

# Process Control Design

PART

# VI

In this final part, we complete the coverage of control engineering by addressing the design of process control systems. Design is perhaps the most challenging, yet enjoyable, subject in control engineering, because it enables us to use all of our analysis methods learned in the previous parts of the book. In fact, the entire point of the analysis methods is to enable us to design, and ultimately to build, equipment that functions according to requirements prescribed at the outset of the design procedure.

Before introducing some of the main concepts and methods in this part, the term *design* needs to be discussed. There have been many attempts to provide a general definition of the term, but no single definition has achieved wide acceptance. Here, we will simply describe the design function relevant to process control, without any claim to generality.

*Design* is the procedure by which an engineer arrives at a complete control system specification that satisfies all performance objectives.

It is important to recognize that the performance specifications are determined by the engineer at the first stage of the design procedure based on physics, chemistry, and the marketplace, which defines production rate, product quality, and economics. The initial objectives are specified independently of the solutions possible.

The result of the design is a complete specification that satisfies the objectives, if possible.

Five important features of design that distinguish it from previous topics are now discussed. The first major feature of design that was not as prominent in previous material is the rich definition of the objectives or performance that the design is to satisfy. Thus, design involves considerable interaction between the objective statement and design results. The objective is usually stated to be the reduction of variability in the operation of a process plant. However, not all variability can be eliminated, and variability is much more important in some variables than in others. In fact, the plant is designed to provide specific variables and systems that can be easily adjusted with minimum effect on plant performance. For example, the cooling water, steam, electricity, and fuel systems are designed to be able to respond rapidly to demands in the plant. Thus, process control generally *moves variability* from important variables to less important variables. This is achieved by controlling the (important) controlled variables by adjusting the (less important) manipulated variables. Therefore, the control design must conform to the priority of variables indicated in the objective statement.

The second major feature of design is the large number of decisions that can be considered. For the purposes of this book, the following categories of design decisions are covered: (1) measurements and sensors, (2) final elements, (3) process design, (4) control structure, (5) control algorithms and tuning, and (6) performance monitoring. As has been seen many times in previous chapters, the process dynamics have a major effect on control performance. Thus, process design changes would be the preferred manner for achieving good control. When a plant is being designed initially, the engineers can make essentially any design changes, although equipment design changes to achieve good dynamic performance may be prohibitively expensive when compared to the alternative of additional instrumentation and control algorithms. Major process equipment options require a thorough safety, reliability, and cost analysis of the alternatives, which is beyond the scope of an introductory process control book but should be included in a plant design project. Therefore, only "minor" process design changes are considered here; examples of minor changes are sizing inventory to attenuate variation and adding bypasses to add degrees of freedom and improve feedback dynamics. Typically, these are possible during initial design and as modifications to existing plants.

The third feature of design is the sequence in which the decisions can be considered. In previous chapters, relatively straightforward analysis methods were presented for, among other topics, controller tuning, cascade design, and multi-loop pairing. Each procedure could be represented in a flowchart or table, with a fixed sequence of steps without iteration. This is not the case for control design, where iterations are frequently required. The order is an especially important issue, because the initial decisions will place limitations on future decisions, and the limitations may not be easily predicted when the initial decisions are made. Thus, the engineer must be ready to rethink previous decisions and be willing to *iterate* by changing some decisions and repeating the design.

The fourth feature is the ambiguity in determining the conclusion of the design procedure. One would have to evaluate most or all possible designs to be sure that the final design is the best. To respond quickly to market demands and limit total cost, the time for design is limited, and judgment must be used in deciding when the design is good enough. The typical procedure is to develop approximate bounds

on the achievable performance and find a low-cost design that approaches the best performance.

Also, situations arise in which the initial objectives lead to unacceptable designs that are very costly and unreliable; in such cases, it is the engineer's task to alter the objective statement to meet the initial intent (e.g., make high-quality product safely), thereby preventing an unsatisfactory design. In fact, very restrictive objectives may not be achievable in the situation defined. For example, for a specified disturbance in the feed composition and flow rate and available sensors, it may not be possible to control the product quality of a chemical reactor within very narrow bounds. Clearly, a major change in the process design or performance specification is required.

The fifth feature of process control design is the concurrent application of process engineering and automatic control technologies. Automatic control principles may indicate that the feedback dynamics of a chemical reactor should be faster; then the chemical engineering principles can be used to select a process change (e.g., increasing the temperature or relocating the sensor). This tight coupling of process and control is the main reason why chemical engineers must learn control and why a "control specialist," without understanding of the process, cannot adequately perform the control design tasks.

The previous material in this book has prepared us well for the design task by providing an understanding of fundamental principles. For example, we can determine the relationship between the flow rate and the dynamic response of a process, and we can determine the manner in which the process dynamics affects feedback control system stability and performance. In addition to basic understanding, analysis provides methods for establishing quantitative relationships between adjustable factors (e.g., parameters and structures in control systems) and the behavior of the system. Thus, analysis directly provides methods for selecting cascade control or an inferential variable. The key point is that the fundamental analysis methods provide the *foundation for design* and thus are employed throughout these chapters.

It must be said at this point that control design—in fact all engineering design—is very challenging and requires considerable practice to master. Topics covered in previous chapters, such as single-loop controller stability analysis and tuning or feedforward controller design, can be learned quickly because they involve a relatively straightforward analysis. As the previous discussion indicates, the design engineer has to master and apply all technologies concurrently. Adding to the challenge is the lack of a single, structured procedure for control design. This is to be expected, because design involves an element of creativity in adding process or control equipment, altering objectives, and specifying control structures. As the reader has already experienced, procedures for stimulating creativity cannot be reduced to a flowchart. However, much can be presented and learned about the design procedure. Certainly, general procedures can be applied to the tasks of collecting information, defining objectives, and evaluating common checklists of potential decisions and outcomes. Also, typical sequences for considering control design decisions can be explained, although the best sequence is problem-dependent. Finally, examples demonstrating the interplay between process and control technology help the new engineer learn how to design. The chapters in Part VI provide guidance on performing the design procedure, by addressing its major features and supplying worked examples.