All of the book reviews in this issue are devoted to proportional-integral-derivative (PID) control, which is the focus of this issue’s special section. We bring you reviews of four books. The book by O’Dwyer provides encyclopedic coverage of PID tuning rules developed over the past half-century. Next, the book by Silva, Datta, and Bhattacharyya focuses on PID control of delay systems of the type considered by Ziegler and Nichols. The third review discusses an edited volume of papers covering a broad range of topics. Finally, the recent book by Åström and Hägglund, which is effectively the third edition of their classic work on PID controllers, is reviewed.

As the associate editor for book reviews, I am continually looking for new books to review. If you are the author of a recently published or soon-to-be-released book relating to any aspect of systems and control, please contact me.

My goal is to make this department as inclusive as possible, covering everything from monographs and textbooks to popular books. I encourage suggestions for books to be reviewed as well as volunteers to review books.

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Handbook of PI and PID Controller Tuning Rules

BY AIDAN O’DWYER

The first controllers with proportional, integral, and derivative (PID) feedback control action became commercially available during the 1930s. The 1940s saw widespread acceptance in industry of pneumatic PID controllers, and their electronic counterparts entered the market in the 1950s. Digital hardware has been routinely used since the 1980s with significant impact on process control. Even several decades after three-mode controllers were introduced, the vast majority of controllers used in the chemical process industry are based on PI/PID models [1]. The popularity of these controllers has led to research on tuning methods, resulting in hundreds of publications on this topic [2]-[9]. Ziegler-Nichols tuning relations [10] and Cohen-Coon tuning rules [12] are among the earliest published methods. Tuning relations based on error criteria [7], as well as more recent model-based tuning rules such as internal model control (IMC) [12] and direct synthesis [13], offer improvements over earlier tuning methods. Tuning rules also exist for unstable processes [14] as well as for tuning in the presence of plant-model mismatch [15].

Despite the numerous approaches available for controller tuning, surveys indicate that poorly tuned control loops are abundant in industry [16]. In fact, some control loops are not properly tuned when they are implemented, while other loops are not updated sufficiently often [16]. This situation is motivation for O’Dwyer’s book, which provides a comprehensive summary of PI and PID controller tuning relations published over the last six decades. Special attention is given to the use of a consistent notation for these tuning methods.

CONTENTS OF THE BOOK

Handbook of PI and PID Controller Tuning Rules is structured into five chapters and two appendices. Chapter 1 provides a general introduction to the topic, while Chapter 2 presents background material needed for using the controller tuning tables presented in Chapters 3 and 4. The book concludes in Chapter 5 with a discussion of performance and robustness issues. A more detailed description of the contents of the book is given below.

Chapter 2 presents PI and PID controller structures that appear in the literature as well as in process control equipment. A list of process models with time delay provides the foundation for defining the tuning rules in the remainder of the book.

The controller tuning rules for PI and PID controllers are presented in Chapters 3 and 4, respectively. Before a controller can be tuned, it is necessary to specify the structure of the controller as well as the form of the model used to represent the dynamic response of the controlled variables. Once this information is determined, the reader can compute tuning parameters using the formulas presented in Chapters 3 and 4. These chapters contain a total of 112 tables.

Analytical calculations are provided in Chapter 5 for gain and phase margins of PI/PID controllers when the process model consists of a first-order plus time-delay transfer function. These calculations are graphically illustrated for several tuning methods and varying ratios of the time delay to the plant time constant. The results from this chapter are taken from work of the author [17], [18].

CONTRIBUTION OF THE TEXT

The summary of controller tuning methods and the reference list are comprehensive. The core information of the book is mostly provided in table form. Unfortunately, little background material is presented on the ideas behind the controller tuning methods; instead, the reader is referred to the relevant references. Overall, the emphasis is on summarizing methods, with little information given on the advantages and disadvantages of different techniques.
While the book provides the most comprehensive summary of PID controller tuning rules to date, the value of many of these tuning relations is questionable. Although tuning rules that provide the best performance often vary from case to case, modern rules such as IMC and direct synthesis tend to provide better results than traditional techniques such as Ziegler Nichols or Cohen-Coon tuning. While these and many other tuning rules are presented in the book, no clear guidelines are provided on which tuning rules to try first. In all likelihood, a reader who has sufficient experience to make this decision is probably already familiar with the principal methods.

As far as the audience is concerned, the book is more suited as a reference text for practitioners than as a textbook for a course or for self-study. To use the book, a reader must know the structure of the controllers to be tuned as well as which tuning algorithm is most suitable. Since the book does not provide a discussion of which controller tuning methods should be used for which types of problems, and due to a lack of examples in the text, it will be difficult for an inexperienced reader to decide which tuning rule to apply. Compared to textbooks on controller tuning and design, for example, [1]–[9], this book provides limited background information on the ideas underlying individual tuning rules. However, the book provides by far the most comprehensive collection of controller tuning rules available in the literature, and as such provides a valuable record of the development of this important subject. The active area of PID research is indebted to the author's immense efforts in summarizing the past six decades of research and development.

Juergen Hahn

REVIEWER INFORMATION

Juergen Hahn received his diploma degree in engineering from RWTH Aachen, Germany, in 1997 and his M.S. and Ph.D. degrees in chemical engineering from the University of Texas, Austin, in 1998 and 2002, respectively. He was a postdoctoral researcher in chemical engineering at the Institute for Process Systems Engineering at RWTH Aachen, Germany. He joined the Department of Chemical Engineering at Texas A&M University, College Station, as an assistant professor in 2003. He has been the recipient of a Fulbright Scholarship and the RWTH Aachen Springorum Medal. He was selected as the 2004 Referee of the Year by the Journal of Process Control. His research interests include process modeling, process analysis, systems biology, and nonlinear model reduction.

REFERENCES

addressing robustness considerations and adaptive tuning of PID coefficients. Many results are obtained by traditional analysis or are empirical in nature and arrived at by computer simulations. The book by Åström and Hägglund [3] summarizes many studies up to that time. The readers can find many results in this issue of IEEE Control Systems Magazine devoted to PID control.

Those who have followed the area closely will notice that the authors of PID Controllers for Time-Delay Systems have taken a path quite different from other researchers. In particular, the authors have concentrated on characterizing the complete set of PID controls that stabilize a system. This approach gives the old topic a rather modern flavor. The significance of this line of research is obvious. One need only think of the role that the Youla parameterization of all stabilizing controllers plays in robust control theory [4]. Indeed, a reasonably tractable expression of this set opens up many new possibilities. For example, one can improve the robustness and fragility (defined as the tendency for the closed-loop system to be destabilized by small perturbations in the control parameters) of PID control and mathematically optimize performance indices to improve the performance of the system.

As is well known, the parameterization and optimization of controllers with fixed structure (such as PID control and static output feedback control) presents a difficult mathematical problem. The authors of the book and other researchers have made impressive progress in PID control in this regard.

**GENERAL COMMENTS**

This book is a systematic presentation of many important aspects of the authors’ work on PID control with emphasis on time-delay systems. The book describes the set of PID controllers that stabilize the system and explains how to use this set to design PID controllers that achieve robustness, nonfragility, and improved performance. Systems without delay, treated in the earlier book [5], are also summarized. This summary serves as an introduction to a more involved analysis for time-delay systems. First-order systems with delay are covered thoroughly using Pontryagin’s theorem, and the resulting stabilizing set of controllers is described in surprisingly simple form. Uncertain systems in the form of Kharitonov-like theorems and higher order systems are also studied using additional techniques.

As applications of the theory, the book evaluates existing PID tuning rules from the point of view of robustness and fragility. The book also presents several algorithms that optimize robustness and nonfragility, while optimizing performance criteria.

The book is of interest to practicing engineers, graduate students, and researchers working in the systems and control area. The authors do an excellent job presenting the materials systematically, striking a balance between mathematical rigor and accessibility to average readers. The book contains numerous diagrams and many illustrative examples to enhance its readability. The background needed to understand the book is rather modest. Average practicing engineers and graduate students with preparation from basic control classes should be able to understand the material. The following is a more detailed description of the contents.

**CONTENTS**

The first chapter introduces the basic concept of PID control, including the motivations, identification of system parameters, common tuning methods, and integrator windup.

 Chapters 2–4 concentrate on PID control of systems without delay. This portion of the book is a nice summary of the previous book [5]. Chapter 2 introduces the Hermite-Biehler interlacing theorem and its generalization to polynomials, which is the main tool for analyzing stability in the next two chapters. Chapter 3 characterizes the set of all stabilizing proportional and proportional-derivative (PD) controllers. Chapter 4 extends the results of Chapter 3 to PID control. The last section of Chapter 4 considers discrete-time systems.

 Chapter 5 provides background for time-delay systems. After a brief introduction, this chapter shows how time delay occurs and how quasipolynomials appear in the characteristic equation of the systems. The chapter then discusses the Padé approximation and its limitations. Next, Pontryagin’s theorem, which generalizes the Hermite-Biehler theorem to quasipolynomials, is presented. At the end of the chapter, the authors introduce an alternative approach to analyzing the stability of time-delay systems proposed by Walton and Marshall.

 The next three chapters are devoted to characterizing the complete set of stabilizing controllers for a first-order system with a delay. Chapter 6 considers proportional control, Chapter 7 considers PD control, and Chapter 8 considers PID control. The progressive structure gives the reader a chance to become familiar with methods of analysis for simpler cases before being confronted with the full complexity of PID control.

 Chapter 9 covers PID controller design for various systems. First, delay-free interval systems are considered using analysis along the line of Kharitonov’s theorem. The next topic considered is first-order systems with time delay in which the delay lies within a known interval. Then, the issue of nonfragility is considered, and an algorithm is described to find PID parameters with a ball of maximum radius completely contained in the set of stabilizing PID controllers. Finally, several examples are given to illustrate the design of PID control to satisfy time-domain performance specifications.

 Chapter 10 evaluates several existing PID tuning rules from the robustness and fragility point of view. The range of system parameters is given for each tuning rule such that the system remains stable when the PID parameters deviate from the nominal value within the given range.

 Chapter 11 describes PID design for systems of arbitrary order with time delay using the generalized Nyquist criterion. The last chapter presents useful algorithms for PID control based on the theory discussed in previous chapters as well as work by the authors and other researchers.
CONCLUSIONS
This book, written by some of the main contributors to the subject, covers an important new perspective on PID control. The book is of interest to practicing engineers, graduate students, and researchers working in the systems and control area. The materials are understandable to average readers with a basic knowledge of systems and control. The book is very well written and can be used for self-study and as a reference.

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REFERENCES

PID Control: New Identification and Design Methods

BY MICHAEL A. JOHNSON AND MOHAMMAD H. MORADI

Despite significant strides in the development of advanced control schemes over the past two decades, the classical proportion-integral-derivative (PID) controller and its variants remain the controllers of choice in many industrial applications. While the computational capability of modern-day control implementation environments continues to increase, PID controllers remain an engineer’s preferred choice because of their structural simplicity, reliability, and the favorable ratio between performance and cost. Beyond these benefits, PID control offers simplified dynamic modeling, lower user-skill requirements, and minimal development effort, which are issues of substantial importance to engineering practice [3].

PID Control: New Identification and Design Methods explores the continuing fascination with PID control. As noted by the editors in the preface, the book was conceived as a set of chapters on new ideas being investigated, with a more appropriate title being “some new identification and design methods.” The goal is not to provide comprehensive coverage of all new developments in the field but rather to highlight some promising novel directions.

The text is an edited volume containing 13 contributed chapters from 18 authors. The authors’ intended use of the book is as a textbook for advanced courses, a reference and self-study guide for academic researchers and practitioners, a source for new ideas, and a channel for enabling contact among PID control researchers. Each chapter is consistently structured with a description of learning objectives, presentation of background material, theoretical development, demonstrations through case studies involving simulated or experimental examples, and individual references for each chapter.

CONTENTS OF THE BOOK
Following a presentation of background material, the book is devoted to describing methods that involve increasing amounts of model information and sophistication. The main categories are:

- model-free methods, which do not rely on explicit identification of significant model information
- nonparametric model methods, which involve identifying model points of a nonparametric model, such as a frequency response
- data-intensive methods, which lie in between nonparametric and parametric approaches; these methods include subspace methods, which depend on significant process data, as well as fuzzy logic methods
- parametric model methods, where the starting point is a known transfer function model.

Chapters 1 and 2 provide background material on PID control that is meant to serve as a foundation for the ensuing chapters. Chapter 1, authored by M.A. Johnson, introduces the basic technology of PID control. Implementation aspects of PID control, such as bumpless forms that minimize derivative kick, are described. The chapter also includes descriptions of selected commercial implementations of PID control. Since very little of this information is presented in standard texts, I deem this presentation as particularly useful. Chapter 2, coauthored by M.A. Johnson and M.H. Moradi, focuses on PID control...
control fundamentals. The content of this chapter is more in line with what one would find in a typical academic textbook, with topics spanning from dynamic modeling to multivariable PID forms. Overall, Chapters 1 and 2 present solid reference material on PID control basics and fundamentals, constituting one of the strongest sections of the book.

Chapter 3, coauthored by J. Crowe and M.A. Johnson, discusses online model-free methods, with emphasis on the iterative feedback tuning (IFT) method attributed to [2]. Such methods rely on the process to directly generate gradient information needed for optimization, without requiring any explicit model computations. A controller parameter-cycling tuning method attributed to the first author, which performs the gradient and Hessian generation more efficiently than IFT, is presented and evaluated in the second half of the chapter.

Chapters 4 and 5 focus on nonparametric methods for PID tuning through the concept of relay feedback, a well-known technique that experimentally locates critical points in the frequency response that can then be used for controller tuning. Chapter 4, written by K.K. Tan, T.H. Lee, and R. Ferdous, describes the fundamentals of relay feedback. The material in this chapter is similar to what can be found in a text such as [1]. Besides controller tuning, the use of relay methods for controller performance assessment is illustrated. The chapter also includes a presentation of an experimental example. Chapter 5, by M.H. Moradi and M.R. Katebi, discusses the use of relay feedback for multivariable systems. Various schemes for relay-feedback experiments that can be applied to multivariable systems are described by the authors, with a presentation of corresponding algorithms for controller design. The methods in Chapter 5 are applied to academic examples involving the 2 × 2 Wood-Berry distillation column model and a 3 × 3 hypothetical linear system. In contrast to Chapter 4, neither experimental results nor more demanding examples are presented on this topic.

Chapters 6 and 7, both coauthored by J. Crowe and M.A. Johnson, focus on phase-locked loop methods. Phase-locked loops are feedback loops that lock on to a frequency associated with a phase or gain specification. These techniques have an advantage over relay feedback methods in that they can be applied under conditions of significant load disturbances and noise, circumstances in which the standard relay approach fails to provide satisfactory results. However, the time required for these techniques to reach the desired frequency point is usually longer. A thorough comparison to relay approaches is provided in these chapters. Chapter 6 describes the basic underlying theory, while Chapter 7 focuses on the algorithms and associated technology involved with implementing the methods for PID autotuning.

Chapter 8, by H.-P. Huang and J.-C. Jeng, focuses on identifying simple models meaningful for PID control based on step and relay tests on the plant. The process reaction curve method and graphical means for obtaining model parameters for first- and second-order models with deadtime are discussed, as well as means for obtaining these models from relay feedback. Chapter 8 is the only chapter in the text that describes the use of the internal model control (IMC) design procedure obtaining PID tuning rules from simple models. The chapter concludes with an assessment of optimal PI/PID control performance contrasting integral absolute error (IAE) norm criteria and rise time.

Chapter 9, by K.S. Tang, G.R. Chen, K.F. Man, and S. Kwong, describes fuzzy logic and genetic algorithms for PID tuning. The authors’ motivation for these approaches is the premise that, in problems with large delays, parameter variations, and nonlinearities, conventional PID controllers often fail. This chapter is one of the few chapters that address the use of PID control in a nonlinear environment. An example problem involving a simple nonlinear plant model is examined. It would have been helpful to show a comparison to some well-established technique for designing nonlinear PID controllers, for instance, gain scheduling [1], to justify the effort involved in implementing a fuzzy/genetic algorithm approach. The chapter concludes by referring the reader to a series of industrial applications of fuzzy PID control.

Chapter 10, by A. Sanchez, M.R. Katebi, and M.A. Johnson, focuses on subspace methods for restricted-complexity controller design from closed-loop data. Since subspace methods can be used to obtain models for multivariable systems without requiring much a priori knowledge of the system structure, these methods have significant appeal. A series of case studies involving simulation of an activated sludge wastewater treatment plant are presented. To my disappointment, the identification data used to generate the modeling results is never shown. Given the importance of data quality in identification problems, particularly under closed-loop conditions, I would have preferred a discussion regarding the information content required for success of the algorithm in lieu of the emphasis on parameter estimation.

Chapters 11–13, comprising the final section of the book, focus on parametric design methods that assume that a transfer function model is available at the onset of the design procedure. Chapter 11, by Q.C. Wang, Yong Zhang, and Yu Zhang, focuses on the design of PID controllers for multivariable systems. Both fully decentralized PID controllers and PID controllers with decoupler designs are presented, with the latter problem posing challenges for systems possessing nonminimum phase behavior. Chapter 12 deals with restricted-complexity-structure optimal control. This chapter is authored by P. Martin, M.J. Grumble, D. Greenwood, and M.A. Johnson. The idea here is to design controllers that minimize an LQG objective but conform to the PID structure. Both single-loop and multivariable algorithms are discussed.

The final chapter, Chapter 13, coauthored by M.H. Moradi, M.A. Johnson, and M.R. Katebi, addresses the topic of predictive PID controllers. In this chapter, the goal is to establish links between PID control design and predictive control methods through two classes of methods. The first half of the chapter is devoted to Smith-predictorlike approaches in which prediction of delayed effects is incorporated into the feedback loop to create an enhanced PID-like control structure. The
second approach is to design a bank of PID controllers whose manipulated variable responses are matched by an approximation problem to those of a generalized predictive controller (GPC). In all of these multivariable approaches, the design procedures are fairly elaborate, and considering how widespread predictive control has become (with some vendors now offering implementations on process-connected devices where PID control was previously the only option), it seems that there is a diminishing practical incentive for exploring these types of problems. Nonetheless, it is useful for the control community to be aware of these techniques and to recognize that there exist circumstances under which PID-like controllers can mimic the performance of more sophisticated predictive control algorithms.

**EVALUATION AND CONCLUSIONS**

As an edited text with a large number of individual contributors, it is somewhat of a challenge to make broad statements regarding the effectiveness of this book. In general, the book is well organized and provides a wealth of new information. At first glance, it does not come across as a highly pedantic text. While it is not intended to be a stand-alone reference for “all things that are PID control,” I do believe that the book serves a useful role in informing the control community of the variety of methods and approaches for PID controller tuning that are currently available. Individuals and research groups that devote significant attention to PID design topics should seriously consider adding this text to their reference collection.

Shortcomings of the book come at various levels. Despite the plethora and diversity of methods that are presented, the bulk of these methods are geared toward circumstances in which the magnitude of noise and disturbances experienced by the plant during controller tuning is low. I would have preferred to see greater focus on identification and PID design methods that address process conditions involving significant load disturbances and noise, situations that are often found in industrial practice. Alternatively, some of the methods that are presented, such as the restricted complexity subspace identification approach in Chapter 10, could have been made stronger by using simulations or case studies to illustrate how these methods work under demanding experimental conditions.

The biggest shortcoming of the text is that very little mention is made of available software or computing resources that can be accessed to implement the techniques presented in the various chapters. While dedicated sections describing algorithms are included throughout the book, these sections limit the usefulness of the text as a reference and study guide. Considering the large number of simulated examples and the obvious use of MATLAB to generate solutions in these cases, it is a pity that the corresponding .m and .mdl files are not made available to the readers. A great number of the methods, particularly those presented in the final chapters, are quite complex, and even a basic implementation for evaluation purposes would entail significant effort.

Also disappointing was the lack of solid references on several subjects. For example, the discussion of antiwindup techniques, an important practical consideration in PID control implementation, is rather superficial. Even though PID tuning relying on IMC is the basis for the methods presented in Chapter 8, none of the primary references for this work are cited in the chapter. I also found throughout the text a problem that I usually call to the attention of my undergraduate students when documenting and presenting control results; in the case studies for many chapters, only the controlled variable response is presented, while both manipulated and controlled variable responses should be included to fully assess a control system’s performance.

One also sees a fair amount of repetition of background material between the chapters, which could have been reduced by better coordination among the authors. Similarly, the book could have benefited from a textwide analysis of benchmark problems whose solution would then be consistently illustrated among the various chapters. Such an approach would have provided readers with a systematic basis for evaluating the benefits and drawbacks of the various methods presented. Despite these shortcomings, the book represents a welcome addition to the control field and should be considered by any serious researcher in the field of PID control.

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I wish to acknowledge helpful discussions with Prof. Sebastián Dormido of the National Distance Learning University (UNED) of Spain, who hosted the reviewer while the evaluation of this book was taking place.

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**REVIEWER INFORMATION**

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**REFERENCES**


Advanced PID Control

BY KARL J. ÅSTRÖM AND TORE HÄGGLUND

Proportional-integral-derivative (PID) control is by far the most widely used form of feedback control. Despite the extraordinary progress that has taken place in control theory over the last 20 years, industrial engineers tend to view much of control theory as esoteric and of little relevance to industrial problems. In the mid-1980s, the authors of this text, Åström and Hägglund, turned their attention to the PID controller. At that time, the treatment of PID in most textbooks was given only a few pages and was restricted to an idealized version of its operation. In the academic community, there existed the belief that PID control was a research area with little opportunity. It is fair to say that the authors’ work changed this situation. Today, many introductory textbooks include at least one chapter related to PID control, and there is no doubt that PID control is an active area of research.

In the early 1980s, the tuning formulas proposed by Ziegler and Nichols 40 years earlier represented the state-of-the-art in industrial PID control. Modern attempts at developing automatic PID tuning were model based, with the exception of Foxboro’s EXACT controller. Introduced in 1984, this controller was based on heuristic logic developed using computer simulation studies [2].

The relay-tuning method proposed by Åström and Hägglund in 1984 [3] had its roots in the classical method of Ziegler and Nichols. That relay-tuning method calculates the controller’s PID parameters using knowledge of only one point on the open-loop Nyquist curve. The point of intersection of the Nyquist curve with the negative real axis is determined by increasing the gain of a proportional controller until a sustained oscillation of constant amplitude is obtained. A disadvantage of this method is the fact that the user cannot control the amplitude of the resulting oscillation. The ingenious idea of Åström and Hägglund was the realization that this point can be determined by replacing the proportional controller with a relay. The relay induces a limit cycle when the loop is closed, with the great advantage that the amplitude of the limit cycle can be set by the amplitude of the relay characteristic. This technique, which was patented by Åström and Hägglund, is incorporated in many commercial PID controllers.

Advanced PID Control is the most recent of a trilogy of PID books written by Åström and Hägglund over the past 20 years. The previous books are Automatic Tuning of PID Controllers [4] and PID Controllers: Theory, Design, and Tuning [5]. To understand the contribution of the most recent book, it is helpful to reexamine the first two texts.

The goal of [4] was to introduce autotuning and adaptation to control practitioners. Autotuning is the capability to automatically adjust the controller parameters on demand from an operator or an external signal. Adaptation is the continuous adjustment of the parameters to enhance performance. At the time when [4] was published, several commercial products with these capabilities were beginning to appear on the market. Automatic Tuning of PID Controllers discusses many useful ideas employed by control practitioners but which are rarely mentioned in standard control texts.

The scope of their second book [5] is considerably larger. This book provides a self-contained, well-thought-out, and accessible introduction to a wide range of topics and fundamental principles underlying PID control. The main goal was to provide the technical background for understanding PID control in a comprehensive fashion. This goal was achieved with a level of mathematics that is accessible to control practitioners.

Based on its table of contents, Advanced PID Control follows more or less the same structure as its predecessor. However, there are major differences. Traditionally, PID tuning and design have been based on ad hoc techniques that take advantage of the special structure of the PID controller. Consequently, PID control has not followed the control mainstream, where robust control theory has provided design methods based on loop shaping. Advanced PID Control seeks to remedy this situation by applying these ideas to PID control.

CONTENTS OF THE BOOK
Chapter 1 provides a brief introduction to the core concepts used throughout the book and an outline of the text’s contents. Chapter 2 introduces basic approaches for analyzing the behavior of feedback-controlled processes. Time and frequency representations are introduced as a prerequisite to understanding the dynamics of closed-loop systems. The objective is to derive simple models that describe the process sufficiently well in the frequency range that is critical to successful control. Two dimensionless parameters, namely, the normalized time delay and the gain ratio, are introduced to quantify the difficulty of controlling a process.

A comprehensive study of the PID algorithm is provided in Chapter 3. Taking as a starting point the textbook form of PID, several modifications are discussed that result in a more practical controller. Implementation issues that must be considered in practice are then introduced, including derivative filtering, antiwindup mechanisms, and the changing of set-point values. The chapter thoroughly examines these issues. Alternative PID structures, such as standard noninteracting, interacting, and parallel structures, as well as conversion from one form to another, are treated. The chapter ends by considering the questions of when PID control is usable and when more sophisticated control is advisable.

Chapter 4 discusses controller design in general. A clear overview of the basic design principles is provided. The design objectives are expressed as requirements on load...
disturbance response, measurement noise response, setpoint response, and robustness. From a practical point of view, an interesting result for two degree-of-freedom controllers is that one can design for robustness and disturbance response independently. This chapter also emphasizes one of the most important objectives of this book, namely, to demonstrate that PID control design can be treated using ideas from mainstream controller design.

Chapter 5 focuses on feedforward design, which is an effective strategy for reducing the effect of measurable disturbances. The ideal feedforward strategy is to use a close approximation to the inverse process model. The chapter presents several alternatives to this approach. The use of a two-degree-of-freedom controller structure separates the design problems of load disturbance response and setpoint response.

Chapter 6 treats special cases of the general PID design problem presented in Chapter 4. Since the complexity of the controller is restricted, two alternatives emerge: 1) simplify the process models in such a way that the design method yields a PID controller or 2) design the controller using a complex model and approximate it with a PID controller. This chapter seeks to find a balance between an historical overview and the presentation of new methods. A critical review is given of several methods, including Ziegler-Nichols, rule-based empirical tuning, pole placement, lambda tuning, algebraic design, and optimization methods. Strengths, weaknesses, and limitations of each method are summarized. All of these methods share the common property that robustness to process variations must be examined after the design is complete. This philosophy is not in agreement with the main thrust of recent control theory, where robustness of the completed design is guaranteed a priori. The authors present a novel tuning method called MIGO (M, constrained integral gain optimization), which can be considered as a translation of robust design principles to PID design. MIGO seeks to maximize the integral gain (and thereby minimize the integrated error) such that loop-gain frequency response lies outside the classical $M_c$-circle.

Chapter 7 develops simple tuning rules in the same spirit as Ziegler and Nichols. The goal is to obtain rules that can be employed for both manual tuning and automatic tuning for a wide range of processes. These tuning rules, dubbed AMIGO (approximate MIGO), were developed by applying MIGO to a large batch of representative processes and correlating the PID resulting parameters to simple features of the process dynamics. The authors identify key differences between processes that are delay dominated and those that are lag dominated.

The performance of a PI controller can be improved if predictive capability is included. Possibilities other than derivative action may offer improved performance. In this regard, Chapter 8 examines useful alternatives to dealing with time delays. Various model-predictive controllers are treated, including the Dahlin-Higham controller and the minimum variance controller. The treatment of the Smith predictor provides a new perspective on this technique. Since the classical robustness metrics, namely, gain margin and phase margin, may not capture the robustness issues associated with a Smith predictor controller, a new robustness metric—the delay margin—is introduced in this chapter.

Chapter 9 discusses techniques for adaptation and automatic tuning of PID controllers. Automatic tuning of PID controllers can be realized by joining the methods for obtaining process dynamics presented in Chapter 2 with the methods for calculating the PID parameters given in Chapters 6 and 7. The authors present several adaptive approaches, including gain scheduling, automatic tuning, and continuous adaptation. The chapter ends with a description of commercial controllers in which adaptive methods have been successfully employed.

Before tuning the controller, it is important to conduct a loop assessment of the system, including an examination of sensors and actuators, signal ranges, nonlinearities, noise levels, and disturbances. Chapter 10 provides an overview of methods for commissioning, supervising, and diagnosing control loops. The goal is to supervise the performance of the system during operation so as to guarantee that specifications are met.

Up to this point, the book has focused on control of a single PID loop. Chapter 11 is devoted to the relevant issue of interacting PID loops. Of particular importance, it is shown that controller parameters in one loop can act as a significant load disturbance to the dynamics of other loops. Basic measures of interaction are presented, such as Bristol’s relative gain array, so as to determine whether the control problem can be solved using simple loops. The problem of pairing inputs and outputs as well as a design method based on decoupling are presented in this chapter.

Chapter 12 shows how complex control systems can be built from simple components such as PID controllers, linear filters, gain schedules, and simple nonlinear functions. Various control paradigms are presented, including repetitive control, cascade control, midrange and split-range control, ratio control, and control with selectors. Neural and fuzzy techniques in the context of PID control are also discussed to indicate how they can be interpreted both as rule-based control and as nonlinear control.

Finally, Chapter 13 provides the reader with a discussion of some implementation issues related to PID control. The authors follow the historical development starting with pneumatic and electronic implementation of analog controllers. A detailed presentation of computer implementation issues, such as sampling, prefiltering, and discretization of the PID algorithm, is then provided. Operational aspects and human-machine interfaces, such as bumpless transfer at mode switches and parameter changes, are also presented.

**INTENDED AUDIENCE**

*Advanced PID Control* is addressed to a broad audience, ranging from control practitioners to academic researchers. As a result, the book has several differing objectives. The treatment in the book, however, is well balanced and accessible.
It is clear that the authors have taken great care in the text’s presentation to make it accessible to a broad readership. I foresee this text being used in several ways:

- As a text for independent study by control practitioners. The book provides an accessible introduction to the fundamental principles underlying PID control as well as a wide range of related topics.
- As one of several texts in an introductory automatic control course at the graduate level.
- As part of a training for individuals in industry. I have used [5] in this fashion with great success.
- As a general reference. The text is quite comprehensive and would be an invaluable source for researchers and practitioners.

**SUMMARY**

Åström and Hägglund’s book is a remarkably clear, accessible, and up-to-date text. Several other books have appeared in the last few years on this subject, although with a more limited scope [6]–[15]. While the present book has some overlap with these texts in terms of its coverage, *Advanced PID Control* stands on its own as a complete work. The text provides a rigorous yet accessible introduction with a unique perspective. The strength of the book is its systematic approach to structuring the PID control problem along the lines of the major developments in control theory over the past two decades. This book is a welcome addition to the existing literature on PID control and will certainly become a standard reference.

**Sebastián Dormido**

**REVIEWER INFORMATION**

Sebastián Dormido graduated from the Universidad Complutense of Madrid in 1968 and received the Ph.D. degree in control engineering from the Universidad del Pais Vasco in 1971. From 1968–1975, he was with the Department of Computer Science and Automatic Control of the Universidad Complutense and Universidad del Pais Vasco. From 1975–1982, he was with the Facultad de Ciencias Físicas of the Universidad Complutense de Madrid, and, in 1982, he joined the Facultad de Ciencias of the Universidad Nacional de Educación a Distancia (UNED). In 1982, he became head of the Department of Computer Science and Automatic Control. His research interests include process control, predictive control, robust control, object-oriented languages for modeling and simulation of hybrid systems, and control education with special emphasis on remote and virtual labs. He has supervised 25 doctoral theses and coauthored more than 180 conference and journal papers. Since 2002, he has served as president of the Spanish Association of Automatic Control (CEA), where he has promoted the relationship between academia and industry.

**REFERENCES**