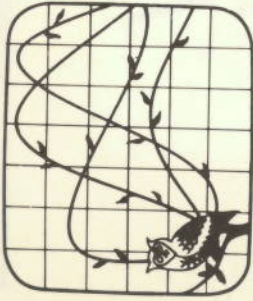


Exhibit 2006



HRW
Series in
Electrical and
Computer Engineering

M. E. Van Valkenburg, Series Editor Electrical Engineering
Michael R. Lightner, Series Editor Computer Engineering

- P. R. Bélanger, E. L. Adler, and N. C. Rumin **INTRODUCTION TO CIRCUITS WITH ELECTRONICS: AN INTEGRATED APPROACH**
- L. S. Bobrow **ELEMENTARY LINEAR CIRCUIT ANALYSIS**
- L. S. Bobrow **FUNDAMENTALS OF ELECTRICAL ENGINEERING**
- C. T. Chen **LINEAR SYSTEM THEORY AND DESIGN**
- D. J. Comer **DIGITAL LOGIC AND STATE MACHINE DESIGN**
- D. J. Comer **MICROPROCESSOR BASED SYSTEM DESIGN**
- C. H. Durney, L. D. Harris, C. L. Alley **ELECTRIC CIRCUITS: THEORY AND ENGINEERING APPLICATIONS**
- M. S. Ghausi **ELECTRONIC DEVICES AND CIRCUITS: DISCRETE AND INTEGRATED**
- G. H. Hostetter, C. J. Savant, Jr., R. T. Stefani **DESIGN OF FEEDBACK CONTROL SYSTEMS**
- S. Karni and W. J. Byatt **MATHEMATICAL METHODS IN CONTINUOUS AND DISCRETE SYSTEMS**
- B. C. Kuo **DIGITAL CONTROL SYSTEMS**
- B. P. Lathi **MODERN DIGITAL AND ANALOG COMMUNICATION SYSTEMS**
- C. D. McGillem and G. R. Cooper **CONTINUOUS AND DISCRETE SIGNAL AND SYSTEM ANALYSIS** Second Edition
- D. H. Navon **SEMICONDUCTOR MICRODEVICES AND MATERIALS**
- A. Papoulis **CIRCUITS AND SYSTEMS: A MODERN APPROACH**
- S. E. Schwarz and W. G. Oldham **ELECTRICAL ENGINEERING: AN INTRODUCTION**
- A. S. Sedra and K. C. Smith **MICROELECTRONIC CIRCUITS**
- N. K. Sinha **CONTROL SYSTEMS**
- M. E. Van Valkenburg **ANALOG FILTER DESIGN**
- W. A. Wolovich **ROBOTICS: BASIC ANALYSIS AND DESIGN**

CONTROL SYSTEMS

Naresh K. Sinha

McMaster University
Hamilton, Ontario, Canada

HOLT, RINEHART AND WINSTON

New York Chicago San Francisco Philadelphia
Montreal Toronto London Sydney Tokyo
Mexico City Rio de Janeiro Madrid

Acquisitions Editor: Deborah Moore
Production Manager: Paul Nardi
Project Editor: Lila M. Gardner
Designer: Andrea Da Rif
Illustrations: Scientific Illustrators

Copyright © 1986 CBS College Publishing

All rights reserved.
Address correspondence to:
383 Madison Avenue, New York, NY 10017

Library of Congress Cataloging-in-Publication Data

Sinha, N. K. (Naresh Kumar)
Control systems.

Includes index.

1. Automatic control. 2. Control theory. I. Title.
TJ213.S47444 1986 629.8 85-24796

ISBN 0-03-069357-8

Printed in the United States of America
Published simultaneously in Canada
6 7 8 9 038 9 8 7 6 5 4 3 2 1

CBS COLLEGE PUBLISHING
Holt, Rinehart and Winston
The Dryden Press
Saunders College Publishing

Contents

PREFACE

1. INTRODUCTION

2. MATHEMATICAL MODELS OF PHYSICAL SYSTEMS

2.1	Introduction
2.2	Differential Equations and Transfer Functions for Physical Systems
2.3	Electrical Analogs for Mechanical Systems
2.4	Modeling an Armature-Controlled DC Servomotor
2.5	Simplification of Block Diagrams
2.6	A DC Position-Control System
2.7	Mason's Rule
2.8	Summary
2.9	References
2.10	Problems

I

Introduction

The subject of control systems is of great importance to all engineers. The objective is to free human beings from boring repetitive chores that can be done easily and more economically by automatic control devices. The recent developments in the large-scale integration of semiconductor devices and the resulting availability of inexpensive microprocessors has made it practical to use computers as integral parts of control systems, making them cheaper as well as more sophisticated.

Historically, the first automatic control device used in the industry was the Watt fly-ball governor, invented in 1767 by James Watt, who was also the inventor of the steam engine. The object of this device was to keep the speed of the engine nearly constant by regulating the supply of steam to the engine. A schematic diagram is shown in Fig. 1.1. The two fly balls in the governor rotate about a vertical axis at a speed proportional to the speed of the engine. Due to the centrifugal force acting on them, they tend to move out. This movement controls the supply of steam to the engine through a mechanical linkage to the steam flow valve in such a manner that the steam supply is reduced when the speed is high and increased when the speed is low.

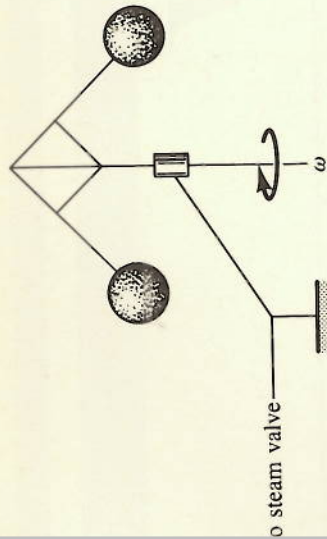


FIGURE 1.1. The Watt fly-ball governor.

It was found that by a proper design of the governor the speed of the engine shaft could be kept within narrow limits of a specified value. It was also observed that to increase the sensitivity of the governor, it tended to "hunt" or oscillate about the desired setting. It was about 100 years later that a complete analysis was made by James Clerk Maxwell (more well known for his contributions to electromagnetic field theory).

Much later it was realized that all automatic control systems worked on the principle of feedback. By a coincidence, about the same time the theory of amplifiers had been developed by electrical engineers who had been concerned with transmitting telephone signals over long distances. In the early 20th century, the Nyquist theory of stability developed about the same time as the theory of automatic control came during World War II. Servomechanisms were utilized for the control of anti-aircraft guns, and many peacetime applications followed. Some of these included automatic control of machine tools, automatic "pilot" for aircraft, automatic control of voltage at electric power stations, and automatic regulation of voltage at electric power stations. Although originally the theory was based on frequency response methods, in the 1960s the impact of the digital computer and the development of time-domain theory using state variables. This theory is useful as more sophisticated multivariable control systems were developed for more complex processes. As computers have become cheaper and more compact, they have been utilized as components of more advanced control systems.

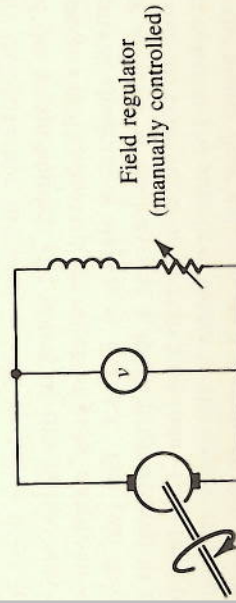


FIGURE 1.2. A voltage control system.

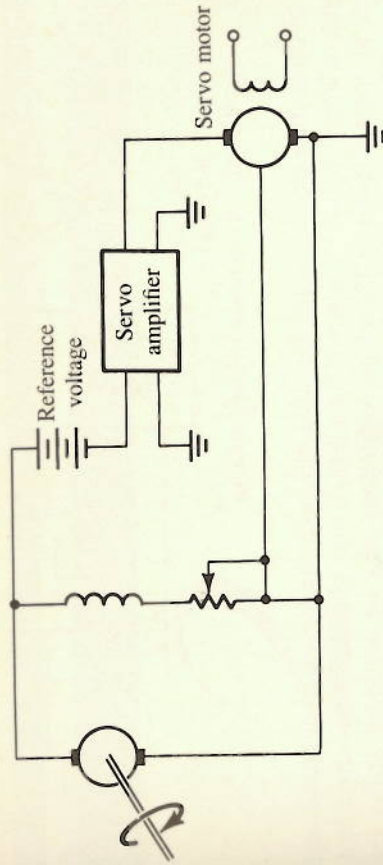


FIGURE 1.3. Automatic voltage regulator.

Let us consider some simple examples of control systems. Figure 1.2 shows the scheme for controlling the voltage at an electric power station in the 1940s. A human operator was required to watch a voltmeter connected to the busbars and adjust the field rheostat in order to keep the voltage close to the specified value. A scheme for automatic voltage regulation is shown in Fig. 1.3 and shows that it works by comparing the actual value of the voltage with the desired value. The difference or "error" is applied to a servomotor, after suitable amplification. This servomotor drives a shaft coupled to the field rheostat to alter the resistance in the field winding in such a manner that the error is reduced. Hence, it may be said that "feedback" is utilized to obtain automatic control. As a matter of fact, all automatic control systems use feedback and can be represented by the block diagram shown in Fig. 1.4. It can be seen that the controlled output is fed back and compared with the reference input. The difference, called the "error," is then utilized to drive the system in such a manner that the output approaches the desired value (i.e., the reference input).

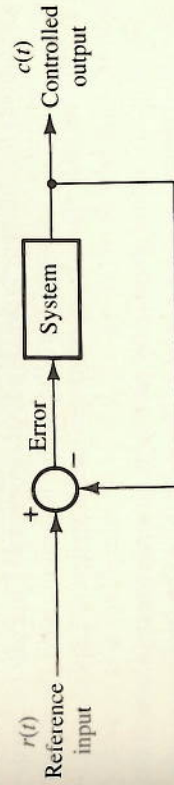


FIGURE 1.4. Block diagram of automatic control system.

Another example is the home heating system. A thermostat senses the temperature and if it is lower than a set value, the furnace is turned on. The furnace is turned off when the temperature exceeds another set value. The block diagram is shown in Fig. 1.5. Although it is similar to Figs. 1.3 and 1.4, it may be noted that this is an on/off-type control system, whereas the voltage regulator is a continuous-type system.

It was noticed at the very outset that if one tried to improve the accuracy of a control system by increasing the loop gain, it led to instability,

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.