Design and Application of Process Control Systems

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Printed in the United States of America.
10 9 8 7 6 5 4 3 2

ISBN 1-55617-639-2

Library of Congress Cataloging-in-Publication Data
Corripio, Armando B.
Design and application of process control systems / by Armando B. Corripio.
p. cm.
Includes bibliographical references and index.
ISBN 1-55617-639-2
1. Chemical process control. I. Title.
TP155.7.C67 1998
660' .2815--dc21

97-29091

CIP

Aknowledgments

Many people had a hand in the creation of this ILM. My partner in crime, Professor Carlos A. Smith of the University of South Florida, who convinced me to develop and teach short courses in automatic process control. The students in the first courses, who wanted to know more about the inner workings of the process and suggested a course on process concepts. The people of Union Carbide at Taft, Louisiana, who requested that the course be modified to include control applications. The ISA Education Services people who allowed me to teach and develop the course through the years. Greg Shinskey, whose ideas on control systems design have guided me, and Edgar Bristol, who brought some of the key ones to my attention. Finally my friend Dr. Rafael Juantorena, who read the lecture notes and suggested they should be published as an ILM, and Dr. Paul W. Murrill, who kindly went along with the idea, got the contract for the ILM, and encouraged me along the way. To all of them go my sincere thanks.

In preparing the ILM I have eliminated most of the equations and derivations which had crawled into the lecture notes of the short course when I was a lot younger and immature. They have been replaced with word descriptions of the process relationships that make control systems work.

My thanks to Mrs. Darla Dao, who prepared the first electronic manuscript of the lecture notes for the short course.

This ILM is dedicated to my wife Consuelo, her courage is an inspiration in my life.

Armando B. Corripio

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UNIT 1:
Introduction and Overview

UNIT 1

Introduction and Overview

Welcome to ISA's Independent Learning Module Design and Application of Process Control Systems. This unit provides you with an overview and the information you need to take this self-study course.

Learning Objectives — When you have completed this unit you should be able to:

A. Know the purpose of the course.

B. List the course objectives.

C. Determine the organization of the course.

D. Proceed through the course.

1-1. Purpose

The purpose of this ILM is to teach you the principles that underlie the response of the process in industrial control systems. These principles are essential for the proper design and analysis of process control systems.

1-2. Audience and Prerequisites

This course has been designed for instrumentation and control engineers and technicians who, already familiar with the principles and hardware of industrial instrumentation and control systems, want to learn more about the industrial processes they control and operate. The course will also be helpful to students in technical schools, colleges, or universities who wish to gain some insight into chemical process principles as they relate to the design and application of automatic control systems.

There are no specific prerequisites for this course, other than a general understanding of high school physics. However, you are assumed to have some familiarity with instrumentation and control concepts, whether acquired through field experience or academic study. Any of the three ILMs listed at the end of this unit are particularly helpful in reviewing some of these concepts.

Some simple mathematics are used in this ILM to present and analyze the formulas that represent the response of the process. However, you are not expected to be intimately familiar with the mathematics to understand the concepts that are presented. The intent is to keep mathematics from becoming a barrier to your understanding of the principles of automatic process control.

1-3. Study Materials

This textbook is the only study material required in this course; it is one of ISA's ILM series. It is an independent, stand-alone textbook that is uniquely and specifically designed for self-study.

Appendix A contains a list of suggested additional reading resources on the material of the ILM. You will also find it useful to study the other ILMs that are available from ISA. Some of these ILMs contain additional details on some of the concepts presented here. These will be individually referenced in the appropriate units and listed at the end of the units.

1-4. Organization and Sequence

The material in this course is presented in the same order as they are taught in the chemical engineering curriculum. The course is organized in ten units, counting this introductory unit. The next unit reviews the basic process control strategies that are used in the control applications of the rest of the units. Units 3 and 4 present control systems that maintain the flow of material and energy in balance. Units 5 and 6 deal, respectively, with the control of liquid and gas flow systems. The control of heat transfer processes is presented in Unit 7, while control systems for distillation columns and other separation processes are presented in Units 8 and 9. Finally, Unit 10 presents the control of chemical reactors. In each unit the basic principles are reviewed first. Then they are applied to design typical control applications.

As is the case with other ILMs, the method of instruction used in this ILM is self-study. You select the pace at which you learn best. You may completely skip or browse through some units with which you feel you are intimately familiar and devote more time to other units that may contain material new to you.

Each unit is designed in a consistent format with a set of specific learning objectives stated at the very beginning of the unit. Note these learning objectives carefully; the material in the unit will teach to these objectives. Each unit contains examples to illustrate specific process control applications. At the end of each unit there is a set of simple questions (to review the concepts), and application exercises (to allow you to test your skill in designing the control systems for them). All questions and exercises have solutions contained in Appendices B and C, respectively, against which you should check your solutions.

This ILM belongs to you; it is yours to keep. We encourage you to make notes in the textbook, taking advantage of the ample white space provided on every page for this specific purpose.

1-5. Course Objectives

When you have completed this entire ILM you should be able to:

- **Design control systems to maintain the inventory of material and energy in the process.**
- **Maintain the appropriate ratio of reactants in combustion and other processes.**
- **Select the appropriate manipulated variables for the control of blending processes.**
- **Predict the installed characteristics of a control valve.**
- **Pick automatic control systems for pumps and compressors.**
- **Design temperature control systems for heat exchangers and chemical reactors.**
- **Control heat transfer rates in condensers, reboilers, and furnaces.**
- **Apply automatic control to distillation columns.**
- **Know how to control gas absorbers, strippers, liquid extractors, evaporators, and driers.**
- **Design control systems for tubular, stirred-tank, and chemical reactors.**
- **Control pH in neutralization systems.**

Besides these overall course objectives, each individual unit contains a list of its own learning objectives to help you direct your study.

1-6. Course Length

The basic premise of ISA's ILM System is that students learn best if they proceed at their own pace. As a result, there will be a significant variation in the amount of time taken by individual students to complete this ILM. On the average, most students will complete this course in 30 to 40 hours, but individual experience and personal capabilities will do much to vary this time estimate. I hope that the time you spend studying this subject is not only profitable, but also enjoyable.

References

1. Murrill, P. W. 1990. *Fundamentals of Process Control Theory*. Second edition. Research Triangle Park, NC: ISA.

2. Murrill, P. W. 1988. *Application Concepts in Process Control*. Research Triangle Park, NC: ISA.

3. Corripio, A. B. 1990. *Tuning of Industrial Control Systems*. Research Triangle Park, NC: ISA.

UNIT 2:
Review of Process Control Strategies

UNIT 2

Review of Process Control Strategies

This unit presents a brief review of the basic process control strategies that will be used in the rest of the course to build the control systems for industrial processes. It also gives the motivation for learning the basic principles that govern the response of the process.

Learning Objectives — When you have completed this unit you should be able to:

A. Know the role of process models in control system design.

B. Apply and tune feedback controllers.

C. Apply ratio control.

D. Design feedforward control systems.

2-1. The Role of Process Models in Control Systems Design

To design a control system you must first decide on the control objectives and select the process variables that can be measured to achieve them. Next, you must select the process variables that are to be manipulated and identify the disturbances that can affect the control objectives. Finally, you must decide how to combine the measured variables to calculate the values of the manipulated variables that will achieve the objective. The particular way in which the variables are combined constitute the control system.

The three basic control strategies on which most process control systems are based are:

- feedback control,
- ratio control, and
- feedforward control.

This unit briefly reviews these strategies. The rest of the units will use them to design process control systems. However, what determines how these strategies are put together for a specific application is the way the process variables are related in the process, that is, by a process model.

Many fine control schemes are based on very simple linear models, that is, models in which the output variables are assumed to be related to the input variables through simple linear combinations. These models constitute approximations to the real behavior of the process in a narrow region around the operating point. Therefore, a control system based on such a linear model can only perform well around the operating point at which the model is valid; its performance deteriorates when the process conditions change.

This course will teach you how to design control systems based on models that are specific to each process and, therefore, can perform well over wide ranges of the operating conditions. You will also learn to evaluate when a particular process requires more than just a simple linear model. This is because the models will be based on basic physical principles:

- **Conservation of mass and energy**
- **Phase and chemical reaction equilibrium**
- **Rate of transfer of heat, mass, and momentum**

Greg Shinskey, a recognized and experienced control systems designer, says[1]:

> The development of a suitable control-system structure begins with the formulation of a process model. We must know how the process responds to inputs before we can close loops through controllers. Steady-state relationships are the most important because they determine the fundamental stability modes of the process. Furthermore, they are relatively easy to obtain using material and energy balances and thermodynamic laws.
>
> Knowledge of the process is a prerequisite to the design of an effective control system.

The main objective of this course is to teach you the basic principles that will allow you to know your process so that you can design effective control systems for it. The models to be taught will be kept simple. These are the models on which tried-and-true control schemes are based, the schemes that have been found successful in practice. Today there is significant development work in the use of on-line computer simulations of the process for control and optimization. Although these techniques are promising, they are in the early development stages and out of the scope of this course. Additional development is taking place in the use of artificial neural networks and other sophisticated computer algorithms for process modeling and control. These techniques are also promising, but out of the scope of this course.