Introduction

Reader's guide

In this book, we present a method of teaching the theory of the control of linear continuous systems. This method consists of introducing some basic definitions, and then presenting the theory related to these systems in the form of solved problems while appealing to computer tools for the more difficult problems. This method has another advantage, in that students will be more involved in the educational process and will have to play an active and dynamic role that will be beneficial to their training.

The objective of this book is to provide the reader with problems and their solutions in order to aid them to acquire and deeply understand the fundamental notions related to the foundations of the control of linear continuous systems, and to help them to be able to implement control systems. Many problems can be solved using available software such as MATLAB. We have rejected this solution. The computer has become an essential tool, but we see very dangerous drift. In fact, students have blind confidence in this tool. They tend to lose their spirit of criticism and analysis. As teachers, we have to review our pedagogy. In other words, the primary purpose of this book is to help the reader to acquire a deep knowledge of the theoretical tools related to the control of linear continuous systems. For example, learning how to sketch a root locus is very important in order, among other things, to check the results of a simulation, and drawing a Bode diagram manually gives us an understanding of how the location of poles and zeros affects the shape of this diagram. This does not prevent the reader from using computer tools in order to obtain, for example, a more precise drawing of the root locus or a rapid study of the stability of the system. We recall the main definitions and theoretical tools at the beginning of each chapter.

The first chapter is dedicated to process modeling. It presents some modeling techniques for chemical, electrical and mechanical systems. A set of accurate models is presented. Taking into account developments in computer technology, phenomenological models can be used in order to support decisions that need to be taken online.

The reader should observe that, for a given process, many phenomenological models can be developed. They depend on the assumptions made about its behavior and the desired objective, i.e., for what purposes the model will be used. In a sense, the model designer can be considered as a photographer who get obtain, for the same subject, different photos with different zooms. The main objective of Chapter 1 is to help the reader to understand and to develop phenomenological models, or at least to be able to understand the main lines related to the kinds of models developed by engineers involved in the areas concerned (electrical, chemical, mechanical, etc.). The treatment presented in this chapter is not intended as a complete description of modeling techniques but merely as a basic introduction to the subject. This introduction may help automatic-control engineers to communicate easily with engineers involved in other areas.

The main core of Chapter 2 deals with the use of Laplace transforms for solving various kinds of problems. In particular, the derivation of transfer functions, as well as block diagrams and their simplifications, is considered. Laplace transforms significantly support the modeling of systems by providing simple rules for manipulating a set of interconnected systems. Of paramount concern in linear control theory is the transfer function, which leads to block diagrams. Block diagrams agglomerate all the available information concerning a given process. We end the chapter by presenting a general method for calculating the coefficients of the partial fraction expansion of a rational function.

Chapter 3 is devoted to the transient and frequency analysis of linear systems. Many examples are treated in order to illustrate such an analysis. We present a set of approaches to the statement of the frequency response of a given system. As a large class of systems can be modeled by a first – or second-order – system, we present a set of identification techniques based on the impulse and step responses of these systems, and simple ideas for distinguishing a high-pass filter from a low-pass filter. The chapter also presents an analysis of some commonly used filters (band-pass, notch, etc.). Chapter 4 is dedicated to stability and precision analysis. Stability is one of the most important challenges in the design of control systems. Before one optimizes the behavior of, for example, a chemical reactor where an exothermic reaction takes place, it is necessary to study its stability. Algebraic and graphical stability criteria are presented. A method based on integral phase evaluation is presented. This method allows one to check the stability of feedback systems without visual inspection of the Nyquist diagram. Examples illustrating precision and stability analysis are described. A set of examples should help the reader to draw easily the root locus of any system.

The primary purpose of Chapter 5 is to introduce a number of PID tuning techniques. We focus our attention mainly on the ideas behind the development of these tuning techniques. It is impossible to make an analytical comparison of the available PID tuning techniques because they are based on different model approximations, different control objectives and, sometimes, different PID parameterizations. Taking into account the control objective and the process model, the reader has to select the tuning method which yields the best control performance. In a thermal power plant, it may happen that a turbine is damaged, and it is necessary to heat the turbine at specific points to straighten it. These specific points, as well as the energy to be used for heating the turbine, depend on the know-how of the technician who carries out this job. This know-how cannot be found in books on heat transfer and materials. This job can be compared to the job of a PID designer (open-loop shaping by manipulating the gain, zeros and poles) who has to select the PID settings in order to modify the diagram (Bode, Nyquist or Nichols) of the uncompensated system such that the diagram (frequency-response curve) of the compensated system will correspond to the desired diagram (a curve which meets the control specifications). We can also compare the job of a PID designer to the operation done by an ophthalmic surgeon in order to correct the curvature of the eyes of a person with myopia using a laser. Several problems dealing with the design of transfer functions from specifications related to the desired dynamics of the controlled system are presented in detail. The chapter ends with a brief introduction to the integrator wind-up problem, and to the two main useful representations of non-linear systems, namely the Wiener and Hammerstein structures. These structures are very interesting in the sense that if they are connected to the inverse of the static non-linear part, any control strategy designed for linear systems can be implemented.

In each chapter, we recall the necessary mathematical tools in a very simplified and didactic manner. As signal processing and automatic control use the same tools, we study some commonly used filters.

The book ends with an Appendix which presents some mathematical and practical developments related to the impulse function (or Dirac delta function) and its relation to the residence time and the unit step, as well as some proofs concerning stability. We present proofs of the Nyquist and Routh–Hurwitz criteria, and a proof related to the asymptotes of the root locus. We present a rigorous statement of the formulae giving the intersection of the asymptotes of the root locus with the real axis. Some of these results are difficult to find in books dedicated to the control of continuous linear systems. These results are very important in the sense that:

1) for a given plant, stability is the main objective to be achieved, before optimizing its behaviour;

2) the proofs constitute good exercises in themselves.

Recent chemical disasters remind us, unfortunately, that stability is very important. For example, it is absolutely necessary to stabilize a chemical reactor where an exothermic reaction occurs, before optimizing its yield. The Appendix also deals with the quas-ilinearization of non-linear systems such as relays. This method is used to find the limit cycle (crossover frequency) and some other points of the frequency responses of systems, which are useful in some PID tuning methods.

In summary, the objective of this book is to provide the reader with a sound understanding of the foundations of the modelling and control of linear continuous systems. In other words, this book should provide the reader with depth and breadth of knowledge in this field. It contains more than 150 solved problems. This book is written in such a manner that students should be able to extend their knowledge to address new problems that they have not seen before. From a mathematical point of view, this book is self-contained. The book also can serve as a tool for students to test their knowledge.

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