Stability and stabilization of infinite dimensional systems with applications

Zheng-Hua Luo, Bao-Zhu Guo, Omer Morgul, Springer, London, 1999, ISBN: 1-85233-124-0

Spurred by the outer space applications, such as flexible link manipulators and antennas, a flurry of research activities have been focused on the control of flexible structures. A reasonable decay rate of vibration is essential for proper functioning of such structures. While finite-dimensional approximations (such as assumed mode method or finite element method) of such systems can lead to some valuable insight, they may lead to substantial errors such as “spill-over”. Therefore, an infinite dimensional analysis is essential for a complete understanding of the nature of such problems.

In this book, Luo, Guo and Morgul gave a systematic presentation of the mathematical machinery needed to analyze the stability of infinite-dimensional (or distributed parameter) systems, with special emphasis on flexible mechanical structures. The “with application” part of the title is well justified since they devoted a substantial portion of the book analyzing many specific structures, mostly spatially one-dimensional systems under various collocated feedback control schemes. The contents reflect the recent research achievements of the authors. Most results are accompanied by rigorous proofs, and many proofs are original. The book is well organized. Many examples included illustrate the concepts well. There are a few minor mistakes, grammatical errors, and misuse of words, which, however, do not prevent the reader from understanding the contents, and they are more than balanced by the clear and carefully structured presentations. For anyone (researchers and graduate students in applied mathematics, as well as those in control engineering with some background knowledge on functional analysis) interested in infinite-dimensional systems and its applications, this book should serve as a good introduction and valuable reference. I will give a detailed review of each chapter in the following.

Chapter 1 is a general introduction to the topic. It first points out some subtleties of stability problems of infinite-dimensional systems. Concepts which are equivalent for linear finite-dimensional case, such as left half plane eigenvalues and exponential stability, are no longer equivalent for infinite-dimensional case. Then four practical systems (heat equation, population equation, and equations of motion for strings and rotating beams) are presented as examples of infinite-dimensional system. The rest of the chapter gives a nice overview of the book.

The next two chapters present the theoretical framework, although a few more theoretical results are presented in later chapters as needed. Chapter 2 gives a systematic presentation of semigroup theory on Banach space. It is mainly focused on strongly continuous semigroups (C_0-semigroups), and the corresponding infinitesimal generators. It also discusses differentiable, analytic, compact, and integrated semigroups and abstract Cauchy problem. Nonlinear semigroups of contraction is also presented. Consistent with the central theme of the book, a substantial portion is devoted to various semigroups of contractions and dissipative operators. Most of the materials in this chapter are classical results, except for the n-times integrated semigroups, which was proposed only recently, and is accorded substantial treatment here.

Chapter 3 is the central theoretical part of the book. It discusses the stability analysis of systems described by C_0-semigroups. It begins with two examples substantiating the subtleties of the stability problems in infinite-dimensional systems mentioned in Chapter 1. Then it presents Spectral Mapping Theorem relating the spectrum of C_0-semigroups and the corresponding generators. A number of classes of systems satisfying the spectrum-determined growth condition (the growth rate equals spectral bound) is identified. To tackle the more general cases, the relationships between weak stability and asymptotic stability are discussed, and necessary and sufficient conditions in terms of the spectrum of infinitesimal generators are presented. Essential spectrum, which is responsible for the violation of spectrum-determined growth condition, is investigated. The invariance principle for nonlinear semigroup is the last topic of the chapter.

The last three chapters analyze practical systems using the theory developed in the previous two chapters. Chapter 4 is a long chapter with close to 100 pages. It studies the dynamic model and static sensor feedback control of rotating beams and translating beams using Euler–Bernoulli model, with the implicit assumption that either the (angular) acceleration or the (angular) velocity may be directly commanded. First the equations of motion of the rotating beams are derived using Hamilton's Principle, and put in the form of abstract Cauchy problem, and the properties of the corresponding operator is characterized. It is first illustrated that exponential stability can never be achieved using linear velocity feedback since the infinitesimal generator is a compact perturbation of one generating unitary C_0-group. Then it is shown that the strain feedback for rotating beams and shear force feedback for translating beams can stabilize the system based on A-dependent and contraction semigroup argument. The problem is re-analyzed using energy multiplier method to show that stability is actually exponential. Exponential stability of the shear force feedback control for rotating beam is investigated using more sophisticated technique. The hybrid system consisting of ordinary and partial differential equations, describing the additional goal of maneuvering the beam to the designated position, as well as the nonlinear problem arising from adaptive control, are also investigated. The effect of damping is considered in a separate section.

Chapter 5 discusses the passivity approach of stability analysis. This framework is intended to design dynamic feedback control. After general characterization of infinite-dimensional passivity, it is shown that wave equation, Euler–Bernoulli and Timoshenko models of the rotating beam are passive with appropriate inputs and outputs. Then the single-input–single-output version of finite-dimensional positive real transfer functions are characterized, and stability of passive systems with strictly positive real feedback control is established, which is an extension of the well-known finite-dimensional version. The last part of the chapter is devoted to proving that a sufficiently small time-delay will not destabilize such systems if appropriate damping is present. The energy multiplier method is used.

Chapter 6 is devoted to hyperbolic systems. For a rather general class of such systems involving first order partial derivatives with respect to time and one dimensional space, it was proved to satisfy the spectrum-determined growth condition. Serially connected vibrating string with point stabilizers and vibrating cable with tip mass, as well as spatially one-dimensional thermoelastic systems are analyzed. Finally, a spatially two-dimensional hyperbolic system with low order perturbation is shown to violate the spectrum-determined growth condition (Renardy's counterexample).

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