

Fundamentals of Process Control Theory

Third Edition

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Unit 2:

Basic Control Concepts

UNIT 2

Basic Control Concepts

This unit introduces the basic concepts encountered in automatic process control. Some of the basic terminology is also presented.

Learning Objectives — When you have completed this unit, you should:

- A. be able to explain the meaning of the following terms:
 - 1. controlled quantities
 - 2. disturbances
 - 3. manipulated quantities
- B. understand the basic concept of feedback control
- C. understand the basic concept of feedforward control
- D. have a general overview of process automation

2-1. Control History

The first well-defined use of feedback control seems to have been James Watt's application of the flyball governor to the steam engine in about 1775. As a matter of interest, most of the early applications and theoretical investigations of feedback control were associated with governors, and these usually were in industrial applications. Broader use of automatic control began to be made in the late 1920s, and the first general theoretical treatment of automatic control was published in 1932. The growth in industrial usage has been steady and strong.

Many new technologies have been applied to process control hardware as the industrial use of automation techniques has developed and matured in the past seventy years. An important example of this was the application of digital computer and microprocessor capabilities to process control in the 1960s. As a result, process automation received a significant and very special boost in technology. Today, many industries allocate in excess of 10 percent of their plant investment capital outlays for instrumentation and control. This percentage has doubled over the past thirty years and shows no signs of diminishing.

The underlying theory of automatic control has also developed rapidly, and a firm and broad foundation of understanding has been created. Today's applications are based on this foundation. Many modern practitioners encounter difficulty, however, applying well-defined

mathematical theories of automatic process control. This difficulty is quite natural, but much of the problem is due to the fact that teachers do not focus sufficient attention on illustrating theoretical principles by studying day-to-day industrial applications. The principle purpose of this book is to alleviate this problem by showing the actual use of control theory in practice.

2-2. The Variables Involved

To understand automatic process control, you must first fix in your mind three important terms that are associated with any process: *controlled quantities*, *manipulated quantities*, and *disturbances*. These are illustrated in Fig. 2-1. The controlled quantities (or *controlled variables*) are those streams or conditions that the practitioner wishes to control or to maintain at some desired level. These may be flow rates, levels, pressures, temperatures, compositions, or other such process variables. For each of these controlled variables, the practitioner also establishes some *desired value*, also known as the *set point* or *reference input*.

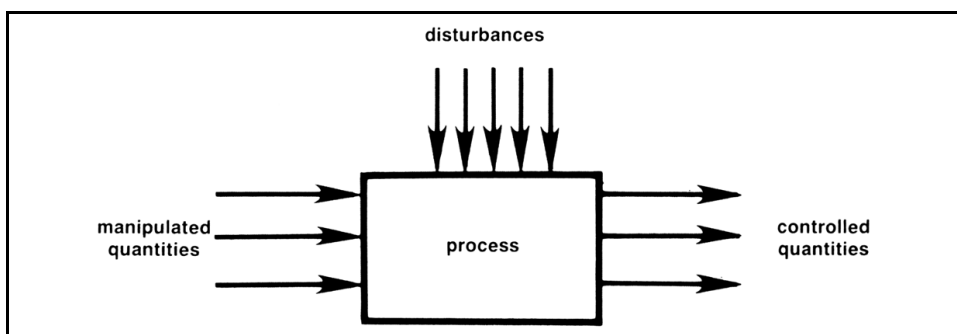


Figure 2-1. The Variables Involved

For each controlled quantity, there is an associated manipulated quantity or *manipulated variable*. In process control this is usually a flowing stream, and in such cases the flow rate of the stream is often manipulated through the use of a control valve. Disturbances enter the process and tend to drive the controlled quantities or controlled variables away from their desired, reference, or set point conditions. The automatic control system must therefore adjust the manipulated quantities so that the set point value of the controlled quantity is maintained in spite of the effects of the disturbances. Also, the set point may be changed, in which case the manipulated variables will need to be changed to adjust the controlled quantity to its new desired value.

Fig. 2-2 shows a typical home heating system. In such a system, the controlled variable is room temperature. (Your intent, of course, is to maintain creature comfort in the room, and you control “comfort” by controlling a variable that can be measured easily, such as temperature.) A number of disturbances cause room temperature to vary, for example, outside ambient temperature, the number of people in the room, the type of activity taking place in the room. The automatic control system is designed to manipulate the fuel flow to the furnace in order to maintain room temperature at its desired value or set point in spite of the various disturbances.

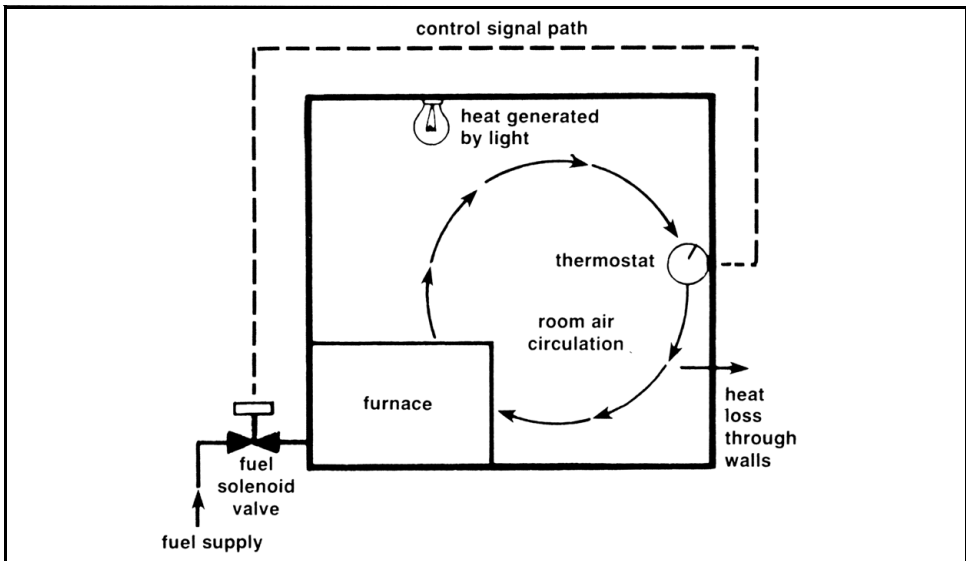


Figure 2-2. A Home Heating System

2-3. Typical Manual Control

Before studying automatic process control, it is helpful to spend a moment or two reviewing a typical manual operation. This is illustrated in Fig. 2-3, which shows a process with one controlled quantity. On the stream leaving the process, there is an indicator to provide the operator with information on the current actual value of the controlled variable. The operator is able to inspect this indicator visually and, as a result, to manipulate a flow into the process to achieve some desired value or set point of the controlled variable. The set point is, of course, in the operator's mind, and the operator makes all of the control decisions. The problems inherent in such a simple manual operation are obvious.

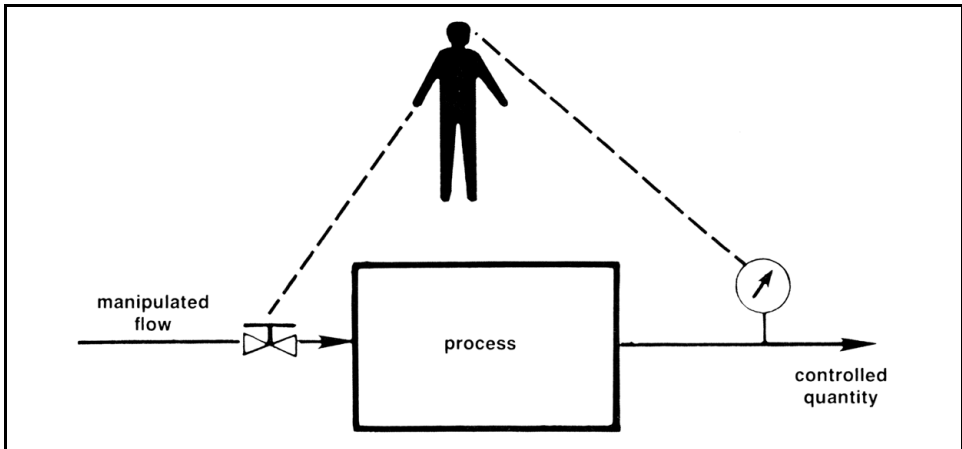


Figure 2-3. Typical Manual Control

2-4. Feedback Control

The simplest way to automate the control of a process is through conventional feedback control. This widely used concept is illustrated in Fig. 2-4. Sensors or measuring devices are installed to measure the actual values of the controlled variables. These actual values are then transmitted to feedback control hardware, and this hardware makes an automatic comparison between the set points (or desired values) of the controlled variables and the measured (or actual) values of these same variables. Based on the differences (“errors”) between the actual values and the desired values of the controlled variables, the feedback control hardware

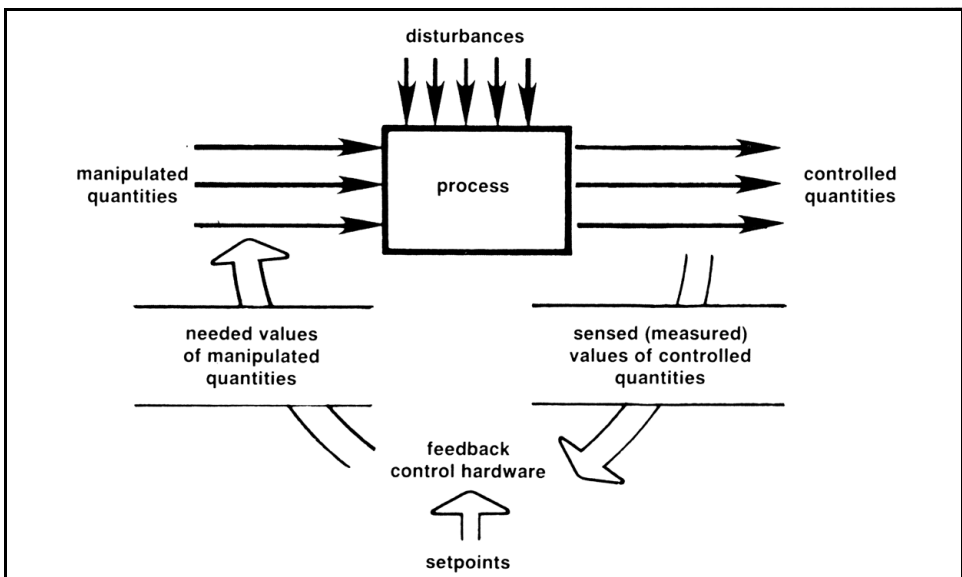


Figure 2-4. Feedback Control Concept

calculates signals that reflect the needed values of the manipulated variables. These are then transmitted automatically to adjusting devices (typically control valves) that manipulate inputs to the process.

The beauty of feedback control is that the designer does not need to know in advance exactly what disturbances will affect the process, and, in addition, the designer does not need to know the specific quantitative relationships between these disturbances or their ultimate effects on the controlled variables. The control hardware is used in a standard format, and all feedback control loops tend to reflect the general conceptual framework illustrated in Fig. 2-4. To a very significant extent, this standard pattern exists regardless of the specific nature of the process or the controlled variable involved.

The particular hardware used in a loop and the particular matching of one hardware piece to another is an important responsibility for the designer, but the overall control strategy is always the same in feedback control. Such feedback control is the simplest automatic process control technique that can be used, and it represents the basis for the vast majority of industrial applications.

2-5. Manual Feedforward Control

Feedforward control is much different in conception from feedback control. A manual implementation of feedforward control is illustrated in Fig. 2-5. As a disturbance enters the process the operator observes an indication of the nature of the disturbance, and based on that entering disturbance the operator adjusts the manipulated variable so as to prevent any ultimate change or variation in the controlled variable caused by the disturbance. The conceptual improvement offered by feedforward control is apparent. Feedback control worked to eliminate errors, but feedforward control operates to prevent errors from occurring in the first place. The appeal of feedforward control is obvious.

Feedforward control does escalate tremendously the requirements of the practitioner, however. The practitioner must know in advance what disturbances will be entering the process, and he or she must make adequate provision to measure these disturbances. In addition, the control room operator must know specifically when and how to adjust the manipulated variable to compensate exactly for the effects of the disturbances. If the practitioner has these specific abilities and if they are perfectly available, then the controlled variable will never vary from its desired value or set point. If the operator makes some mistake or does not anticipate all of the disturbances that might affect the process, then the controlled variable will deviate from its desired value, and, in pure feedforward control, an uncorrected error will exist.

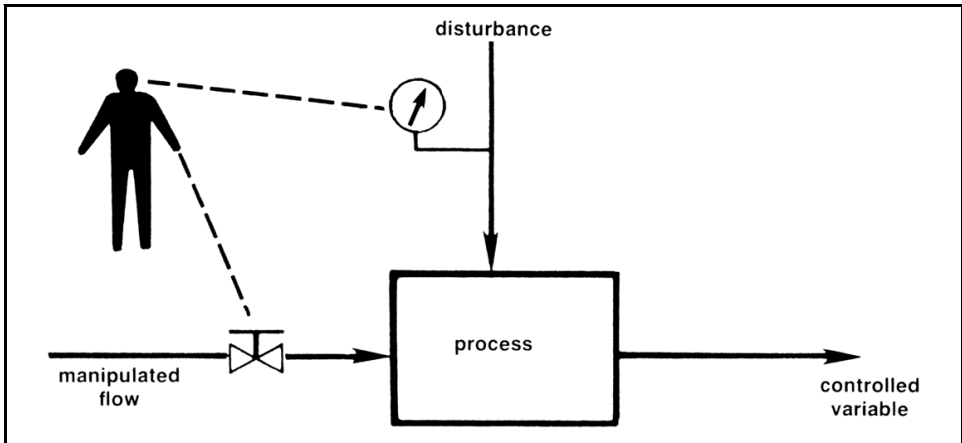


Figure 2-5. Manual Feedforward Control

2-6. Automatic Feedforward Control

Fig. 2-6 shows the general conceptual framework of automatic feedforward control. Disturbances are shown entering the process, and sensors are available to measure these disturbances. Based on these sensed or measured values of the disturbances, the feedforward controllers then calculate the needed values of the manipulated variables. Set points that represent the desired values of the controlled variables are provided to the feedforward controllers.

It is clear that the feedforward controllers must make very sophisticated calculations. These calculations must reflect an awareness and understanding of the exact effects that the disturbances will have on the controlled variables. With such an understanding, the feedforward

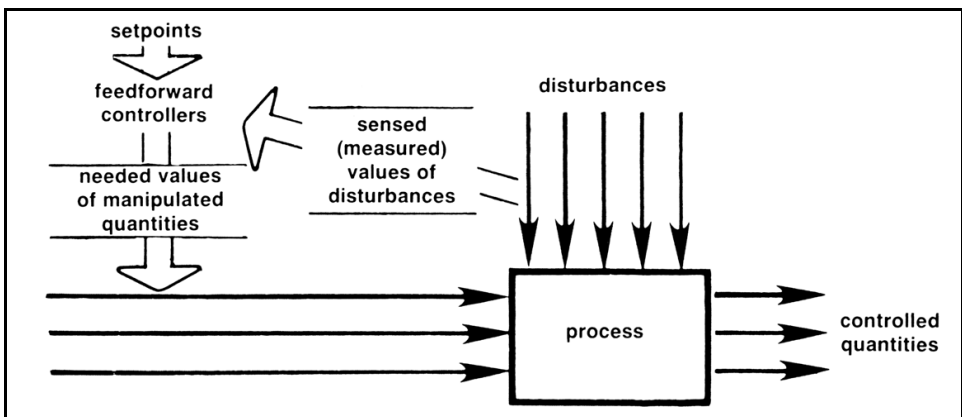


Figure 2-6. Feedforward Control Concept

controllers are able then to calculate the exact amount of manipulated quantities required to compensate for the disturbances. These computations also imply a specific understanding of the exact effects that the manipulated variables will have on the controlled variables. If all of these mathematical relationships are readily available, then the feedforward controllers can automatically compute the variation in manipulated flows that is needed to compensate for variation in disturbances. The escalation in the theoretical understanding required is obvious. Feedforward control, while conceptually more appealing, significantly escalates the technical and engineering requirements of the designer and practitioner. As a result, feedforward control is usually reserved for only a very few of the most important loops within a plant. While the number of applications is small, their importance is quite significant.

Pure feedforward control is rarely encountered, and it is more common for a process to have combined feedforward and feedback control loops. This will be illustrated in Unit 11 where feedforward control is discussed in greater detail.

2-7. Process Control *and* Process Management

Process automation is commonly used to derive the maximum profitability from a process. In the previous sections of this unit there was an implicit assumption that we knew the desired values (typically “desired” in order to achieve maximum profitability) for the controlled quantities. Once these desired values are known, automation techniques are applied to achieve and/or maintain these desired values or set points. Upon reflection, however, it can be seen that some of the most significant questions associated with the profitability of a process are those that must be answered to determine the desired values. This is basically the supervisory or management function, and quite often it is left for the human operator to determine. But, in recent years, with the significant advances in process automation many of these supervisory or management functions have themselves become automated, and the ability to achieve technological solutions and hardware answers for such management questions is a significant part of the modern control scene.

In a particular process, as the level of automation is increased, most of the initial steps involve using conventional process control (such as feedback control). However, as the level of automation increases more and more of the automation is associated with process management. This is illustrated in Fig. 2-7.

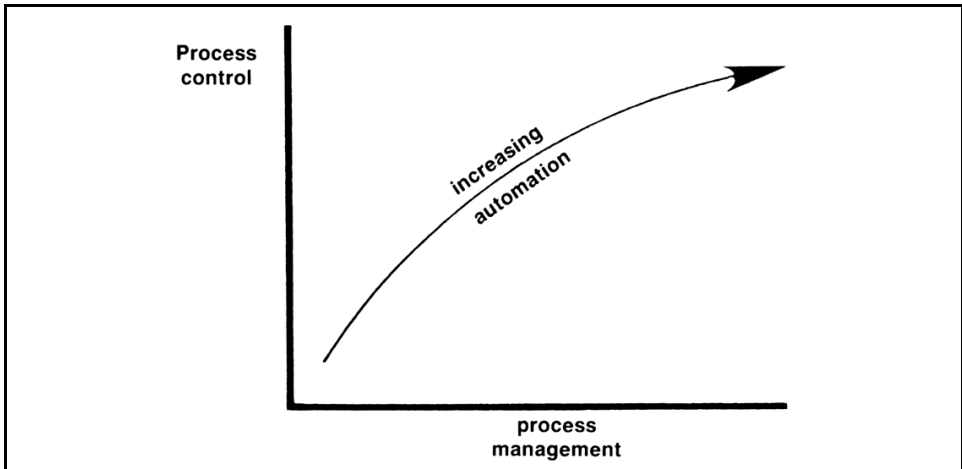


Figure 2-7. Process Control *and* Management

The combination of these two phenomena—process control and process management—must be reflected in our overall understanding and appreciation of process automation. A more detailed comparison of these two subjects will be presented in Section 16-1.

EXERCISES

- 2-1. Consider an electric oven in a typical modern kitchen. Identify the controlled variable, the manipulated variable, and the disturbances.
- 2-2. Consider an automatic gas-fired, home hot-water tank. Identify the controlled variable, the manipulated variable, and the disturbances.
- 2-3. Imagine you own a backyard swimming pool! Describe a manual control system to measure pH and to add an acidic solution to adjust pH. Define the controlled variable, the manipulated variable, and the disturbances.
- 2-4. Now automate the control of your swimming pool! Assume you have a tank of acid solution to pump into your pool to control pH; use feedback control.
- 2-5. The “Cruise Control” feature used to control speed in an automobile is a good example of feedback control. Outline its operation in terms of feedback control.
- 2-6. Consider a gas-fired, home hot-water tank being used in a house that uses a lot of hot water. This heavy usage, of course, is the disturbance or load on the tank. Using a diagram, show how such a tank could be controlled using feedforward control.