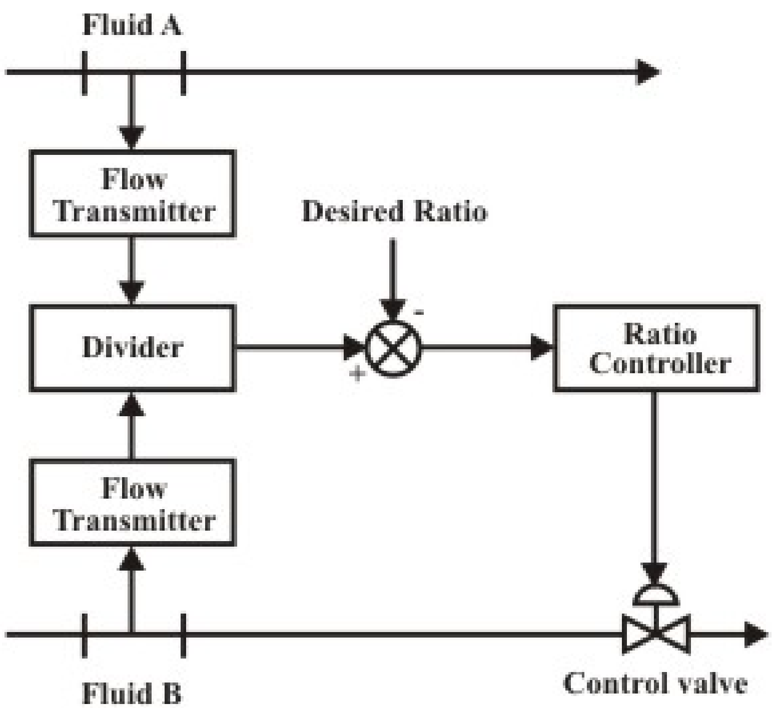


Fig. 5 A possible configuration for achieving ratio control

The second possible scheme for ratio control is shown in Fig. 6. Suppose the flow rate of fluid B has to be maintained at a constant fraction of flow rate of fluid A, irrespective of variation of flow rate of A (q_A). In this scheme the flow rate of fluid A is multiplied with the desired ratio (set externally) that gives the desired flow rate of fluid B. This is compared with the actual flow rate of fluid B and fed to the controller that operates the control valve.

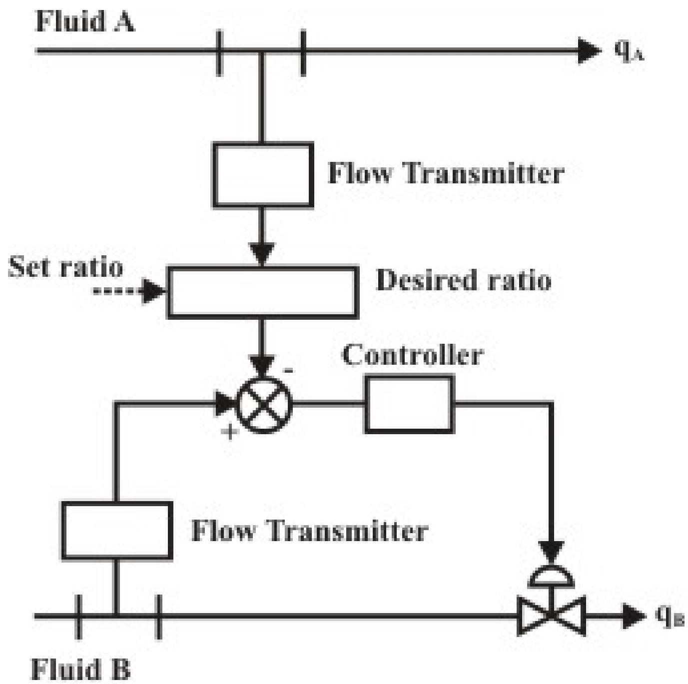


Fig. 6 Ratio control

Suppose that the above scheme (Fig. 6) is used for controlling the fuel-air ratio in a burner where airflow rate (fluid B) is controlled. But the desired ratio is also dependent on the temperature of the air. So an auxiliary measurement is needed to measure the temperature of air and set the desired ratio. Such a scheme is shown in Fig. 7.

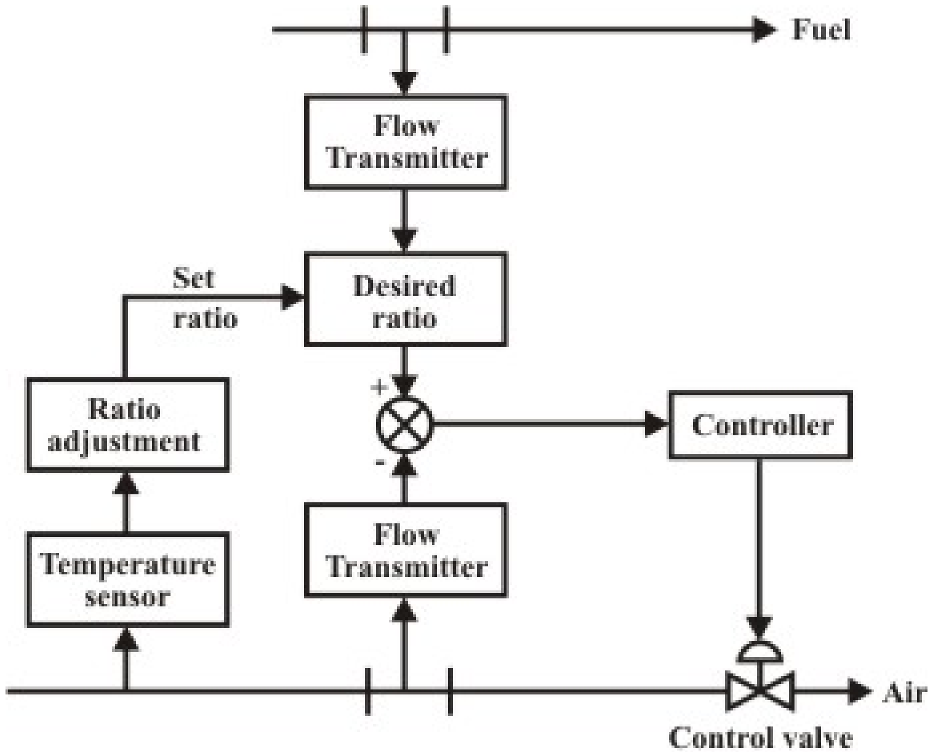


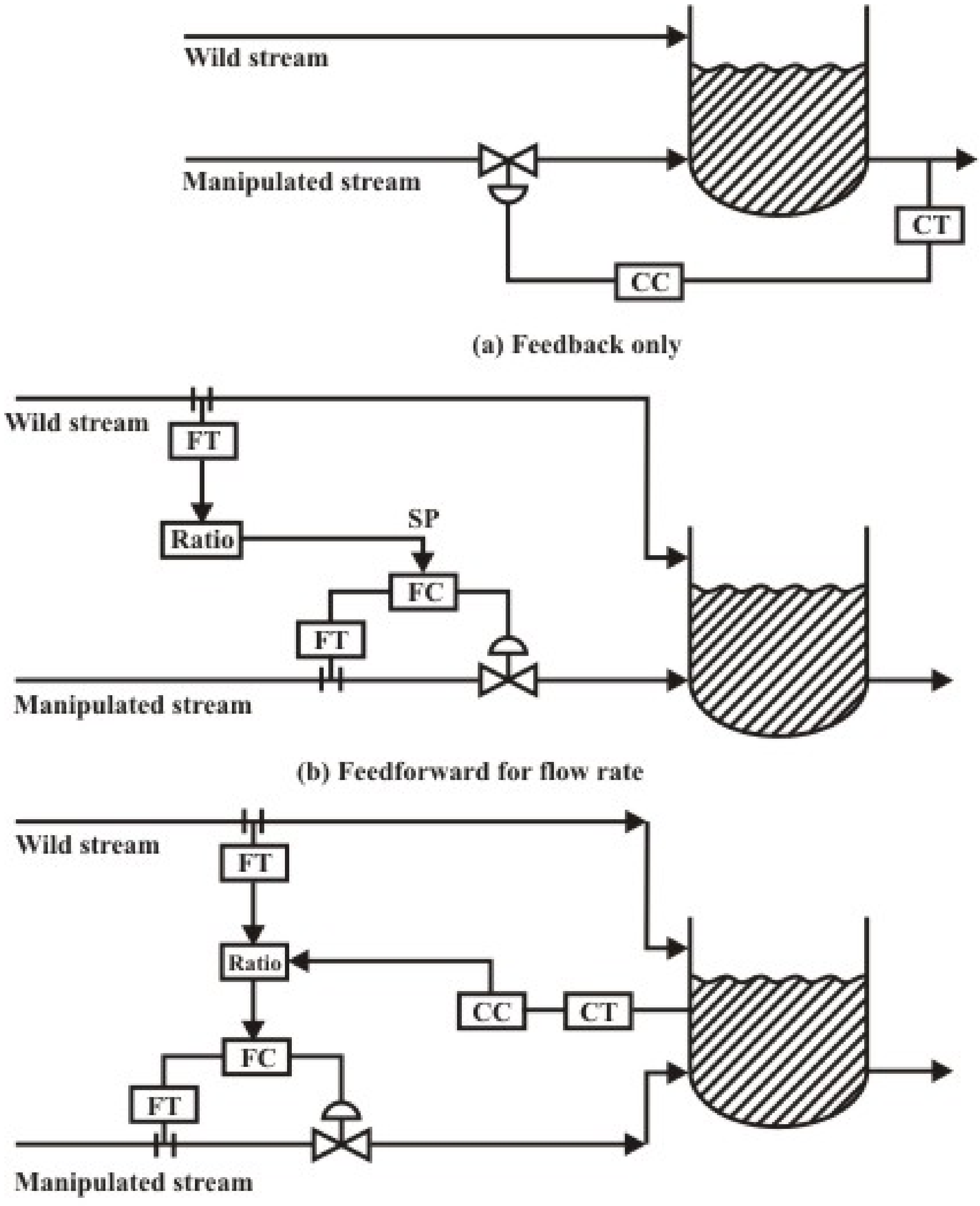
Fig. 7 Ratio control with ratio adjustment mechanism

The controllers in ratio control are usually P-I type. This is in order to achieve zero steady state error for maintaining the desired ratio. Derivative action is avoided because the flow is always noisy.

Example -2

We have mentioned earlier that ratio control is a special type of feedforward control. We shall elaborate this point in the following example [4]. Effects of control actions in feedback only mode, feedforward only mode and feedforward-feedback mode will also be elaborated in the context of control of a blending process.

Consider a blending system where two streams are blended; one is uncontrolled wild stream that acts as disturbance and another is controlled and acts as the manipulated variable. The ratio of these two streams affect the quality of the output of the process.



(a) Feedback only

(b) Feedforward for flow rate

(c) Feedforward/feedback

FC - Flow Controller　　FT - Flow Transmitter
CC - Composition Controller　　CT - Composition Transmitter

Fig. 8 Comparison among Feedback, Feedforward and Feedforward-feedback Control

First consider a simple feedback system shown in Fig. 8(a). The composition of the output stream is unmeasured and fed to the composition controller that controls the flow rate of the manipulated stream. But the performance of this system may not be satisfactory, since any variation of the wild stream will cause the change in composition of the output, that will be felt after certain time. As a result the performance of the feedback controller is sluggish.

On the other hand the performance of the blending process can be made considerably faster if he incorporate the ratio control scheme as shown in Fig. 8(b). In this case, the disturbance (flow rate of wild stream) is measured and corrective action is taken immediately by controlling manipulated stream so as to maintain a constant ratio between them. It is evident that this the control action is feedforward only, since the composition of the output stream is not unmeasured.

But the above scheme also suffers from certain limitations, since the composition variation due to other disturbances is not taken into account. So though faster, if may not yield the desired performance. The performance may be further improved by choosing a feedforward-feedback control scheme (Fig. 8(c)) where the composition of the output stream is measured and the composition controller sets the desired ratio to be maintained.

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. K. Ogata: Modern Control Engineering (2/e), Prentice Hall of India, New Delhi, 1995.
4. W.L. Luyben and M.L. Luyben: Essentials of Process Control, McgrawHill, NY, 1997.

Review Questions

1. When would you recommend the use of feedforward controller? What is the advantage of using this control?
2. Draw the general block diagram of a feedforward-feedback control scheme and develop the transfer function of the feedback controller.
3. What modification of the transfer function of the feedforward controller is suggested when the obtained transfer function of the controller is not proper?
4. Explain with an example the principle of ratio control. Elaborate with a block diagram any one scheme for achieving ratio control.
5. Why the controller used for ratio control is normally P-I type?