Control Loop Foundation

Batch and Continuous Processes

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1 Introduction

This book originally started as a special class for new engineers within one of Emerson Process Management's engineering divisions, but has since grown in both scope and depth of material that is addressed. There are many aspects of process control systems, and the book is structured to allow engineers, managers, technicians, and others that are new to process control to get up to speed more quickly on process control and related areas. Experienced control engineers will benefit from the application examples and workshops on process control design and implementation of multi-loop control strategies.

The material is presented in a manner that is independent of the control system manufacturer.

The background material included in the first part of the book will be helpful to a new engineer who is just starting in this field and perhaps has never worked in a plant environment. Much of the material presented on the practical aspects of control system design and process applications is typically not included in process control taught at the university level.

Many of the topics that are addressed in the book are areas that the authors have learned through hands-on experience gained while working in the design and commissioning of process control systems. Also, we have benefited from the insight of many people working in process control. This is a good way to learn, but it's maybe not always the best or most efficient way to become proficient in these areas. Our goal, then, is to address concepts and terminology that an engineer needs when working in the process industry. We hope that this information will provide helpful insight as you look at a specific control system and how it's used, and how best to use this equipment while addressing the different application

requirements. Whether you are working as a process control engineer in a manufacturing plant, working in a controls group in an engineering department, or working in an instrumentation department within a manufacturing plant, we hope the information provided here will help you in your work and will set a solid foundation that allows you to confidently address new control applications in the future.

A lot has changed in the process industry over the last 30 some-odd years since we first started work as process control engineers. When we first started working with process control systems, as an engineer you often had an opportunity to see the whole project—working with the plant, developing the controls strategy, documentation, and user interface, and then commissioning the system. In some cases, this involved modifying the control system software and hardware required to support the control strategy. This opportunity existed because at that time, the control groups were often small and were focused on supporting plant operations. In some cases, you'd be given a plane ticket, travel to the plant site, discuss the application's requirements, come back to the office to develop the process control strategy and user interface, and then return to the plant to commission the control system. The ultimate measure of success was whether the plant was happy with the system's performance and with the benefits realized as a result of improved plant efficiency or throughput. As an engineer, you also had the personal satisfaction of providing the operators with better tools to manage and improve plant performance.

Today, many control system design organizations are much bigger; thus, it is possible for a person working on some aspects of a control system not to be involved in operator training or the commissioning of the control system. This is unfortunate since in that case you don't have an opportunity to see the full picture of how things fit together or to get direct and immediate feedback on how well a new or updated control system performed and whether it was necessary to make changes in the field to meet plant operators' or management's operational requirements. So, the application examples in each chapter are designed to help you gain an appreciation for all aspects of the design, implementation, and commissioning of a control system.

The book's background material is organized so that new concepts build on material presented in previous sections. As you read the book, we suggest you cover the material in the order it is presented. If you have worked with control systems in the past, then the first part of the book may cover material you already know. Even so, it would be a good idea to at least review those chapters. Many of the terms introduced in the first portion of the book are defined to establish a basis for understanding, which will be required to appreciate and apply the material on control system design

and implementation presented in later sections of the book. Also, this background material is intended to promote an appreciation for the way in which many of the terms and concepts that form the foundation of industrial process control have evolved over time and through the efforts of many people involved in control system design and implementation. An understanding of these terms and why they have been traditionally described in a certain way can be helpful when considering the best way to meet the requirements of a new process. Also, with this understanding, it should become clear that the control system can and should be designed independent of the equipment manufacturer and the technology used.

We also take the approach that you may not have worked in a process plant environment and that you may be unfamiliar with the field devices that the control system interfaces with, how these devices work, and the limitations of these devices. Thus, the background material in the first part of the book covers concepts and terminology that you'll find helpful in working with these field devices. For example, some chapters are dedicated to an overview of wiring and the field devices that are typically used in industry. The field devices (measuring devices and actuators) selected to instrument a process can impact control system performance, including the accuracy and speed with which changes in the process can be sensed and corrected. In addition, the wiring of the control system varies depending on whether a field device uses analog or digital technology.

Throughout the book, we show examples of drawings and other documents that are typical of what is used in industry to support control system design and maintenance. If you are involved in control system design, then it will be necessary for you to create documents that outline the basic control requirements and detail the measurement, calculation, and control strategy that will be used to address these requirements. Within the process industry, the engineering firm that initially designs a plant or the engineering department of a company that commissions new plant construction establishes the standards for control system documentation. In nearly all cases, the basic types of documents used in the process industry are fairly well standardized, even though there may be some variation at the detail level. Process examples are included to illustrate how these documents are used during the design and maintenance of the control system. An understanding of control system documentation is helpful when you are talking to someone about process control since such discussions often involve pulling out and reviewing some of these documents. Thus, it is important to understand why these documents are created, what information each document should communicate, and how to understand the symbols and terminology used in these documents.

Having established a background on field devices and control system documentation, we then address techniques that may be used to describe the dynamic behavior of a process. In the chapter on process characterization, we introduce terminology to describe both the static and dynamic responses of a process. This material sets a foundation for the remaining chapters on control design. How process behavior impacts control system design and commissioning will become clear as we address control system design.

At various points in the chapters on process characterization and control system design, you will have an opportunity to apply these concepts by using example workshops. These workshops are provided on a website and thus may be accessed without special tools or special software. The only thing that is required is access to a high-speed Internet connection and the web browser installed on your personal computer. In the Appendix, we provide detailed directions on how to access the website that supports these workshops. A video that shows the workshop solution is contained on the website. In addition, after some chapters there are questions that you may want to review and answer to judge how well you understand and remember the material. These questions are structured to be fun as well as informative. As you consider the appropriate answer to a question, feel free to go back through the chapter if you are uncertain of the answer. The objective of these study questions is to reinforce the learning process.

In looking at control system design, it is important to keep in mind the plant's requirements and how the control system will be used in the plant. For example, what are the production and quality objectives that must be met? If you don't have a clear picture of the goals to be achieved, it will be difficult to choose the measurement and control techniques that should be employed in the control system design. As part of the material presented on control system design, we'll review the primary function performed by a control system, and then present each of the control techniques that are most often used in industry today.

In general, the world of process control is broken into batch and continuous control. In a batch environment, where control is more sequence- or logic-oriented, the manufacturing steps are described by a procedure called a "recipe." A batch process is characterized by a constantly changing environment in which the controls and measurements must function over a wide range of operating conditions. A continuous control environment differs in that the objective is to maintain the process at the set of operating conditions needed to sustain a target production rate and quality level. In this book, we focus on the continuous control techniques that are the foundation of both batch and continuous applications. An over-

view is provided on the terminology used to describe batch procedures; thus, for more information on the structure of a batch recipe, the user is referred to the relevant standards, which are unique to the batch industry.

After covering the techniques that are traditionally used in industry, we then provide a brief introduction to advanced control. The material on advanced control techniques is designed to show how these tools may be used to better address the control requirements of interactive processes or processes characterized by difficult dynamics. A good understanding of traditional continuous control is needed to be able to evaluate whether these advanced control techniques are necessary to meet your control requirements. If you find this material on advanced control of interest, then there are a number of other references that address advanced control techniques in more detail.

A dynamic process simulation is built into the example workshops mentioned above, in order to give you an opportunity to obtain realistic "hands-on" experience with the control techniques presented in this book. The authors have found that during the pre-commissioning checkout of a control system, it is often helpful to create a dynamic process simulation that interacts with the control system. A process simulation environment that works with the control system may also be used to create an operator training program. When the process simulation is tied into the control system, the control operation and process response will approach those encountered in actual plant operation. A chapter is dedicated to the techniques that may be used to create a process simulation using the same tools that are commonly available within most process control systems.

Throughout the book, as control techniques are introduced, how each technique may be applied to address various process control requirements is illustrated using simple process examples. The last chapter of the book contains additional, more complex examples that illustrate how these basic techniques may be combined to meet a variety of control requirements. If you have read the preceding chapters and worked through the associated workshops, then you will have the foundation required to understand these more advanced process examples. As you study these examples, it should become clear that these more complex control techniques are made up of various combinations of the basic control techniques that we covered in previous chapters. It is our hope that the understanding you achieve by reading the book and going through the workshop exercises will set a foundation that will serve you well in addressing other control applications you may encounter.

In developing the book, the authors were careful to show how process control ties into the operator interface. Operators must be able to monitor

the process and respond to changes in plant conditions. A significant part of the operator interface is directly tied to the control strategy. Through the operator interface, operators start and stop batch procedures, change setpoints, change production rates, start up and shut down equipment, and perform a wide range of other actions. The alarm system is often carefully designed to focus operator attention on the highest priority items first. As part of the design process, displays are carefully organized to show information related to a specific piece of equipment, a particular process, or some sequence of operations. Although the overall design of operator displays is beyond the scope of this book, enough information is provided to give you a good understanding of the working relationship between the control strategy and the operator graphic displays.

The reader should feel free to contact the authors at their email addresses if they have questions about the book or about the use of the web-based workshops. All royalties from this book will be given directly to universities and education programs to promote and enhance the understanding of process control. A beneficiary of each year's royalties will be chosen by the authors.