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Chemical Process Control

An Introduction to Theory and Practice

GEORGE STEPHANOPOULOS

Department of Chemical Engineering
Massachusetts Institute of Technology

P T R PRENTICE HALL, Englewood Cliffs, New Jersey 07632

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Preface

As its title suggests, this is an introductory text to the theory and practice of chemical process control. It is intended to cover the needs, as these pertain to the scope of basic chemical engineering education, (1) of a first undergraduate course in process dynamics and control, and (2) of the first part of an advanced undergraduate or graduate course in process control.

During the last ten years, academic research and industrial practice in chemical process control have been shaped by the following important realizations:

1. The structure of chemical processes has become increasingly complex, due to better management of energy and raw materials. As a consequence, the design of control systems for complete plants now constitutes the focal point of engineering interest, rather than controller designs for single processing units. Furthermore, the design of a control system has become intimately related to the design of the process itself.
2. Designing a control system implies identification of control objectives; selection of appropriate measurements and manipulations, as well as the determination of loops connecting these; and identification of the proper control laws. In other words, it is a much more involved question than the traditional one of controller tuning.

3. The advent and rapid growth of digital computers has revolutionized the practice of chemical process control and has allowed the industrial implementation of advanced control concepts.

Today, it is widely believed that education in chemical process control has not been adapted to follow modern directions, as these are depicted above. The present text represents an attempt to bridge the classical approach to process control problems with the current and future trends and needs. It is primarily an educational vehicle rather than a practical guide to the solution of specific industrial problems. Here, the emphasis is on understanding the nature of process control problems and their attributes, as well as on systematizing the approach to their solution. Needless to say, several design tools and methodologies have also been included, but with reduced emphasis. Thus it is hoped that the following aspects will emerge after studying this book:

1. Chemical process control is a subject of study with its own intricacies and challenges. It is intimately related to chemical engineering science and practice, and as such it is not the degenerate child of any other branch of engineering.
2. The design of a control system is not a mathematical problem, but should be perceived as an engineering task, with all its attractive challenges and practical shortcomings.
3. A good understanding of physical and chemical phenomena taking place in a chemical process is of paramount importance for the design of simple and effective control schemes.
4. Several alternative control configurations are usually possible for a given processing unit or a complete plant. The selection of the "best" among them is the central question to be resolved.
5. There exist a plethora of analytical tools and design methodologies that one should be familiar with before attempting to tackle process control problems.

The text is divided into seven parts. Each part includes a number of chapters with a common general orientation.

Part I (Chapters 1 through 3) represents a general introduction to the control aspects of a chemical process. An attempt is made to define what we mean by process control, to identify the needs and incentives for process control, to analyze the design questions and formulate the problems that must be solved, and to provide the rationale for studying the material that follows in the subsequent chapters.

Part II (Chapters 4 and 5) introduces the reader to the modeling requirements for process control. It demonstrates how we can construct useful models, starting from basic principles, and determines the scope and difficulties of mathematical modeling for process control purposes.

Part III (Chapters 6 through 12) is devoted to the analysis of static and dynamic behavior of processing systems. The emphasis here is on identifying those process characteristics which shape the dynamic response for a variety of processing units. The results of such analysis are used later to design effective controllers. Input–output models have been employed through the use of Laplace transforms.

Part IV (Chapters 13 through 18) covers the analysis and design of feedback control systems, which represent the control schemes encountered most often in a chemical plant. Emphasis has been placed on understanding the effects which various feedback controllers have on the response of controlled processes, and on the selection of the most appropriate among them. The subject of controller tuning has been deemphasized, and as a consequence, the traditional root-locus techniques and frequency response tuning methods have been scaled down.

Part V (Chapters 19 through 22) deals with the description, analysis, and design of more complex control systems, with one controlled output. In particular, Chapter 19 introduces the concept of feedback compensation with Smith's predictor, to cope with systems possessing large dead times or inverse response. Chapter 20 describes and analyzes a variety of multiloop control systems (with one controlled output) often encountered in chemical processes, such as cascade, selective, and split-range. Chapter 21 is devoted exclusively to the analysis and design of feedforward and ratio control systems, while Chapter 22 makes a rather descriptive presentation of adaptive and inferential control schemes: why they are needed and how they can be used.

Chapters 23 through 25 constitute Part VI and are devoted to multivariable control problems. The emphasis here is on generating alternative control configurations in a systematic manner and screening them for the best. It is not meant to cover all aspects of multivariable control, and only one design technique (relative-gain array) is presented for the selection of the least interacting loops. Simple, noninteracting control loops are also designed for low-order systems. Chapters 23 and 25 offer an introduction to the control design problems for complete chemical plants. Also, they outline systematic procedures which can be used to synthesize control schemes for such complex systems.

Part VII (Chapters 26 through 31) is an introduction to process control using digital computers. Initially (Chapter 26), the characteristics of a digital computer control loop are analyzed in terms of the new hardware elements as well as the new control design questions. Chapters 27 through 29 provide the analytical tools for analyzing the response of open-loop and closed-loop discrete-time dynamic systems. Chapter 30 outlines the most popular procedures for designing digital feedback controllers, while Chapter 31 discusses computer-aided, on-

line identification of chemical processes and its use for the development of adaptive control systems.

The present book is the culmination of seven years of teaching process control at the University of Minnesota and the National Technical University of Athens. It was designed in such a way as to provide a simple, smooth, and readable account of process control aspects, while providing the interested reader with material, problems, and directions for further study.

With few exceptions, every chapter contains the proper amount of material for just one lecture. In order to maintain continuity and flow of the main text, two mechanisms have been used. First: specific details are usually grouped at the end of each section under the heading Remarks. Second: additional, useful, but not necessary material has been put into appendices at the end of the corresponding chapters. Many examples have been used throughout the text either to explain some concepts or to demonstrate the use of various techniques. Not all of the examples need to be covered during a lecture hour, and some of them can be left for individual study.

To enhance the educational value of the book, a series of Things to Think About at the end of each chapter, as well as a large number of homework problems at the end of each part, have been included. Occasionally, the Things to Think About will direct the reader to find the answers in other books, papers, or handbooks, which he or she can find listed in the sections of annotated bibliography at the end of each part.

I am vastly indebted to many people who have helped and inspired me, in various ways, to start, continue, and complete this book. First and foremost, my gratitude goes to the "Chief," Neal R. Amundson, for supporting me at the conception of this book and strengthening my resolve in so many direct and indirect ways. Rutherford Aris, Arnie Fredrickson, and Skip Scriven may not have realized what an influence their generous presence, "teachings," and friendship have had in shaping this book. Thanks are due to J. Wei for his encouraging words to continue with this project, and to M. M. Denn for being so gracious and helpful when this book was in its embryonic stage. The constructive criticism of J. M. Douglas has been immensely helpful. His generous permission to use passages from his work on the control system design for complete plants is gratefully acknowledged.

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Shirley Tabis typed the original manuscript with great care, artistic taste, skill, and dedication, unparalleled in my own experience.

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George Stephanopoulos
Athens, Greece