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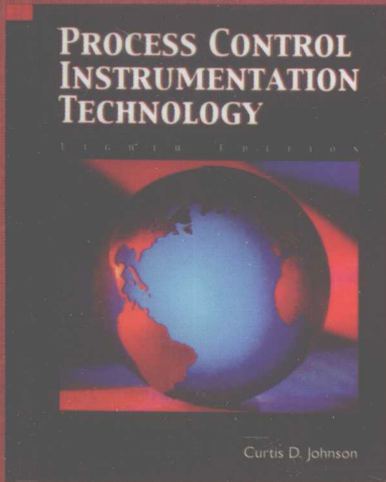

过程控制仪表技术

（第8版）

Process Control Instrumentation Technology

(Eighth Edition)

Curtis D. Johnson

清华大学出版社

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影印版前言

由 Curtis D. Johnson 教授（University of Houston）编著的《过程控制仪表技术》一书自出版以来受到广泛的欢迎，目前该书已出到第 8 版，其中添加了许多自动化领域新技术发展的内容，实现了与最新科技发展同步的目标。

全书共分为两部分，第一部分为前 6 章，作者从人们对生产设备手动操作的实际经验出发，系统地介绍了控制原理、控制设备和控制系统的基本概念。在测量信号的变换和处理方面，把工业仪表中的模拟电路、可编程控制器（PLC）及信号采集系统中的数字电路结合工业电子学中的基本理论融会贯通加以介绍。在测量信号的获取方面，重点对温度、机械量和光学传感器的原理、器件、特性和应用进行了详细的分析。书中第二部分为后 6 章，首先讲述了控制信号的类型和执行器，接着重点介绍了离散、连续、计算机及总线网络控制系统的构成、特点和技术指标。结合系统的要求，讲解了 PLC 的原理和编程方法，位式控制、PID 概念及模拟调节器，工业控制计算机硬件、软件的配置等内容。最后介绍了串级和多变量控制系统以及系统的调节质量评定和调节参数的整定方法。

尽管涉及工业测量和调节控制内容的同类教材很多，但这本书有它自己的特点：

（1）测量技术和控制技术相结合。把工业电子学的知识和工业仪表中的模拟电路、信号采集系统中的数字电路相结合；把被控系统的特性和调节器的功能相结合。这样就为控制系统中的装置与系统、理论与实际相结合打下了基础，克服了目前我国自动化专业教育中理论、系统、装置、应用互相分割的状况。

（2）例题习题非常丰富。书中每章结束都有习题，而且在每个章节中还附有大量的例题。这些例题和习题都是围绕核心概念，结合实际应用的典型问题，通过解题可以使读者加深对基础理论的理解，学会设计和调试的方法，扩展应用的思路。

全书内容全面，包括了自动化学科领域中最基础、最常用的知识和概念。论述通俗易懂，在讲解控制理论中的数学问题，或用电子学知识解释模拟调节器电路时，删繁就简，准确明了。紧密联系实际，书中有很多实际控制系统和仪表装置的设计范例及典型方法，可供读者在实际工程中应用。本书可作为自动化学科领域的教学参考书，尤其适合作为双语教学用书，对本领域的工程技术人员也会有很大的帮助。

王俊杰　教授
清华大学自动化系
检测与电子技术研究所
2009 年 7 月

PREFACE

This edition of *Process Control Instrumentation Technology* is the result of a very intense and hectic several months spent incorporating some of the major changes in the way control systems and process control are implemented. Many changes have been dictated by observations of the changing technology of control systems. Following is a brief summary of some of the most important revisions.

The section on Industrial Electronics is renamed Power Electronics and rewritten to include more current devices such as GTOs, MOSFETs, and IGBTs. The coverage of ac motors is reworked to bring it up to date. Although this is not an electrical machines and electronics text, the brief summary of these topics should at least be current.

The greatest revolution in control systems is the growing employment of computers and computer networks in process control. Chapter 11 is modified significantly to improve coverage of computer-based controllers and the rapidly developing field of distributed control and control system networks. The discussion and treatment of the fieldbus networks now in common use is expanded. Finally, every example and problem in the book is reworked and checked for accuracy, as are those in the solutions manual.

This book is intended for a reader who has at least a working knowledge of algebra and trigonometry, but familiarity with calculus would also enhance understanding. In addition, a solid understanding of basic electricity along with some working knowledge of analog and digital electronics is essential to good comprehension of the topics.

The text is based upon a two-semester sequence. The first semester is expected to cover the first six chapters. This starts with a general review of control systems and process control in Chapter 1, which also includes the very important topics of first- and second-order time response. Chapters 2 through 6 cover the general topics of measurement from analog and digital signal conditioning to the most common sensors used in the control industry.

Chapters 7 through 12 constitute the second semester and cover the final control element and PLCs, as well as the principles of controller action, analog and digital controllers, process-control networks, and an overview of control-loop performance and tuning. Many users simply pick those chapters that best suit the educational objectives of their program.

I used the World Wide Web extensively to research topics I wanted to include in this revision, and was amazed at the extent of information about every little aspect of control systems and process control. I found excellent material—from elegant tutorials on loop tuning to specifications associated with fieldbus standards. I was tempted to include the URLs of some of these sites, but decided against that because of the volatility of such sites. Instead, I urge the reader to use available search engines to seek out tutorials, informational sites, and application notes associated with process control and instrumentation. The Website maintained for this book (*www.uh.edu/~tech13v/pcit*) can be used for posting identified errors, corrections, and other information about process control.

The author can also be contacted directly via e-mail at: *cjohnson@uh.edu*.

Acknowledgments

I would like to thank my wife, Helene Blake, for her continued support through these many years and many revisions. She is helping me now, even as I type, with some of the necessary editing of the manuscript.

A number of reviewers provided excellent suggestions for improving the content and presentation in the book. Nearly all these suggestions were incorporated (I regret that not all of them could be made). The reviewers were Joe E. Ashby, Indiana State University; Gerald W. Cockrell, Indiana State University; Sri R. Kulla, Bowling Green State University; and Paul Ricketts, New Mexico State University.

Ancillaries

An online Instructor's Manual with PowerPoint™ slides is also available to instructors through the Johnson catalog page at **www.prenhall.com**. Instructors can search for a text by author, title, ISBN, or by selecting the appropriate discipline from the pull down menu at the top of the catalog home page. To access supplementary materials online, instructors need to request an instructor access code. Go to **www.prenhall.com**, click the **Instructor Resource Center** link, and then click Register Today for an instructor access code. Within 48 hours of registering you will receive a confirming e-mail including an instructor access code. Once you have received your code, go to the site and log on for full instructions on downloading the materials that you wish to use.

CONTENTS

CHAPTER 1

Introduction to Process Control

INSTRUCTIONAL OBJECTIVES

This chapter presents an introduction to process-control concepts and the elements of a process-control system. After you read this chapter and work through the example problems and chapter problems you will be able to:

- Draw a block diagram of a simple process-control loop and identify each element.
- List three typical controlled variables and one controlling variable.
- Describe three criteria to evaluate the performance of a process-control loop.
- Explain the difference between analog and digital control systems.
- Define supervisory control.
- Explain the concept behind process-control networks.
- Define accuracy, hysteresis, and sensitivity.
- List the SI units for length, time, mass, and electric current.
- Recognize the common P&ID symbols.
- Draw a typical first-order time response curve.
- Determine the average and standard deviation of a set of data samples.

1.1 INTRODUCTION

Human progress from a primitive state to our present complex, technological world has been 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.*

In this section, a specific system will be used to introduce terms and concepts employed to describe process control.

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 output flow rate varies as the square root of the height, $Q_{out} = K\sqrt{h}$, 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 level will drop, if $Q_{out} > Q_{in}$, or rise, if $Q_{out} < Q_{in}$.

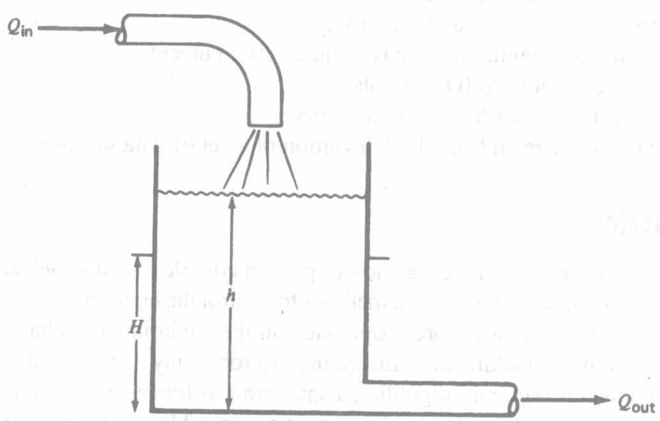

FIGURE 1.1
The objective is to regulate the level of liquid in the tank, h, to the value H.

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.

EXAMPLE 1.1 The tank in Figure 1.1 has a relationship between flow and level given by $Q_{out} = K\sqrt{h}$ where h is in feet and $K = 1.156\ (\text{gal/min})/\text{ft}^{1/2}$. Suppose the input flow rate is 2 gal/min. At what value of h will the level stabilize from self-regulation?

Solution

The level will stabilize from self-regulation when $Q_{out} = Q_{in}$. Thus, we solve for h,

$$h = \left(\frac{Q_{out}}{K}\right)^2 = \left(\frac{2\ \text{gal/min}}{1.156\ (\text{gal/min})/\text{ft}^{1/2}}\right)^2 = 3\ \text{ft}$$

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 that the output flow rate can be changed by the human. The output flow rate is called the *manipulated variable* or *controlling variable*.

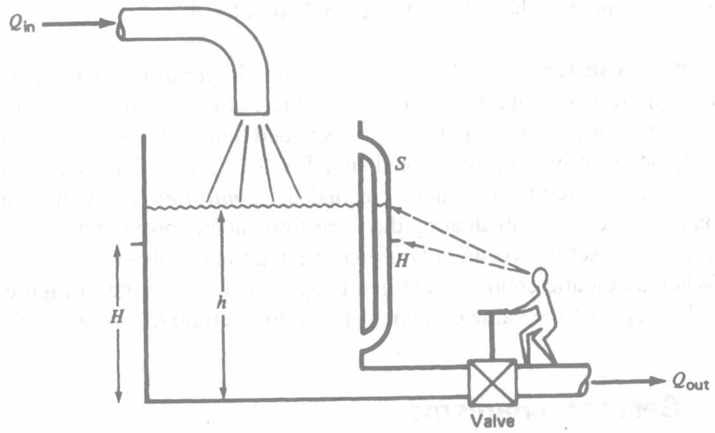

FIGURE 1.2
A human can regulate the level using a sight tube, S, to compare the level, h, to the objective, H, and adjust a valve to change the level.

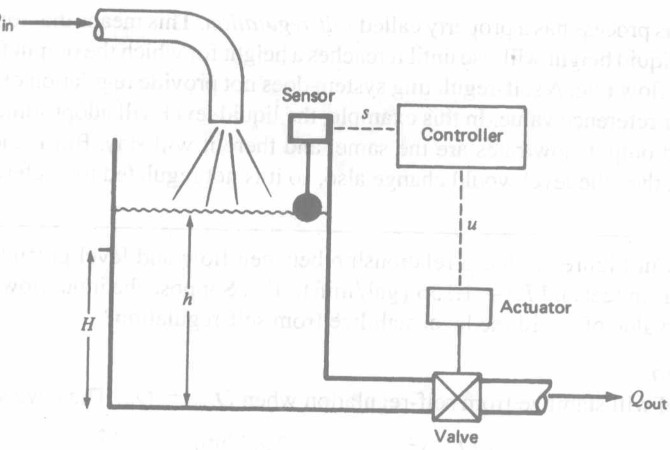

FIGURE 1.3
An automatic level-control system replaces the human with a controller and uses a sensor to measure the level.

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.

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 that 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 and convert it into a proportional signal, *s*. This signal is provided as input to a machine, electronic circuit, or computer called the *controller.* The controller 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 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 commonly used type of control system, 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. In-

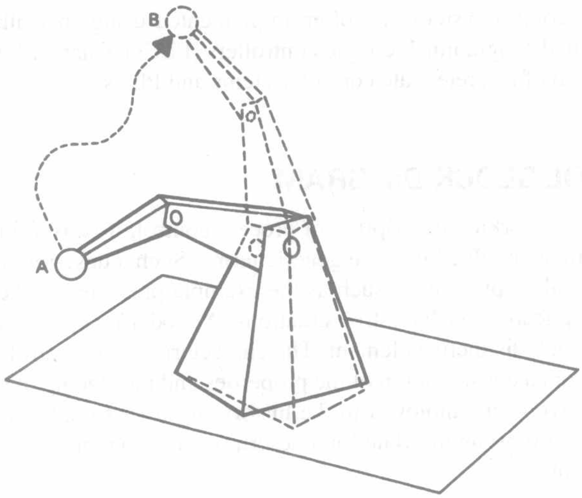

FIGURE 1.4
Servomechanism-type control systems are used to move a robot arm from point *A* to point *B* in a controlled fashion.

stead 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 that for process-control systems, but the dynamic differences between regulation and tracking result in differences in design and operation of the control system. This book 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 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.