

Preface

The subject of dynamics originated from Sir Isaac Newton's monograph *Philosophiæ Naturalis Principia Mathematica*, and Lord Rayleigh paved the way for its further development with his *Theory of Sound*. These provided the basis for the unique position of the field of dynamics in mechanics. Since then, many scientists and engineers have applied and furthered this knowledge in various fields of applied science and technology.

With the enormous investment made in civil, mechanical, and aerospace engineering during the twentieth century, designs were pushed to the limits of their performance capacity, with the trend being toward high-speed operations, adverse environment capability, light weight, etc. With the requirement of functionality in an unpredictable, highly uncertain environment, practitioner engineers encountered more and more problems with regard to dynamics. Pure mathematics is sometimes satisfied with showing that the non-existence of a solution implies a logical contradiction, while engineers might consider numerical results the desirable goal. Although dynamics as a scientific topic is by no means fully understood (and perhaps never will be), the great amount of activity in this field during the last century has made it possible to form a practical subject in a fairly systematic, coherent, and quantitative manner. All these factors have pushed applied dynamics into a greater complexity than it has ever had before, and also promoted the subject into one of the essential tools in current engineering.

Thanks to the rapid development of computer technology, more portable and accurate testing equipment and techniques, as well as a few breakthroughs in computation algorithms, during the last 50 years applied dynamics has found efficient and unique ways of developing. This raised a vast amount of challenges in implementing designs in reality, while also putting ever higher demands on engineers, requiring a thorough understanding of the subject. In spite of increased engineering knowledge, the practical problems regarding dynamics and vibrations are in some cases handled without success despite large expenditures of money. Moreover, even if engineers can perform sophisticated computer-based dynamic analysis tasks, many of them lack an actual understanding of the essential principles of dynamics, and hence of the links between theory and application. This leads to an insurmountable barrier when they are requested to validate/verify and provide insightful explanations of analysis results, or to further improve the engineering designs with regard to vibrations, which poses a significant safety

hazard and can also result in significant economic loss. These considerations motivated the author to write this book.

With the objective of providing up-to-date knowledge of dynamic analysis, which is of great importance from the point of view of engineering, in the preparation of the book, the author tried to link the general principles of dynamics with their applications from various angles in order to make it possible for readers from various backgrounds to appreciate their significance. The book aims to be as elegant as is possible given this wide-ranging treatment of the subject.

The book is intended to serve as an introduction to the subject and also as a reference book with advanced topics. A balance between the theoretical and practical aspects is sought. All the chapters are addressed to practitioner engineers who are looking for answers to their daily engineering problems, and to students and researchers who are looking for links between theoretical and practical aspects, and between phenomena and analytical explanations. It should also be of use to other science and engineering professionals and students with an interest in general dynamic analysis.

The book is written in such a way that it can be followed by anyone with a basic knowledge of structural analysis. The mathematical background assumed for reading this book is a working knowledge of differential equations, matrix manipulation, and an elementary knowledge of statistics/probability. In addition, readers are also assumed to have basic knowledge on the strength of materials.

The book covers topics on the concepts, principles, and solutions of dynamics and vibrations. These are essential for engineers and researchers to further explore any type of dynamic analysis, such as mechanical vibrations or dynamic structural responses due to environmental loads such as wave, wind, earthquake, and ice loading, etc. The core knowledge of linear and nonlinear dynamics, damping effects, random vibrations, and modal analysis is elaborated. The various solution schemes and selection criteria for a given problem are discussed. The modeling and measuring of damping are also elaborated. Special topics on seismic responses, fatigue assessment, human body vibrations, and vehicle-structure interactions are discussed. The engineering applications, relevant codes and practice, and their links with theory are also provided in relevant chapters.

The first three chapters present and discuss the phenomena, concepts, and principles of dynamic analysis with discussions on their applications.

Chapter 1 gives an introduction to dynamics in the physical world, distinguishes its essential differences from its static counterpart, and briefly summarizes general methods for treating a dynamic problem. **Chapter 2** elaborates the basic formulation of governing equations of motions, which include the formulation of and relationships among Newton's second law of motions, Hamilton's principle, and Lagrange's equation, the three pillars of classical dynamics. This chapter also provides preparatory work for solving both free (**Chap. 3**) and forced (**Chap. 11**) vibration problem. Between chapters on free and forced vibrations, important topics focusing on eigenfrequencies and mode shapes are examined in **Chap. 4** (for presenting eigenanalysis for discrete systems and a brief introduction on vibration-based structural health monitoring), **Chap. 5** (eigenproblem for continuous system), **Chap. 6**

(vibration under axial load), and [Chap. 7](#) (eigenproblem for nonuniform beams and foundations).

Note that explicit and concise equations to describe a dynamic system and its responses, like a deterministic one such as Newton's, is seldom able to reflect real-world phenomena, which are complex, noisy, high-dimensional, etc., and for which the instantaneous value cannot be explicitly predicted at any time instant or reproduced. These can be treated by statistical description and characterizing randomness (probability distribution) of loads and responses, which promoted the research and application of stochastic dynamics. Therefore, [Chaps. 8](#) and [9](#) systematically examine the deterministic and stochastic loads and responses from a statistical point of view. The essential concepts of Fourier and power spectrum as well as the relationship between a spectrum and its statistical properties are discussed. These form the pillar for stochastic dynamics, which is in parallel to and promotes a wider application of Newton's equations.

In [Chap. 10](#), concepts of short and long-term probability distribution and number of occurrence are introduced. They pave the way for a reasonable understanding of load level at a given return period and for a further extension to reliability and risk assessment. This is also a part of background knowledge for assessing fatigue damage due to dynamic loading ([Chap. 17](#)).

With the understanding of spectrum analysis and power spectrum ([Chap. 9](#)), the power spectrum densities due to specific environment loads with wind, wave, ice, and earthquake loadings are presented in [Chap. 12](#).

As [Chaps. 8](#), [9](#) and [10](#) provide a broad overview of loads and responses, they enable efficient solutions for forced vibration problems as elaborated in [Chap. 11](#). When reading [Chap. 11](#), readers need to bear in mind that if the excitations are of a deterministic nature, a direct solving of equations of motions is preferred. However, if excitations are of strong stochastic nature, a random vibration approach is more efficient.

In [Chap. 13](#), the solution to the dynamic responses is extended from a single-degrees-of-freedom to a multi-degrees-of-freedom system. In addition, the most popular numerical methods (i.e., the direct/exact method, modal superposition method, and the direct integration methods) are discussed with an emphasis on their applicabilities.

As the estimation and modeling of the damping are rather difficult tasks for both engineering and research purposes, and in the meantime the resulting uncertainties with damping pose a great challenge to reach a reasonable accuracy for the calculated dynamic responses (a phenomenon more apparent for dynamic sensitive structures), [Chap. 14](#) is therefore dedicated to an elaboration of the effects, modeling, and measuring of various types of damping.

As almost all applied processes exhibit nonlinearities in various forms and extents, it is of particular importance to study nonlinear dynamics and vibrations. Therefore, [Chap. 15](#) elaborates this topic by distinguishing them from their linear counterpart, summarizing their causes and sources, and by presenting the relevant numerical solution strategies used in engineering practice.

For dynamic analysis with any extent of difficulty for a real system or a structure, the numerical challenges generally arise from three aspects: space and time discretization and various types of nonlinearities. In the last 60 years, these have attracted extensive research efforts and become almost matured for engineering applications by finite element analysis (for space discretization), finite difference (Newmark's type) method (for time discretization), and linear iteration (Newton's type) method (for solving nonlinearities). These three methods form the cornerstones of current applied dynamic analysis. The finite element method can be studied in many available literatures, and the finite difference and linear iteration methods are elaborated in [Chaps. 11](#) and [15](#), respectively.

After digesting the first 15 chapters, readers should have the capability to find solutions of dynamic responses in their specific fields of applications. In [Chaps. 16](#) to [19](#), the essential knowledge presented in the first 15 chapters is extended to a few of their application areas, with discussions on seismic responses ([Chap. 16](#)), fatigue assessment ([Chap. 17](#)), human body vibrations ([Chap. 18](#)), and vehicle-deck dynamic interactions ([Chap. 19](#)).

While the book does not seek to promote any specific "school of thought," it inevitably reflects this author's "best practice" and "working habit." This is particularly apparent in the topics selected and level of detail devoted to each of them, their sequences, and the choices of many mathematical treatments and symbol notations, etc. The author hopes that this does not deter the readers from seeking to find their own "best practice" and dive into the vast knowledge basin of modern dynamics, which is extremely enjoyable as readers go deeper and wider.

Most of the chapters in this book can be covered in a two-day industry course in a brief manner, a one-week intensive course for either industry or university, or a two-semester course in an elaborated form for graduate students. The first four chapters together with [Chaps. 11](#), [13](#), and [14](#) can also form a one-semester undergraduate course on structural dynamics or mechanical vibrations.

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