

Control Systems

4th Stage

LECTURE 1

Introduction to Control Systems

Dr. Aws Zuhair

❖ **Reference**

- Katsuhiko Ogata, Modern Control Engineering, 5th Edition

❖ **Content**

- Introduction
- Examples of Control Systems
- Closed-Loop Control VS. Open-Loop Control
- Closed-Loop Control VS. Open-Loop Control

❖ **Lecture Objectives**

- An introduction to the control systems
- Knowing the parts and the names of the control systems
- Explain the differences between open loop and close loop control systems

1. Introduction

Control theories commonly used today are classical control theory (also called conventional control theory), modern control theory, and robust control theory.

Automatic control is essential in any field of engineering and science. Automatic control is an important and integral part of space-vehicle systems, robotic systems, modern manufacturing systems, and any industrial operations involving control of temperature, pressure, humidity, flow, etc. It is desirable that most engineers and scientists are familiar with theory and practice of automatic control. The first significant work in automatic control was James Watt's centrifugal governor for the speed control of a steam engine in the eighteenth century.

As modern plants with many inputs and outputs become more and more complex, the description of a modern control system requires a large number of equations. Classical control theory, which deals only with single-input, single-output systems, becomes powerless for multiple-input, multiple-output systems. Since about 1960, because the availability of digital computers made possible time-domain analysis of complex systems, modern control theory, based on time-domain analysis and synthesis using state variables, has been developed to cope with the increased complexity of modern plants and the stringent requirements on accuracy, weight, and cost in military, space, and industrial applications.

Modern control theory is based on time-domain analysis of differential equation systems. Modern control theory made the design of control systems simpler because the theory is based on a model of an actual control system. However, the system's stability is sensitive to the error between the actual system and its model. This means that when the designed controller based on a model is applied to the actual system, the system may not be stable. To avoid this situation, we design the control system by first setting up the range of possible errors and then designing the controller in such a way that, if the error of the system stays within the assumed range, the designed control system will stay stable. The design method based on this principle is called robust control theory. This theory

incorporates both the frequency response approach and the time-domain approach. The theory is mathematically very complex.

Before we can discuss control systems, some basic terminologies must be defined.

1.1 Controlled Variable and Control Signal or Manipulated Variable

The controlled variable is the quantity or condition that is measured and controlled. The control signal or manipulated variable is the quantity or condition that is varied by the controller so as to affect the value of the controlled variable. Normally, the controlled variable is the output of the system. Control means measuring the value of the controlled variable of the system and applying the control signal to the system to correct or limit deviation of the measured value from a desired value.

In studying control engineering, we need to define additional terms that are necessary to describe control systems.

1.2 Plants

A plant may be a piece of equipment, perhaps just a set of machine parts functioning together, the purpose of which is to perform a particular operation. In these lectures, we shall call any physical object to be controlled (such as a mechanical device, a heating furnace, a chemical reactor, or a spacecraft) a plant.

1.3 Processes

The natural, progressively continuing operation or development marked by a series of gradual changes that succeed one another in a relatively fixed way and lead toward a particular result or end; or an artificial or voluntary, progressively continuing operation that consists of a series of controlled actions or movements systematically directed toward a particular result or end.

1.4 Systems

A system is a combination of components that act together and perform a certain objective. A system need not be physical. The concept of the system can be applied to abstract, dynamic phenomena such as those encountered in economics.

The word system should, therefore, be interpreted to imply physical, biological, economic, and the like, systems.

1.5 Disturbances

A disturbance is a signal that tends to adversely affect the value of the output of a system. If a disturbance is generated within the system, it is called internal, while an external disturbance is generated outside the system and is an input.

1.6 Feedback Control

Feedback control refers to an operation that, in the presence of disturbances, tends to reduce the difference between the output of a system and some reference input and does so on the basis of this difference. Here only unpredictable disturbances are so specified, since predictable or known disturbances can always be compensated for within the system.

2. Examples of Control Systems

In this section we shall present a few examples of control systems.

2.1 Temperature Control System

Figure 1 shows a schematic diagram of temperature control of an electric furnace.

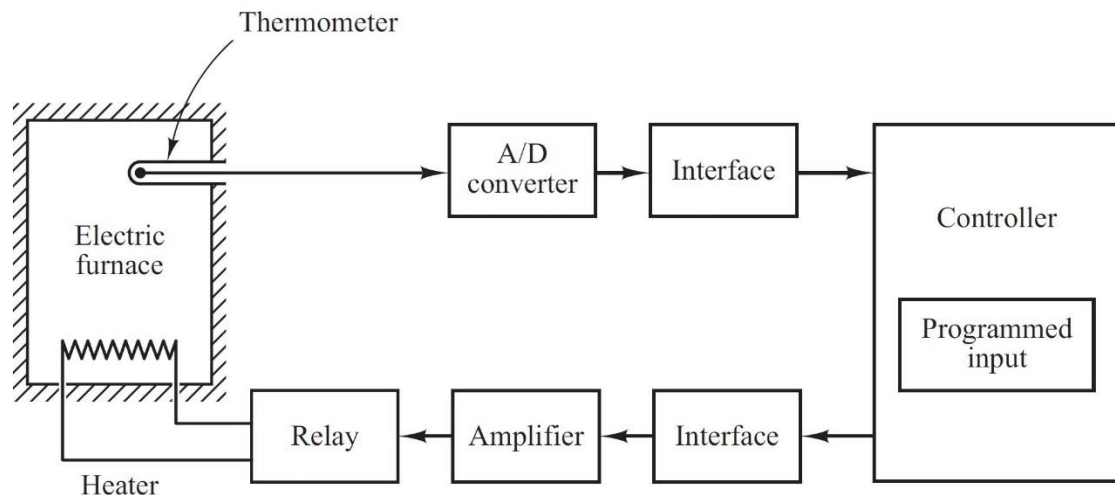


Figure 1: Temperature Control System

The temperature in the electric furnace is measured by a thermometer, which is an analog device. The analog temperature is converted to a digital temperature by an A/D converter. The digital temperature is fed to a controller through an

interface. This digital temperature is compared with the programmed input temperature, and if there is any discrepancy (error), the controller sends out a signal to the heater, through an interface, amplifier, and relay, to bring the furnace temperature to a desired value.

2.3 Business Systems

A business system may consist of many groups. Each task assigned to a group will represent a dynamic element of the system. Feedback methods of reporting the accomplishments of each group must be established in such a system for proper operation. The cross-coupling between functional groups must be made a minimum in order to reduce undesirable delay times in the system. The smaller this cross coupling, the smoother the flow of work signals and materials will be.

A business system is a closed-loop system. A good design will reduce the managerial control required. Note that disturbances in this system are the lack of personnel or materials, interruption of communication, human errors, and the like.

The establishment of a well-founded estimating system based on statistics is mandatory to proper management. It is a well-known fact that the performance of such a system can be improved by the use of lead time, or anticipation.

To apply control theory to improve the performance of such a system, we must represent the dynamic characteristic of the component groups of the system by a relatively simple set of equations.

Although it is certainly a difficult problem to derive mathematical representations of the component groups, the application of optimization techniques to business systems significantly improves the performance of the business system.

Consider, as an example, an engineering organizational system that is composed of major groups such as management, research and development, preliminary design, experiments, product design and drafting, fabrication and assembling, and testing. These groups are interconnected to make up the whole operation.

Such a system may be analyzed by reducing it to the most elementary set of components necessary that can provide the analytical detail required and by representing the dynamic characteristics of each component by a set of simple equations. The dynamic performance of such a system may be determined from the relation between progressive accomplishment and time.

A functional block diagram may be drawn by using blocks to represent the functional activities and interconnecting signal lines to represent the information or product output of the system operation. Figure 2 is a possible block diagram for this system.

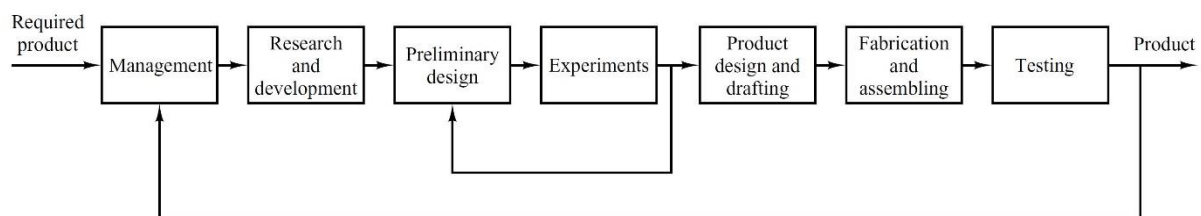


Figure 2: Block diagram of an engineering organizational system

3. Closed-Loop Control VS. Open-Loop Control

3.1 Feedback Control Systems

A system that maintains a prescribed relationship between the output and the reference input by comparing them and using the difference as a means of control is called a feedback control system. An example would be a room temperature control system. By measuring the actual room temperature and comparing it with the reference temperature (desired temperature), the thermostat turns the heating or cooling equipment on or off in such a way as to ensure that the room temperature remains at a comfortable level regardless of outside conditions.

Feedback control systems are not limited to engineering but can be found in various non-engineering fields as well. The human body, for instance, is a highly advanced feedback control system. Both body temperature and blood pressure are kept constant by means of physiological feedback. In fact, feedback performs a

vital function: It makes the human body relatively insensitive to external disturbances, thus enabling it to function properly in a changing environment.

3.2 Closed-Loop Control Systems

Feedback control systems are often referred to as closed-loop control systems. In practice, the terms feedback control and closed-loop control are used interchangeably. In a closed-loop control system the actuating error signal, which is the difference between the input signal and the feedback signal (which may be the output signal itself or a function of the output signal and its derivatives and/or integrals), is fed to the controller so as to reduce the error and bring the output of the system to a desired value. The term closed-loop control always implies the use of feedback control action in order to reduce system error.

3.3 Open-Loop Control Systems

Those systems in which the output has no effect on the control action are called open-loop control systems. In other words, in an open loop control system the output is neither measured nor fed back for comparison with the input. One practical example is a washing machine. Soaking, washing, and rinsing in the washers operate on a time basis. The machine does not measure the output signal, that is, the cleanliness of the clothes.

In any open-loop control system the output is not compared with the reference input. Thus, to each reference input there corresponds a fixed operating condition; as a result, the accuracy of the system depends on calibration. In the presence of disturbances, an open-loop control system will not perform the desired task.

Open-loop control can be used, in practice, only if the relationship between the input and output is known and if there are neither internal nor external disturbances. Clearly, such systems are not feedback control systems. Note that any control system that operates on a time basis is open loop. For instance, traffic control by means of signals operated on a time basis is another example of open-loop control.

3.4 Closed-Loop versus Open-Loop Control Systems

An advantage of the closed loop control system is the fact that the use of feedback makes the system response relatively insensitive to external disturbances and internal variations in system parameters.

It is thus possible to use relatively inaccurate and inexpensive components to obtain the accurate control of a given plant, whereas doing so is impossible in the open-loop case.

From the point of view of stability, the open-loop control system is easier to build because system stability is not a major problem. On the other hand, stability is a major problem in the closed-loop control system, which may tend to overcorrect errors and thereby can cause oscillations of constant or changing amplitude.

It should be emphasized that for systems in which the inputs are known ahead of time and in which there are no disturbances it is advisable to use open-loop control.

Closed-loop control systems have advantages only when unpredictable disturbances and/or unpredictable variations in system components are present. Note that the output power rating partially determines the cost, weight, and size of a control system.

The number of components used in a closed-loop control system is more than that for a corresponding open-loop control system. Thus, the closed-loop control system is generally higher in cost and power. To decrease the required power of a system, open loop control may be used where applicable. A proper combination of open-loop and closed-loop controls is usually less expensive and will give satisfactory overall system performance.

Therefore, it is worthwhile to summarize the advantages and disadvantages of using open-loop control systems.

The major advantages of open-loop control systems are as follows:

- a. Simple construction and ease of maintenance.
- b. Less expensive than a corresponding closed-loop system.

- c. There is no stability problem.
- d. Convenient when output is hard to measure or measuring the output precisely is economically not feasible. (For example, in the washer system, it would be quite expensive to provide a device to measure the quality of the washer's output, cleanliness of the clothes.)

The major disadvantages of open-loop control systems are as follows:

- a. Disturbances and changes in calibration cause errors, and the output may be different from what is desired.
- b. To maintain the required quality in the output, recalibration is necessary from time to time.