BATCH PROCESS AUTOMATION

THEORY & PRACTICE

Howard P. Rosenof
Asish Ghosh

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VNR VAN NOSTRAND REINHOLD COMPANY
New York

Disclaimer: The purpose of this work is educational. The information and teachings herein are thus general in nature and are not intended for designing, constructing, or operating a specific facility.

Library of Congress Catalog Card Number: 86-23332
ISBN 0-442-27708-3

Printed in the United States of America

Van Nostrand Reinhold Company Inc.
115 Fifth Avenue
New York, New York 10003

Van Nostrand Reinhold Company Limited
Molly Millars Lane
Wokingham, Berkshire RG11 2PY, England

Van Nostrand Reinhold
480 La Trobe Street
Melbourne, Victoria 3000, Australia

Macmillan of Canada
Division of Canada Publishing Corporation
164 Commander Boulevard
Agincourt, Ontario M1S 3C7, Canada

16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data
Rosenof, Howard P., 1948-
Batch process automation.
Includes index.
1. Chemical process control—Automation. I. Ghosh, Asish, 1935- . II. Title.
TP155.75.R67 1987 660.2'81 86-23332
ISBN 0-442-27708-3

FOREWORD

While continuous processing has always been considered the ideal method of operation of a chemical plant from the economic viewpoint and still remains the ultimate goal of the chemical engineer designing a new plant or unit, it is always amazing to me to see the amount of batch processing that remains in many chemical and petroleum plants. In addition, the more specialized companies such as the chemical specialties makers, the drug companies, and others require even more batch reaction equipment to carry out their production functions successfully. This major need for batch equipment is usually because these latter industries produce very high quality products in quantities too small to justify the economic cost of continuous production equipment. In addition, the use of batch equipment has allowed the production of purities and other quality parameters not readily attainable in continuous equipment.

Batch equipment with its dynamically changing operating conditions during the period of the batch operation has always posed to the control engineer a challenge that has demanded the ultimate in his technical ingenuity. Each of the emerging automatic control technologies has been applied to batch equipment control as it has been developed, with an ever increasing success as control capabilities have advanced. Nevertheless, the batch reactor has continued to challenge the control engineer because of the great individuality and consequent lack of generality shown by each batch reactor control situation.

Major advances have been achieved in batch reactor control with the development of the programmable controller and the minicomputer during the 1970s. These remain the major competitive technologies today since the microprocessor based, distributed control systems have generally not yet shown enough computational ability to supersede the earlier technologies. How long this latter condition will hold in the face of the continued expansion of the capabilities of distributed control systems remains to be seen.

The field of batch reactor control has developed a major literature of technical reports and papers on reactor mathematical models, on process control theory and technology, and on operational applications. The major media for these papers have been in the technical journals, conference proceedings, and related publications of the American Institute of Chemical Engineers, the American Chemical Society, and the Instrument Society of America. The technical journals, *Instruments and Control Systems* and *Control Engineering*, have also published an extensive set of papers in this area.

Despite the many papers, very few books about batch reactor control have been published. Thus *Batch Process Automation: Theory and Practice*, by Rosenof and Ghosh, fills a long felt need for the profession. These authors have covered all aspects of the field from the basic definitions of the field to discussions of such advanced topics as: optimal scheduling of batch reactor systems, proper use of plant safety interlocks, some of the more detailed aspects of project justification, and methods of testing and proving the final systems design for the project. They have provided important material for all classes of readers from those requiring an elementary treatment to those needing the full technical details of specific examples of process equipment.

The examples chosen by the authors, while perhaps unconventional at first consideration, very descriptively and pointedly illustrate the principles involved and thus provide a very good learning experience for the reader.

I expect this book to be an important addition to the literature of the field of batch process control and one of which Messrs. Rosenof and Ghosh should be very proud. I am happy to be able to contribute to it in this small way.

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PREFACE

A well-designed control system can go a long way toward making a batch-process plant reliable, safe, and easy to operate. It helps achieve manufacture within specification and allows the flexibility to make different grades of product, thus helping the process achieve financial success. On the other hand, a poorly designed system can be a money loser. Its products may be unrepeatable or even unsalable, with operator attention required continuously to second-guess the system's decisions.

We believe that the difference between success and failure is in choosing the right hardware and software and in properly applying them. Control system vendors now provide not only the hardware but also comprehensive software packages for controlling the batch process. Choosing the right combination for an application requires considerable insight into the functions of the control system along with detailed process knowledge. This allows the user to generate an appropriate specification of the requirements.

Choosing the right hardware and software combination is only the first step toward success. This must be followed by the arduous task of design and application unique to the process to be controlled. Over the years, we have developed an approach to planning and implementing batch control systems. We have seen first-time batch automation users learn the intricacies of this business, take an active role in determining system requirements, and take full responsibility for system operation. In contrast, we have met people who experienced substantial disappointment in trying to automate batch processes. In many cases they were able to compare their planning approach with ours and discover the cause of their difficulties. Our employer, The Foxboro Company, has permitted and encouraged us to place our method in the public domain. We have done so by writing articles for major control and user industry publications and by making presentations at professional meetings. This book represents the accumulation of this work and would be useful to anyone interested in automating a batch process.

The book is divided into three parts. Part I (Chapters 1-4) is an introduction to the batch process and the batch control system. It deals with batch and sequential processes and familiarizes the reader with common terms (Chapter 1). It also deals with the historical aspects of batch control and gives an introduction to the equipment used today (Chapters 2 and 3). Finally, the benefits and problems associated with batch-process automation are discussed (Chapter 4). This part will prove invaluable to those unfamiliar with this field. Because standard terms for batch control are yet to be universally accepted, experienced engineers will also find this part useful in orienting themselves toward the terminology used in the rest of the book.

Part II (Chapters 5 and 6) elaborates on the functional requirements of a batch control system and then describes how the typical control system packages available today meet these requirements. This part will be useful in gaining enough appreciation of the batch control systems to allow the reader to make intelligent choices from among the available hardware and software packages. This part will be useful to those unfamiliar or with limited familiarity with batch control and will act as the stepping stone to the next part.

Part III (Chapters 7-14) deals with the practice of automation, which includes the specification, design, implementation, and testing of batch control systems. Chapter 7 gives the essence of our planning method, called design by levels, which divides a batch plant's controls into a hierarchical system. Chapter 8 covers the higher (executive) levels, Chapter 9 the sequence levels, Chapter 10 the regulatory levels, and Chapter 11 the interlock levels. Chapter 8 includes a brief discussion of plantwide batch control, including optimal scheduling. The interested reader should study the literature in operations research. We have assumed that our readers are knowledgeable in continuous-control systems, and we have included, in Chapter 10, only a short discussion of the differences between regulatory controls for continuous and batch processes. Comprehensive discussions on plant safety interlocks are provided in Chapter 11. Chapter 12 has a brief discussion on the possible economic returns for automation at different levels. Hardware architecture and reliability issues are given in Chapter 13. Finally, the importance of testing the designed system along with an outline of the types of tests are given in Chapter 14. This part should prove very useful to experienced engineers. Beginners should thoroughly study the first two parts before reading the third.

Batch processes use and manufacture materials that are toxic, carcinogenic, flammable, explosive, and otherwise dangerous. This book is intended to be used by practicing engineers who have the background to determine which parts of this book are and are not applicable to the specific processes under consideration. Naturally, responsibility for the safety of a process plant remains with those responsible for its design, construction, and operation.

ACKNOWLEDGMENTS

We are grateful to many Foxboro personnel and clients who helped us in developing the implementation methods described in this book. Our special thanks go to William Saunders and Robert Mick, respectively former and present Foxboro colleagues. Bill Saunders developed a highly sophisticated master-sequence recipe application that helped lead to the discussion of this recipe type in Chapters 6 and 8. Bob Mick helped develop the concepts of structured English for documenting sequence logic, as described in Chapter 9.

We also acknowledge the support of The Foxboro Company in preparing this book, and of the many individual management, professional, and technical personnel who helped us in a wide variety of ways. Tom Schonbach, Charlie Hall, Ed Bristol, Ray Sawyer, Al Storti, and Leo Johnson helped establish the Company's commitment to our effort. Dick Sherman provided major assistance with the publication arrangements as well as welcome editorial support. Paulette Bosquette and Mary Nettle provided the word processing support and were tolerant of indecipherable manuscripts and frequent changes of mind. Helen Stevens and the staff of Foxboro's RD & E Library helped us immensely in our research of previous work in this field. Several persons helped us by reviewing our work and offering constructive criticisms: in particular Ed Bristol, Peter Martin, Dave Noon, Mo Prasad, Jim Verhulst, and Jack Wu. In addition to writing the Foreword, Theodore J. Williams reviewed the entire manuscript and made a number of useful suggestions.

HOWARD P. ROSENOF
ASISH GHOSH

CONTENTS

PART I

INTRODUCTION TO DISCONTINUOUS PROCESSES AND THEIR CONTROL

CHAPTER
1

BATCH AND SEQUENTIAL PROCESSES

Although continuous processes are more widely discussed, batch processes are very common. We cook food by batch processes. We prepare dishes by measuring and mixing ingredients, heating the ingredients, mixing in other ingredients at predefined intervals, testing as required (to check quality), and so on. When the cooking is finished, the food is removed from the heat source and served hot or allowed to cool. Thus, a typical cooking process involves a list of ingredients and step-by-step instructions for mixing, heating, frying, roasting, and so on. It also involves testing the food at certain intervals to check for taste and texture and to take the appropriate actions, such as adding spices. Though a procedure might appear straightforward, it may be modified, based on the experience of the cook or the results of the tests carried out during the cooking process.

Figure 1-1 is a recipe for a fruit cake. The procedure can be divided into three broad phases: preparation, cooking, and cooling and storing (Fig. 1-2).

The steps in each phase must be followed in the proper sequence to make a good cake. Some steps, such as the beating of the egg yolks and whites, may be done in parallel with the main activity and therefore are not documented explicitly (they may be shown as separate phases or as part of the same phase). The procedure also involves setting a timer, which possibly generates an audible message (ringing) when the set time of 2½ h has elapsed. Manual intervention is then necessary. The cook must test the cake to determine if it is done or if further baking is needed.

The procedure assumes normal operation with no unexpected happenings. But suppose the oven temperature controller or the timer breaks down, causing

Fruit Cake

1½ cups butter	3½ cups flour
2 cups sugar	½ teaspoon salt
6 eggs, separated	2 cups golden raisins
½ teaspoon cream of tartar	1 cup chopped, dried apricots
1 cup milk	½ cup chopped candied orange peel
1 teaspoon brandy extract (or ¾ cup milk, ¼ cup brandy)	1 cup coarsely chopped walnuts
	1 teaspoon vanilla

Beat butter until light and creamy. Gradually add sugar, beating until smooth. Beat egg yolks together lightly and add. Combine milk, brandy and vanilla. Mix flour and salt together. Alternately add milk mix and flour mix to butter mix. Fold in fruits and nuts. Beat egg whites with cream of tartar until stiff but not dry. Fold whites into batter gently but thoroughly. Pour mixture into two buttered and floured six-cup molds. Bake at 275 degrees for 2½ hours or until they test done. Cool. Unmold.

Figure 1-1. A typical cooking process, for fruit cake (California Raisin Advisory Board, 1983).

the batch to burn. The actions to be taken in such an event are left to the experience and judgment of the cook.

We can find other examples of batch and sequential processes: washing and drying clothes, cleaning dishes, and showering. In contrast, the control of water supply pressure to the house is a continuous process because the supply is maintained at a constant pressure (within limits) even when there are large variations in demand.

In industry, batch and sequential processes are used in many ways. For example, in

Chemical processes, such as manufacturing of polyvinyl chloride (PVC)
Dyeing in the textile industry
The batch digester in the pulp and paper industry
Starting power plants and other basically continuous plants
Manufacturing corn syrup and beer in the food industry
Manufacturing drugs and fine chemicals
Solid material handling, such as iron ore concentration

Even in areas normally associated with continuous processes (e.g., refining petroleum and the manufacturing of petrochemicals), unit start-up and shutdown, along with such functions as wax extraction and catalyst regeneration, are generally sequential. A typical batch process requires continuous control for a limited period of time—for example, maintaining temperature and pressure to specified points in a reactor during a reaction.

```
Preparation Phase

    Beat specified amount of butter until light and creamy
    Add specified amount of sugar and continue beating
    Add beaten egg yolks
    Add the milk mix and flour mix alternately
    Fold in fruits and nuts
    Fold in beaten egg white mix
    Pour the batter in buttered and floured molds
    Go to cooking phase
End of Phase

Cooking Phase

    Set oven temperature to 275°F
    Wait until the oven temperature is greater than or equal to 275°F
    Put the molds with batter in the oven
    Set timer for 2½ hrs.
    Wait for the timer to time out
    If baking not done
    | Then repeat-until baking is done
    | |    |      Set timer for 15 minutes
    | |    |      Wait for the timer to time out
    | |    End repeat-until
    | Else continue
    Go to cooling and storing phase
End of phase

Cooling and Storing Phase
    Switch off the oven
    Take the molds out with the cakes
    Wait until the cakes are cool
    Unmold the cakes and store
End of Phase
```

Figure 1-2. The three-phase procedure for making fruit cake.

DISTINCTIONS BETWEEN PROCESSES

Some engineers argue that all processes are essentially batch: Continuous processes are really batch processes with long holding or operating times. They reason that since all continuous processes need sequential operations during start-up and shutdown, these processes are not truly continuous. This is true, but that argument does not make them batch processes either. During normal operation a batch

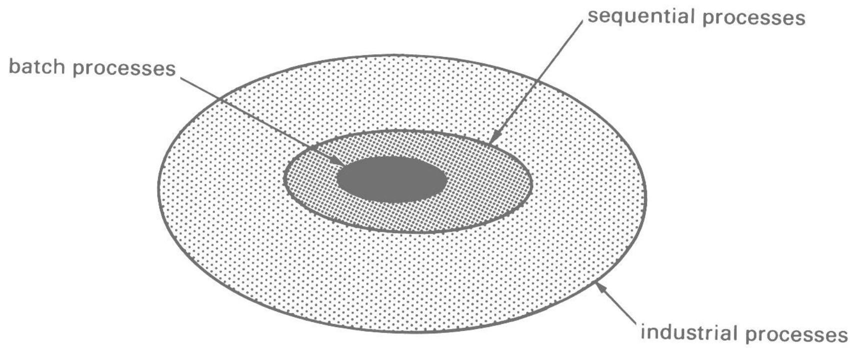

Figure 1-3. Among all processes some are considered sequential, and some of the sequential processes are truly batch processes.

process does not deliver its product continuously, but in batches, whereas a continuous process delivers its product almost continuously. The test of a process lies in the procedure for doubling the amount of product: A batch process must produce twice as many batches of a given size; a continuous process simply must be run twice as long. A batch process is largely sequential, though it may use continuous control functions during certain periods of manufacture. Although continuous processes might need some sequential control, especially during start-up and shutdown, its products are generally manufactured continuously during normal operations. Processes that include batch and continuous operations are discussed later.

So far, we have used the terms "batch process" and "sequential process" rather loosely. They might appear synonymous, but they are distinct: All batch processes are largely sequential, but the converse is not always true. For example, the manufacture of polyvinyl chloride (PVC) or corn syrup, which are batch processes, consists primarily of sequential operations. But the start-up of a steam turbine or the regeneration of the catalyst in a refinery's catalytic cracker unit, though sequential in operation, can hardly be called batch processes. The reason is that neither produces any product in batches. Thus, batch processes are those that manufacture products in batches and are subsets of sequential processes (Fig. 1-3).

CONTROLLING PROCESSES

Controlling batch and sequential processes is quite different from controlling continuous processes. The essential requirement for controlling a continuous process during normal operation is the ability to control to desired set points (within limits) in spite of process and load disturbances. For example, when controlling the crude-oil temperature at the furnace outlet of an oil refinery distillation unit (Fig. 1-4), a controller measures the outlet temperature, compares it with that of a preset value, and generates an output signal. This output signal is