Automatic Control Systems

fifth edition

Benjamin C. Kuo

Professor of Electrical and Compu
University of Illinois at Urbana-C

PRENTICE-HALL, INC., Englewood Clif

Library of Congress Cataloging-in-Publication Data

KUO, BENJAMIN C., (date)
Automatic control systems.

Includes bibliographical references and index.
1. Automatic control. 2. Control theory. I. Title.
TJ213.K8354 1987 629.8'3 86-17047
ISBN 0-13-054842-1

Editorial/production supervision
and interior design: Elena Le Pera
Cover: Original design by Benjamin C. Kuo, adapted by Karen Stephens
Manufacturing buyer: Rhett Conklin

Printed in the United States of America

10 9 8 7 6 5 4

ISBN 0-13-054842-1 025

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S. A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Prentice-Hall of Southeast Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

Contents

PREFACE *x*

1 INTRODUCTION *1*

1.1 Control Systems *1*
1.2 What Is Feedback and What Are Its E
1.3 Types of Feedback Control Systems

2 MATHEMATICAL FOUNDATION *16*

2.1 Introduction *16*
2.2 Complex-Variable Concept *16*
2.3 Differential Equations *19*
2.4 Laplace Transform *22*
2.5 Inverse Laplace Transform by Partial-
2.6 Application of Laplace Transform to t
Ordinary Differential Equations *32*
2.7 Elementary Matrix Theory *34*
2.8 Matrix Algebra *40*
2.9 Vector-Matrix Form of State Equatio
2.10 Difference Equations *47*
2.11 The *z*-Transform *49*
2.12 Application of the *z*-Transform to the
Difference Equations *58*

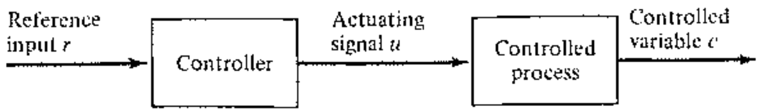

Figure 1-3 Elements of an open-loop control system.

The elements of an open-loop control system can usually be divided into two parts: the controller and the controlled process, as shown by the block diagram in Fig. 1-3. An input signal or command r is applied to the controller, whose output acts as the actuating signal u; the actuating signal then controls the controlled process so that the controlled variable c will perform according to some prescribed standards.

In simple cases, the controller can be an amplifier, mechanical linkages, or other control means, depending on the nature of the system. In more sophisticated electronics control, the controller can be an electronic computer, such as a microprocessor.

Closed-Loop Control Systems (Feedback Control Systems)

What is missing in the open-loop control system for more accurate and more adaptive control is a link or feedback from the output to the input of the system. To obtain more accurate control, the controlled signal $c(t)$ should be fed back and compared with the reference input, and an actuating signal proportional to the difference of the input and the output must be sent through the system to correct the error. A system with one or more feedback paths such as that just described is called a *closed-loop system*.

The block diagram of a closed-loop idle-speed control system is shown in Fig. 1-4. The reference input ω_r sets the desired idling speed. Ordinarily, when the load torque is zero, the engine speed at idle should agree with the reference value ω_r, and any difference between the actual speed and the desired speed caused by any disturbance such as the load torque T_L is sensed by the speed transducer and the

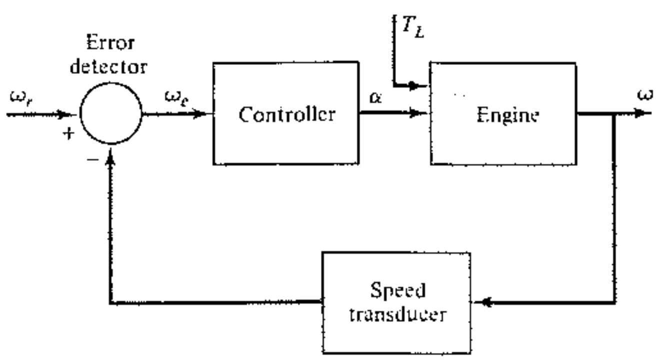

Figure 1-4 Closed-loop idle-speed control system.

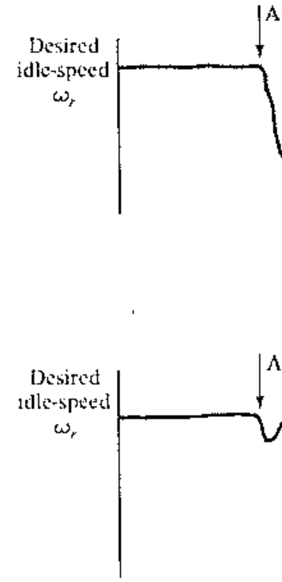

Figure 1-5 (a) Typical idle-speed response of an open-loop system. (b) Typical idle-speed response of a closed-loop system.

error detector, and the controller will operate on the di
to adjust the throttle angle α to correct the error.

Figure 1-5 illustrates a comparison of the typical p
and closed-loop idle-speed control systems. In Fig.
open-loop system will drop and settle at a lower value
In Fig. 1-5(b) the ideal speed of the closed-loop syster
to the preset value after the application of T_L.

The idle-speed control system illustrated above
system whose objective is to maintain the system out

As another illustrative example of a closed-loop c
the block diagram of the printwheel control system of a
typewriter. The printwheel, which typically has 96 or 1
to position the desired character in front of the hamm
selection is done in the usual manner from a keyboar
keyboard is depressed, a command for the printwhe
position to the next position is initiated. The micropro

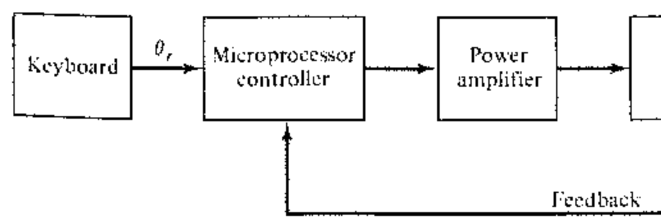

Figure 1-6 Printwheel control sy