时代教育 • 国外高校优秀教材精选

Prentice Hall

（英文版· 原书第7版）

# 控制系统技术概论

## Introduction to Control System Technology

(美)罗伯特 N.贝特森 (Robert N.Bateson) 著

机械工业出版社
CHINA MACHINE PRESS

时代教育·国外高校优秀教材精选

# 控制系统技术概论

（英文版·原书第7版）

# Introduction to Control System Technology

（美）罗伯特 N. 贝特森（Robert N. Bateson）著

机 械 工 业 出 版 社

ISBN 0-13-030688-6


北京市版权局著作权合同登记号：图字：01-2006-0524



**图书在版编目（CIP）数据**

控制系统技术概论：第7版 = Introduction To Control System Technology/(美)贝特森(Bateson, R. N.)著.
—北京：机械工业出版社，2006.4
(时代教育：国外高校优秀教材精选)
ISBN 7-111-18709-1

Ⅰ.控... Ⅱ.贝... Ⅲ.控制系统—高等学校—教材—英文 Ⅳ.TP271

中国版本图书馆 CIP 数据核字(2006)第 021109 号

机械工业出版社（北京市百万庄大街22号 邮政编码100037）
责任编辑：苏颖杰
封面设计：饶 薇 责任印制：洪汉军
北京原创阳光印业有限公司印刷
2006年4月第1版第1次印刷
787mm × 1092mm 1/16 · 45.25 印张 · 870 千字
定价：69.00 元

# 国外高校优秀教材审定委员会

主任委员：

杨叔子

委员（按姓氏笔画为序）：

| | | | | |
|---|---|---|---|---|
| 丁丽娟 | 王先逵 | 王大康 | 白峰衫 | 石德珂 |
| 史荣昌 | 孙洪祥 | 朱孝禄 | 陆启韶 | 张润琦 |
| 张　策 | 张三慧 | 张福润 | 张延华 | 吴宗泽 |
| 吴　麒 | 宋心琦 | 李俊峰 | 佘远斌 | 陈文楷 |
| 陈立周 | 单辉祖 | 周双喜 | 范　瑜 | 俞正光 |
| 赵汝嘉 | 郭可谦 | 翁贻方 | 翁海珊 | 龚光鲁 |
| 章栋恩 | 黄永畅 | 谭泽光 | 郭鸿志 | |

# 出版说明

随着我国加入WTO，国际间的竞争越来越激烈，而国际间的竞争实际上也就是人才的竞争、教育的竞争。为了加快培养具有国际竞争力的高水平技术人才，加快我国教育改革的步伐，国家教育部近来出台了一系列倡导高校开展双语教学、引进原版教材的政策。以此为契机，机械工业出版社陆续推出了一系列国外影印版教材，其内容涉及高等学校公共基础课，以及机、电、信息领域的专业基础课和专业课。

引进国外优秀原版教材，在有条件的学校推动开展英语授课或双语教学，自然也引进了先进的教学思想和教学方法，这对提高我国自编教材的水平，加强学生的英语实际应用能力，使我国的高等教育尽快与国际接轨，必将起到积极的推动作用。

为了做好教材的引进工作，机械工业出版社特别成立了由著名专家组成的国外高校优秀教材审定委员会。这些专家对实施双语教学做了深入细致的调查研究，对引进原版教材提出了许多建设性意见，并慎重地对每一本将要引进的原版教材一审再审，精选再精选，确认教材本身的质量水平，以及权威性和先进性，以期所引进的原版教材能适应我国学生的外语水平和学习特点。在引进工作中，审定委员会还结合我国高校教学课程体系的设置和要求，对原版教材的教学思想和方法的先进性、科学性严格把关。同时尽量考虑原版教材的系统性和经济性。

这套教材出版后，我们将根据各高校的双语教学计划，举办原版教材的教师培训，及时地将其推荐给各高校选用。希望高校师生在使用教材后及时反馈意见和建议，使我们更好地为教学改革服务。

机械工业出版社

# 序

*Introduction to Control System Technology* 由 Robert N. Bateson 编著，原书用作两年制的工程技术人员教材。到 2002 年，该书已历经从第 1 版到第 7 版近 30 年的不断改进完善和内容更新，是一本成熟的自动控制理论与系统的教材和工程技术书籍。

本书的作者有长达 10 年的控制工程技术工作经历，加之非常明确的编著目的——培养学生掌握闭环控制系统构建、控制器设计、系统现场调试等方面的技术与方法，使本书具有理论联系实际、工程背景强的基本特色和鲜明特点。

1. 总体结构独特，突出工程实践

全书正文由五部分组成，思路开阔，内容由浅入深，层次分明，系统性强。第一部分“引论”共四章，占全书除附录外的 23.3% 篇幅，这在其他同类书籍中较为少见，有利于初学者对自动控制的概念、闭环系统的基本组成与常用部件、系统类型、控制的目的与评价标准等有一个全面、清晰的认识。

工程实践内容贯穿于全书的各个章节。在第二部分“测量”中，除分别给出各种常用检测元件的原理外，还特别介绍其各种性能与选择标准，以及信号隔离、阻抗转换、噪声抑制、线性化等处理测量信号的工程实用方法。第三部分“操纵”在全面给出电动、气动、机械等多种执行机构的工作原理和特性的基础上，介绍了工程中执行机构的选择方法和计算。第四部分“控制”则介绍各种常用工业控制方法与控制系统，并给出了相当数量的各类控制系统实例。第五部分“分析与设计”以一阶系统、二阶系统和含纯滞后环节的一阶系统等典型被控对象，介绍了工程上常用分析方法——伯德图方法、乃奎斯特图法和根轨迹法。在控制器设计方面，以 PID 控制器的参数整定为重点，特别列出在控制器设计中应考虑的六个因素，除了各种性能指标外，还包括成本最小化等工程中须考虑的重要问题。

2. 内容融合多门课程，结合技术标准

本书以闭环控制系统的分析、设计为主线，涉及的被控对象包括电系统、气动系统、液压系统、热力系统、机械系统等，将自动控制理论、自动检测技术、电机拖动基础、电力电子技术、过程控制系统、运动控制系统、电气控制与 PLC 等多门课程融合在一起，形成一个有机的整体。

全书内容紧密结合工程实际，术语符合 Instrument Society of America 颁布的 StandardS51.5 “Process Instrumentation Terminology”，图形符号符合 Instrument Society of America 颁布的 ANSI/

ISA-S5.1—1984 标准，并在附录 D 中给出了该标准的摘要。

3. 论述深度把握合理，采用启发性方式叙述

书中每章前都列出该章学习目的和需要重点掌握的内容，便于读者目标明确地学习，并自我衡量是否达到本章学习要求。全书的 16 章中有 14 章都有引论。引论的内容起到如下几个作用：①概括全章的内容；②承上启下，提出问题，以便在此后的各节中逐一解决；③阐明重要概念。

对于概念的阐述采用了图文并茂的方法，尽量避免繁复的数学推导，力图从物理意义上讲解透彻。从重要概念的阐述来看，作者具有坚实的理论基础和丰富的工程实践经验，准确把握了论述深度。

4. 插图强调联系实际，习题侧重工程训练

全书的插图经过精心设计，直观、清晰，有助于概念的理解。书中有相当数量的工程图，如气动控制阀的机械结构图、工业传送带控制系统电气控制原理图等等，体现了与工程紧密联系的特点。一些插图配有较大篇幅的文明说明，一方面方便了读者，另一方面使正文的文字简练。

每章后的习题按节排列，强调概念的强化的工程计算，很少有纯数学演算。

每章后列出的重要术语和解释便于读者复习。

最后，需要指出，书中的控制系统计算机辅助设计和分析的内容采用了作者自行编制的 BASIC 程序，读者也可应用 MATLAB 控制系统控制箱方便地编程实现相同功能。

综上所述，本书理论联系实际、工程背景强的特点在多方面得到体现，适合应用型人才培养的需要，可作为高等院校电气信息类专业自动控制理论、自动控制系统课程教材或教学参考书，也可作为相关领域工程技术人员的自学读物。

北京工商大学
翁贻方
2005 年 8 月

# Preface

## GOAL

The goal of *Introduction to Control System Technology* is to provide both a textbook on the subject and a reference that engineers and technicians can include in their personal libraries. This text can help students master the concepts and language of control and help engineers and technicians analyze and design control systems. The text covers the terminology, concepts, principles, procedures, and computations used by engineers and technicians to analyze, select, specify, design, and maintain control systems. Emphasis is on the application of established methods with the aid of examples and computer programs.

## EVOLUTION OF TEXT

The writing of this text began 34 years ago when I faced the challenge of developing and teaching a control systems course in a 2-year engineering technology program. I had just entered the teaching profession after 10 years as a research engineer at General Mills, where I had become fascinated with control systems. I was especially intrigued by the combined electrical, mechanical, thermal, liquid, and gas elements in the mathematical models used to analyze and design control systems. This fascination led to the completion of an evening MSEE program with a major in control systems and a hands-on design course at Brown Institute in Philadelphia. In my course work, we used straight-line Bode diagrams to design control systems. This method works very well for processes with dead-time lags. The graphical approach gives the designer an "intuitive feel" of the way the controller changes the frequency response of the system. I found that this "feel" was very helpful working on plant start-ups. Indeed, the greatest benefit from learning the frequency-response design method was the understanding and judgment it imparted. It made me a much better engineer.

You can imagine the excitement with which I approached the teaching of my favorite subject. I wanted my students to feel that excitement. I wanted to impart some of the feeling and judgment that I acquired from frequency-response design of a control system. There was

one major obstacle, however. There was no suitable text for my students. So I wrote 100 pages of notes on control fundamentals with emphasis on graphical design using straight-line Bode diagrams. These notes were the genesis of this text. The thrust of the notes was to bring students to the point where they could complete frequency-response design of control systems under my direction. My role was that of a control engineer, and my students were my engineering technicians. Those 100 pages of notes have grown to become the seventh edition of a 700-page textbook, but the thrust has not changed. The thrust of this text is to bring students to the point where they can complete computer-aided, frequency-response design of control systems under the direction of their instructor or control engineer.

Frequency-response graphs are constructed from the transfer functions of the system components. The chapters on common elements and Laplace transforms were written to give students the foundation required to determine these transfer functions. Analogies were used to develop common elements for modeling and analyzing electrical, thermal, mechanical, and fluid flow elements. These analogies helped students translate their knowledge of one type of component to components of other types. The parts on measurement, manipulation, and control extended the students' mastery of transfer functions and developed their ability to select, specify, and design measuring and manipulating systems. Finally, we reached the point where the students actually began the graphical design process. The frequency-response (or Bode) design method worked very well, but constructing and reconstructing Bode diagrams is very tedious and time consuming. By the time the students learned how to construct Bode diagrams, there was little time or energy left to learn how to design the controller. My goal was unfulfilled.

Then I had a dream. My dream was a computer program that would construct the Bode diagrams so that students, technicians, and engineers could concentrate on the design of the controller. The first attempt to realize my dream was a FORTRAN program that generated frequency-response data from the open-loop transfer function. The program made all the design decisions, and all the student had to do was input the transfer function. As an engineering tool, it was great, but as a teaching tool, it failed. Students could complete the design very well, but they did not understand the results. When design exceptions required an override of the program's results, students had no idea what to do—no pain but no gain.

The first program did too much, and the students did too little. The next program generated tables of frequency-response data that the students used to draw the Bode diagrams. It was not as good an engineering tool but was a much better teaching tool. Drawing the graphs took time, but the students did understand the design process.

The third version of the program uses the graphing capabilities of the QuickBASIC programming language. The program DESIGN is an interactive program that plots frequency-response graphs on the screen and accepts user inputs of the control modes. This program emulates the classical Bode design method with precise plots based on the transfer functions of the system components. The designer observes how each control mode changes the shape of the open-loop frequency response of the system. On-screen design decision data allow the designer to determine PID control mode values, which can be easily changed in a "what-if" analysis. This enables the designer to use a "design-by-trial" procedure to search for the best possible control system design. It worked; my dream was fulfilled. DESIGN is both a good engineering design tool and a good teaching tool.

This text was developed to facilitate the education of engineering technicians. Its purpose is to train technicians who understand the language and methods used by engineers, techni-

cians who can use established methods to complete engineering design work under the direction of a control engineer.

I believe an essential part of the education of the engineering technician is to develop the ability to communicate with engineers using their language. Mathematical terms are an essential part of this language. The engineering technician must understand and be comfortable with terms such as derivative, integral, transfer function, frequency domain, and Laplace transform—not at the theoretical level, of course, but certainly at the applied level. A goal of this text is to develop an understanding of the language of control, including the mathematical terms mentioned.

## COMPUTER DISK ANCILLARY

The disk packaged with this text contains QuickBASIC and executable versions of the four programs used in the text. No knowledge of QuickBasic is required to use the executable versions of the programs. They can be executed directly from DOS on any IBM-compatible computer. **You may make copies of these programs and distribute them as you wish.** I hope you enjoy using the programs as much as I enjoyed creating them. The following files are on the disk.

| QuickBASIC Version | Executable Version | Text File |
|---|---|---|
| BODE.BAS | BODE.EXE | HOWTOUSE.EXT |
| DESIGN.BAS | | DESIGN1.HLP |
| | | DESIGN2.HLP |
| LIQRESIS.BAS | | LIQRESIS.HLP |
| THERMRES.BAS | | THERMRES.EXE |

You can run the executable versions directly from DOS on any IBM-compatible PC. Just type the file name at the DOS prompt and press the <Enter> key. For example, the following command will run the program DESIGN from a disk in the A: drive:

```
A:\>DESIGN
```

The file HOWTOUSE.TXT is a DOS text file that contains directions on using the programs. You can print this file from DOS with the following command:

```
A:\TYPE HOWTOUSE.TXT > PRN
```

You can also use Word, WordPerfect, or any other word processor to examine and print HOWTOUSE.TXT.

注： 读者可于 www.cmpedu.com 网站“课件下载”栏目下载以上文件。本书不再提供软盘。

## CHANGES TO THIS EDITION

The primary emphasis for the seventh edition was a complete rework of the exercises at the end of each chapter. Every section was examined, and every question was reviewed. Numer-

ous exercises were added to provide students with multiple opportunities to develop their grasp of the material.

The review also provided ample opportunities to improve the clarity and accuracy of the text. Example 16.3, a walk-through of a run of program Design, was revised to provide better integration of the text and figures.

Most of the material in Appendix C, "Binary Codes," was deleted because most reviewers felt the material was covered in other courses. Only seven binary tables were retained as reference material.

## ORGANIZATION

The book consists of five parts. Part One is an introduction to the terminology, concepts, and methods used to describe control systems. Parts Two, Three, and Four cover the three operations of control: measurement, manipulation, and control. Part Five is concerned with the analysis and design of control systems. Each chapter begins with a set of learning objectives and ends with a glossary of terms. There is sufficient material for a two-semester course, and there are a number of possible sequences of selected chapters for a one-semester course. The following are some suggested sequences for one- and two-semester courses.

### Suggested One-Semester Sequences

A. Process Control Analysis and Design:
   Chapters 1–5, 6.1–6.3, 9.4, 9.5, 13.1–13.3, 14, 5.1–15.9, 16.1–16.6
B. Servo Control Analysis and Design:
   Chapters 1–5, 6.1–6.3, 9.3, 10, 13, 14, 15, 16.1, 16.5–16.7
C. Sequential and PID Control:
   Chapters 1, 2, 5, 9, 10.4, 11, 12, 13, 16.1–16.4
D. Data Acquisition and Control:
   Chapters 1, 2, 5, 6, 7, 8, 13, 16.1–16.4

### Suggested Two-Semester Sequence

Semester 1: Data Acquisition: Chapters 1–8

Semester 2: Control: Chapters 9–16

## ACKNOWLEDGMENTS

I would like to acknowledge and thank the many people who supported me in the preparation of this book. My wife, Betty, has been wonderfully patient and understanding throughout the project. My children, Mark, Karen, and Paul, were always patient, understanding, and supportive.

Special recognition must go to the following for their suggestions, criticisms, and support over the past several editions: Ernest G. Carlson, Don Craighead, Keith D. Graham, Tom

Loftus, Jack Hunger, Samuel Kraemer, and Ed Lawrence. Thanks also to Debbie Yarnell, executive editor at Prentice Hall, and Louise Sette.

I would also like to thank the reviewers of this edition for their excellent comments and suggestions: A. G. Chassiakos, California State University–Long Beach; Dr. Lee Rosenthal, Fairleigh Dickinson University; and Kenneth Exworthy, Northeast Wisconsin Technical College.

*Robert N. Bateson*

# Contents