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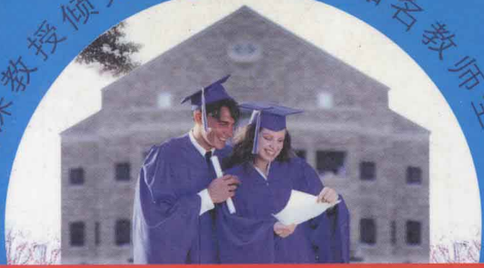


国外高校电子信息类优秀教材

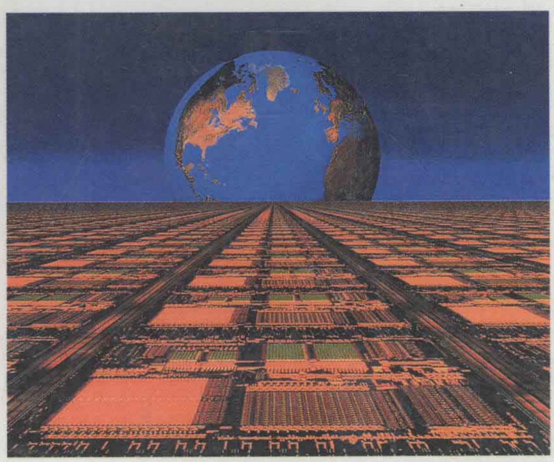
过程控制仪表技术

（第六版）

Process Control Instrumentation Technology

(Sixth Edition)

（英文影印版）



Curtis D. Johnson 著

科学出版社

Pearson Education

培生教育出版集团

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内 容 简 介

本书为国外高校电子信息类优秀教材（英文影印版）之一。

本书介绍了有关控制系统元素和操作的理论性概念，使学生毋需高深的数学和理论基础即可理解；同时力图展示一个控制系统的诸多元素是如何设计和操作的，内容涉及各种传感器和控制器。通过对本书的学习，不仅能提高学生的实际设计能力，而且能使学生深刻理解这些控制元素对整个系统操作的影响。

本书适用于高等院校自动控制、过程控制、仪表和测量专业的本科生，也可供一般工程技术人员参考。

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国外高校电子信息类优秀教材(英文影印版)

丛 书 编 委 会

PREFACE

There is a wide spectrum of knowledge about process control and control systems in our modern world. At one extreme is knowledge that comes from a highly concentrated study of advanced mathematics and the theoretical concepts associated with control systems. Another extreme is knowledge that comes only from the practical, day-to-day experience of assembling, troubleshooting, adjusting, and operating a control system. The objective of this book, from the first edition to this sixth edition, has been to provide a source of knowledge that threads the middle ground between these extremes. We want the reader to understand and appreciate some of the theoretical concepts that underlie control system elements and operations, but without the necessity of advanced math and theory. We want the reader to understand and appreciate some of the practical details of how elements of a control system are designed and operated, but without the necessity of on-the-job experience. With this middle ground of knowledge, one can design the elements of a control system from a practical, working perspective and also understand how these elements affect overall system operation and tuning.

With this objective as a backdrop, we expect the reader to have a background that includes basic physics, strong algebra, and sound analog and digital electronics. Some knowledge of calculus is very beneficial to understanding concepts in later chapters. A laboratory experience to complement this book is invaluable for imparting to the reader a real sense of practical issues.

For this sixth edition a number of errors in previous editions have been corrected. More problems have been added to each chapter in the form of supplementary problems. Appendix 6 provides the derivation of the response of a number of circuits presented in the book. New material was added on solid-state sensors for temperature and pressure, analog-to-digital conversion via frequency counting, and a number of other topics. Many figures have been modified to more correctly reflect modern technology.

In support of feedback on the book, a Web page has been set up, as described on page iv. In addition, Appendix 7, "Internet Resources," has been added. This provides the URLs of some Web pages relevant to process control and instrumentation technology.

The Internet has become a primary worldwide resource for information on nearly any topic. Indeed, this resource is so vast that just searching for Web pages with information relevant to an interest is becoming quite difficult. In the field of process control and instrumentation, there are literally thousands of pages with information that may be of interest. Two Internet resources are provided in this book to aid the reader.

1. A book Web page: URL = www.uh.edu/~tech13v/pcit
   A Web page has been set up for this book to allow information exchange with teachers, practitioners, and students who use the book for classes or reference. This page contains
   - a. Postings of any corrections to text material, examples, or problems
   - b. FAQs regarding book content, examples, and problems
   - c. Periodic updating of information presented in the text
   - d. Suggestions about new problems and lab experiments to support the material presented in the text
   - e. Information on new web sites or other information sources relevant to process control and instrumentation technology
   - f. A feedback mechanism so that users of the book can forward comments and corrections to the author
2. Relevant Web pages
   Appendix 7 lists the URLs for many web pages relevant to process control and instrumentation technology. Readers are urged to use these references for expanded and current information about topics in this book. Many of the pages are from manufacturers of hardware and software used in process control. Therefore, the pages can be a good start for researching available hardware and software to support a specific need. Of course, the list is not exhaustive but serves only as a starting point for seeking more relevant Web pages. Equally important, these pages should be used as the starting point for linking to many other pages with information pertaining to the topics of this text.

I wish to thank the many reviewers and users of the book who provided excellent suggestions on improvements. Specifically, I would like to acknowledge the very helpful comments of Thomas Bellarmine, The University of West Florida; Roger Goggins, ITT Technical Institute; Frederick Henon, CHI Institute; Patrick Kiely, ITT Technical Institute; and Lee Rosenthal, Fairleigh Dickinson University. Many of their suggestions were included in this revision. I am writing this preface in an office overlooking the city of Baku in Azerbaijan. I am here on a sabbatical, working on a project to improve computer literacy, e-mail access, and use of the Internet for individuals in the academic community. I wish to thank my colleagues here, Adil Akundzade, Ayten Javadova, Azer Akhundov, Selvin Dashdamirov, and Kamran Aliyev, for their help and patience while I worked on this revision. I also thank my wife, Helene Blake, who is still with me as I finish this sixth edition, despite my being quite difficult to live with.

Curtis D. Johnson
Baku, Azerbaijan

CONTENTS

1

INTRODUCTION TO PROCESS CONTROL

INSTRUCTIONAL OBJECTIVES

This chapter will consider the overall process-control loop, its function, and its description. After you have read this chapter, you should be able to

- Draw a block diagram of a process-control loop with a description of each element.
- List three typical controlled variables.
- Describe three criteria used to evaluate the response of a process-control loop.
- Define analog signal processing.
- Describe the two types of digital process control.
- Define accuracy, hysteresis, and sensitivity.
- List the SI units of measure for length, time, mass, and electric current.
- Convert a physical quantity from SI to English units and vice versa.
- Define the types of measurement time response.

1.1 INTRODUCTION

Human progress from a primitive state to our present complex, technological world is marked by learning new and improved methods to control the environment. Simply stated, the term *control* means methods to force parameters in the environment to have specific values. This can be as simple as making the temperature in a room stay at 21°C or as complex as manufacturing an integrated circuit or guiding a spacecraft to Jupiter. In general, all the elements necessary to accomplish the control objective are described by the term *control system*.

The purpose of this book is to examine the elements and methods of control system operation used in industry to control industrial processes (hence the term *process control*). This chapter will present an overall view of process-control technology and its elements, including important definitions. Later chapters will study the elements of process control in more detail.

1.2 CONTROL SYSTEMS

The basic strategy by which a control system operates is logical and natural. In fact, the same strategy is employed in living organisms to maintain temperature, fluid flow rate, and a host of other biological functions. This is natural process control.

The technology of artificial control was first developed using a human as an integral part of the control action. When we learned how to use machines, electronics, and computers to replace the human function, the term *automatic control* came into use.

1.2.1 Process-Control Principles

In process control, the basic objective is to regulate the value of some quantity. To regulate means to maintain that quantity at some desired value regardless of external influences. The desired value is called the *reference value* or *setpoint.*

The following paragraphs use the development of a control system for a specific process-control example to introduce some of the terms and expressions in the field.

The Process Figure 1.1 shows the process to be used for this discussion. Liquid is flowing into a tank at some rate Q_{in} and out of the tank at some rate Q_{out}. The liquid in the tank has some height or level h. It is known that the flow rate out varies as the square root of the height, so the higher the level the faster the liquid flows out. If the output flow rate is not exactly equal to the input flow rate, the tank will either empty, if $Q_{out} > Q_{in}$, or overflow, if $Q_{out} < Q_{in}$.

This process has a property called *self-regulation.* This means that for some input flow rate, the liquid height will rise until it reaches a height for which the output flow rate matches the input flow rate. A self-regulating system does not provide regulation of a variable to any particular reference value. In this example the liquid level will adopt some value for which input and output flow rates are the same and there it will stay. But if the input flow rate changed, then the level would change also, so it is not regulated to a reference value.

Suppose we want to maintain the level at some particular value H in Figure 1.1, regardless of the input flow rate. Then something more than self-regulation is needed.

Human-Aided Control Figure 1.2 shows a modification of the tank system to allow artificial regulation of the level by a human. To regulate the level so that it maintains the value H it will be necessary to employ a sensor to measure the level. This has been provided via a "sight tube" S as shown in Figure 1.2. The actual liquid level or height is called the *controlled variable.* In addition, a valve has been added so the output flow rate can be changed by the human. The output flow rate is called the *manipulated variable* or *controlling variable.*

Now the height can be regulated apart from the input flow rate using the following strategy: The human measures the height in the sight tube and compares the value to the setpoint. If the measured value is larger, the human opens the valve a little to let the flow out increase, and thus the level lowers toward the setpoint. If the measured value is smaller than the setpoint, the human closes the valve a little to decrease the flow out and allow the level to rise toward the setpoint.

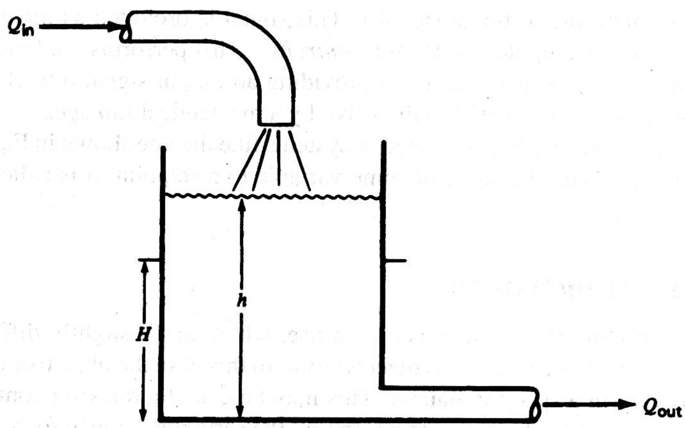

FIGURE 1.1
The objective is to regulate the level of liquid in the tank, *h*, to the value *H*.

By a succession of incremental opening and closing of the valve, the human can bring the level to the setpoint value *H* and maintain it there by continuous monitoring of the sight tube and adjustment of the valve. The height is regulated.

Automatic Control To provide automatic control, the system is modified as shown in Figure 1.3 so machines, electronics, or computers replace the operations of the human. An instrument called a *sensor* is added that is able to measure the value of the level

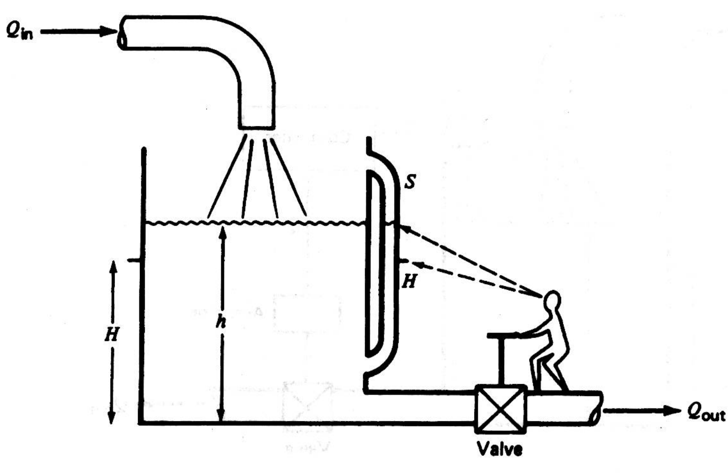

FIGURE 1.2
A human can regulate the level using a sight tube, *S*, to compare the level, *h*, to the objective, *H*, and adjust a valve to change the level.

and convert it into a proportional signal s. This signal is provided as input to a machine, electronic circuit, or computer, called the *controller*. This performs the function of the human in evaluating the measurement and providing an output signal u to change the valve setting via an *actuator* connected to the valve by a mechanical linkage.

When automatic control is applied to systems like the one shown in Figure 1.3, which are designed to regulate the value of some variable to a setpoint, it is called *process control*.

1.2.2 Servomechanisms

Another type of control system in common use, which has a slightly different objective from process control, is called a *servomechanism*. In this case the objective is to force some parameter to vary in a specific manner. This may be called a tracking control system. Instead of regulating a variable value to a setpoint, the servomechanism forces the controlled variable value to follow variation of the reference value.

For example, in an industrial robot arm like the one shown in Figure 1.4, servomechanisms force the robot arm to follow a path from point A to point B. This is done by controlling the speed of motors driving the arm and the angles of the arm parts.

The strategy for servomechanisms is similar to process-control systems, but the dynamic differences between regulation and tracking result in differences in design and operation of the control system. This text is directed toward process-control technology.

1.2.3 Discrete-State Control Systems

This is a type of control system concerned with controlling a *sequence of events* rather than regulation or variation of individual variables. For example, the manufacture of paint might

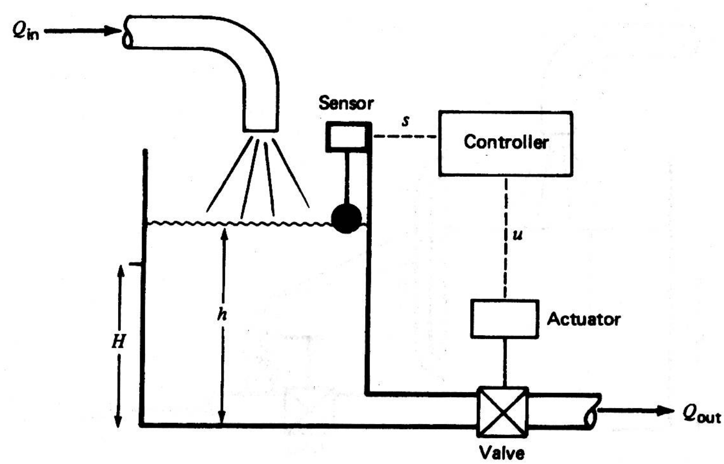

FIGURE 1.3
An automatic level-control system replaces the human by a controller and uses a sensor to measure the level.

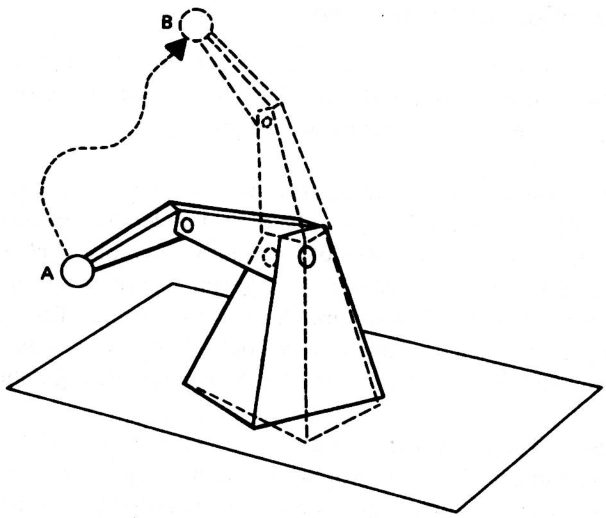

FIGURE 1.4
Servomechanism-type control systems are used to move a robot arm from point A to point B in a controlled fashion.

involve the regulation of many variables, such as mixing temperature, flow rate of liquids into mixing tanks, speed of mixing, and so on. Each of these might be expected to be regulated by process-control loops. But there is also a sequence of events that must occur in the overall process of manufacturing the paint. This sequence is described in terms of events that are timed to be started and stopped on a specified schedule. Referring to the paint example, the mixture needs to be heated with a regulated temperature for a certain length of time and then perhaps pumped into a different tank and stirred for another period.

The starting and stopping of events is a discrete-based system because the event is either *true* or *false*, i.e., started or stopped, open or closed, on or off. This type of control system can also be made automatic and is perfectly suited to computer-based controllers. This type of control system is covered in detail in Chapter 8.

1.3 PROCESS-CONTROL BLOCK DIAGRAM

To provide a practical, working description of process control, it is useful to describe the elements and operations involved in more generic terms. Such a description should be independent of a particular application (such as the example presented in the previous section) and thus be applicable to *all* control situations. A model may be constructed using blocks to represent each distinctive element. The characteristics of control operation then may be developed from a consideration of the properties and interfacing of these elements. Numerous models have been employed in the history of process-control description; we will use one that seems most appropriate for a description of modern and developing technology of process control.