# Preface

This text presents a unified treatment of vibrations and control. Both of these topics fit under the broad title of mechanical systems, hence the main title of the book. I have taught a one-semester course dealing with both of these topics for several years. I have used two excellent books, but the notation is not consistent between the two, and asking students to buy two books is an imposition. This book provides one book with one notation for both topics.

One thing my teaching experience has taught me is that one semester is not enough, and I have included enough material for a 1-year course. Chapters 1–5 cover the topics in a standard vibrations course with some added material on electric motors and vibration measurement. Chapter 6 introduces state space and forms a bridge from the first half of the book to the second. If one were to use the book only for vibrations or only for controls, I would suggest including Chap. 6 in either course. Chapters 7–10 cover linear controls starting with PID control and moving quickly to state space control, where I address controllability, observability, and tracking. Chapter 11 introduces feedback linearization as an easily understandable venture in nonlinear control. I have taken advantage of the fact that kinematic chains with only revolute joints can be controlled using a variant of feedback linearization to introduce nonlinear control of simple robots with only revolute joints. This chapter is a bonus, not necessary for a first course in controls, but there for those who find it useful.

The text is aimed at juniors and seniors in mechanical and related engineering programs, such as applied mechanics, aeronautical engineering, and biomedical engineering, but I hope that it will be useful to working engineers as well. I expect the students to have had exposure to ordinary differential equations, linear algebra, and an elementary course in engineering dynamics. I use free body diagrams early in the text and expect that idea to be familiar to them. I use Euler-Lagrange methods from Chap. 3 onwards. These methods are introduced assuming no previous familiarity with them.

I have found that students don't much like abstract mathematics, so I have tried hard to include examples with a real-world flavor. Some of these examples (a servomotor, suspension of a steel ball by an electromagnet, and the overhead crane) appear early in the text and then reappear to illustrate the new material introduced in each chapter. I have also tried to refresh student memories and/or include basic material they may not have seen. In particular, I spend some time in Chap. 1, which provides an overview of the whole text, on complex notation and the connection between the complex exponential and trigonometric functions. As I work through the first few chapters, I use trigonometric functions and the complex exponential interchangeably to get students used to the connection. The complex exponential is essential once the book moves to state space.

Chapter 2 covers one degree of freedom problems using free body diagrams to develop the equations of motion. I also introduce the concepts of kinetic and potential energy here. Chapter 3 deals with systems with more than one degree of freedom. It includes a careful discussion of degrees of freedom and introduces the whole Euler-Lagrange process for deriving equations of motion. I also introduce a simple DC motor model in Chap. 3 so that I can use voltage as an input for the rest of the text instead of just saying "Here's a force" or "Here's a torque." Chapter 4 covers modal analysis. Chapter 5 discusses vibration measurement, and Fourier analysis, Fourier series, and Fourier transforms, primarily as tools for vibration analysis. I discuss the Gibbs phenomenon and Nyquist phenomena, including aliasing. I prove no theorems.

Most of the world cannot be well modeled by linear systems, so I have included the simulation of nonlinear systems using commercial packages for the integrations. Linearization is a skill that is not generally taught formally. It is very important, even in the age of computers, and I attack it twice, once in Chap. 3 and again in Chap. 6, more formally. The control designs in the text, except for Chap. 11, are all linear, based on choosing gains to drive errors to zero, but I assess their efficacy using numerical simulation of the nonlinear equations.

I cover control in the frequency domain in Chap. 7, introducing the Laplace transform (without theory) and transfer functions. I go through the classical PID control of a second-order (one degree of freedom) system and apply the idea of integral control to automotive cruise control.

I think that control in state space is much more useful. I introduce state space in Chap. 6 and state space control in the time domain in Chap. 8. The rest of the text is cast in state space and in the time domain. Chapter 8 includes the controllability theorem (the algebraic theorem without proof), the reduction of a controllable dynamical system to companion form, the placement of poles by choosing gains in the companion form, and the mapping of the gains back to the original space. Chapter 8 is limited to using full state feedback driving a dynamical system to a (vector) zero. I deal with both linear and nonlinear systems. I design controls for nonlinear systems by linearizing and applying a state space control algorithm, but then I test the controls by solving the full nonlinear systems numerically.

Chapter 9 introduces observers. I go through the examples in Chap. 8 using an observer. I also note that the observer doubles the size of the system and that one needs to take account of that in assessing the control that one designs. In particular, I note that the original system and the observed system may be independently stable, but that does not necessarily extend to the combined system, which can actually be unstable.

Chapter 10 explains how to track a time-dependent reference state, both assuming full state feedback and using an observer. Again I use linear control on nonlinear systems and verify the controls using numerical integration.

The basic control paradigm, executed in state space, is to linearize the system (if necessary), design a linear control, and then assess the linear control on the nonlinear system in simulation.

Chapter 11 addresses nonlinear control by feedback linearization. This is applicable to some simple robots, and I discuss three-dimensional motion briefly in order to deal with realistic robots.

Rochester, NY, USA Roger F. Gans

Springer

http://www.springer.com/978-3-319-08370-4

Mechanical Systems
A Unified Approach to Vibrations and Controls
Gans, R.F.
2015, XVI, 437 p. 62 illus., 38 illus. in color., Hardcover
ISBN: 978-3-319-08370-4