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PEARSON Prentice Hall

Theory of Vibration with Applications
(Fifth Edition)

振动理论及应用（第5版）

William T. Thomson
Marie Dillon Dahleh

PEARSON Education
清华大学出版社

内容简介

本书是振动理论的典型教材之一，以讲述线性振动理论为主，从单自由度、多自由度到连续体，从自由振动到强迫振动（包括无阻尼和有阻尼情况），从简谐激励、冲击激励到一般激励，最后两章还介绍随机振动和非线性振动，内容丰富、叙述清晰、例题和习题与工程应用相结合，是一本在国外受到普遍赞赏的畅销教材，至今已经出到第5版。

利用计算机分析多自由度、复杂结构系统动力响应的数值分析方法已经成为解决工程振动问题必不可少的重要手段，在这方面本书为读者打下了坚实的理论基础。第5版更加强了学生利用MATLAB等软件求解工程振动问题能力的训练。

本书内容与我国多学时振动理论课程的教学要求相近，可以作为力学、汽车等专业本科生和工科专业研究生振动理论课程的外文教材或参考书，也可供有关工程设计人员和研究人员参考。

本书特色

- 是振动理论的典型教材之一，内容丰富、叙述清晰、例题和习题与工程应用结合，在国外受到普遍赞赏。
- 内容与我国多学时振动理论课程的教学要求相近。
- 包括对随机振动和非线性振动的基本理论和基本方法的精炼叙述。
- 重视多自由度和连续体系统动力响应数值分析方法的教学要求。第5版更加强了学生利用MATLAB等软件求解振动问题能力的训练。
- 每章附有大量习题，凡适合用计算机求解的习题都在编号前加字母M。

ISBN 7-302-12137-0

9 787302 121374 >

定价：49.00元

PEARSON
Prentice Hall

http://www.pearsoned.com

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清华大学出版社
北 京

图书在版编目(CIP)数据

振动理论及应用 = Theory of Vibration with Applications：第 5 版 / 汤姆逊（Thomson, W. T.），达利（Dahleh, M. D.）著. 一影印本. 一北京：清华大学出版社，2005.12
（国际著名力学图书. 影印版系列）
ISBN 7-302-12137-0

Ⅰ. 振…　Ⅱ. ①汤…　②达…　Ⅲ. 振动理论一高等学校一教材一英文　Ⅳ. O32

中国版本图书馆 CIP 数据核字（2005）第 136638 号

出 版 者：清华大学出版社　　**地　址**：北京清华大学学研大厦
http://www.tup.com.cn　　**邮　编**：100084
社 总 机：010-62770175　　**客户服务**：010-62776969
责任编辑：陈朝晖
印 刷 者：清华大学印刷厂
装 订 者：三河市春园印刷有限公司
发 行 者：新华书店总店北京发行所
开　本：175 × 235　**印张**：34　**插页**：1
版　次：2005 年 12 月第 1 版　2005 年 12 月第 1 次印刷
书　号：ISBN 7-302-12137-0/O · 504
印　数：1 ~ 3000
定　价：49.00 元

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Theory of Vibration with Applications (Fifth Edition)

William T. Thomson & Marie Dillon Dahleh

影 印 版 序

振动理论在机械、土木、航空航天、交通、能源等众多工程领域均有重要的应用。本书是振动理论的典型教材之一，以讲述线性振动理论为主，最后两章介绍随机振动和非线性振动。

本书叙述清晰、内容丰富、例题和习题与工程应用相结合，是一本在国外受到普遍赞赏的畅销教材，至今已经出到第 5 版。第 5 版加强了计算机解法在振动分析中的应用，训练学生利用 MATLAB 等软件求解振动问题的能力。同时完善了关于拉格朗日方程的教学内容。

全书共分 14 章、7 个附录。第 1 章“振动运动”，讲述简谐运动、周期运动的特性和参数。第 2 章“自由度振动”，讲述无阻尼和有阻尼单自由度系统的自由振动，应用能量法、瑞利法和虚功原理解题。第 3 章“简谐激励振动”，讲述简谐激励下无阻尼和有阻尼单自由度系统的强迫振动，包括转动不平衡、隔振和测振仪器等应用问题以及等效粘性阻尼、结构阻尼等重要概念。第 4 章“瞬态振动”，讲述冲击激励和一般激励下的动力响应、拉普拉斯变换、冲击响应，以及求解时程响应的有限差分法和龙格－库塔法。第 5 章“二自由度及多自由度系统”，以二自由度为重点讲述多自由度系统无阻尼和有阻尼的自由振动和强迫振动，包括弹簧－质量组合振子、汽车、双转盘轴系、双摆等实例。第 6 章“振动系统的特性”，讲述柔度和刚度矩阵概念、互易定理、本征向量的正交性、正交模态迭加、模态阻尼、强迫振动方程的解耦、无约束系统。第 7 章“拉格朗日方程”，讲述广义坐标、虚功、拉格朗日方程、动能、势能和广义力、广义质量、广义刚度和假设模态迭加。第 8 章“计算方法”，讲述与求解本征值和本征向量问题相关的计算方法知识，包括多项式求根、高斯消去法、矩阵迭代法及其收敛性、乔尔斯基分解、雅可比对角化、QR 方法等。第 9 章“连续系统的振动”，讲述弹性连续体的振动，包括弦振动、杆的轴向振动和扭转振动、悬索桥的振动、梁的振动、逐段重复的结构系统（如高层建筑）的振动。第 10 章“有限元法引论”，以梁单元为核心讲述结构动力分析的有限元方法。第 11 章“连

续系统的模态迭加法”，讲述结构动力分析中十分有用的模态迭加法（又称振型迭加法）的基本思想和基本方法。第 12 章“经典方法”，讲述分析振动问题的瑞利法、邓克莱法和传递矩阵法等经典解法。第 13 章“随机振动”，讲述随机振动分析的基本概念和基本方法，包括随机函数的期望值、频率响应函数、概率分布、相关性、功率谱密度、傅立叶变换等。第 14 章“非线性振动”，简介非线性振动理论，包括相平面、平衡稳定性、等倾法、摄动法、迭代法、自激振动、龙格－库塔法等内容。附录 A 是“振动极限的规定”；附录 B 是“拉普拉斯变换简介”；附录 C 是“行列式与矩阵”；附录 D 是“均匀梁的正交模态”；附录 E 是“MATLAB 软件简介”；附录 F 是“计算机程序”，介绍特征行列式展开、迭代法、矩阵乘、杆与梁、扭转系统本征频率、悬臂梁本征频率等计算程序；附录 G 是高阶模态的收敛性。书中凡适合用计算机求解的习题都在编号前加字母 M。

本书内容与我国多学时振动理论课程的教学要求相近，可以作为力学、汽车等专业本科生和工科专业研究生振动理论课程的外文教材或参考书，也可供有关工程设计人员和研究人员参考。

清华大学工程力学系
陆明万

PREFACE

This book is the fifth edition of the *Theory of Vibration with Applications*. For a classical subject like Vibration, an explanation for another revision is in order.

Although the subject of Vibration does not greatly change, the development of new and sophisticated digital techniques keep advancing and increasing the wide variety of problems to be solved and discussed in class.

MATLAB® is a versatile computer software program that is commercially available and adopted by many engineering schools. It is compatible with the previous computational methods of the 4th edition and we have decided to augment and broaden the computer capabilities of the 4th edition with its use in the 5th edition. To undertake this revision, our editor and I have engaged a competent co-author. Dr. Marie D. Dahleh, of our Engineering Department, to work with me on this task.

The authors recognize that problem solving is a vital part of the learning process, and the use of a versatile new computer technique will enhance the student's capabilities not only in the field of Vibration, but to other fields as well. To use MATLAB, or any other new computer method, it is not necessary to completely understand the detailed mathematics on which the software program is based. On this point, I am reminded of a timely quotation by Oliver Heavyside, a famous British mathematician and engineer of the early 20th century, who was being criticized for his innovative mathematics. His response to them was; "Should I refuse my dinner because I do not understand the process of my digestion?"

As in earlier editions, the first four chapters, which deal with single-degree-of-freedom systems, need very few changes. However, wherever appropriate, MATLAB has been introduced to familiarize the reader with the MATLAB commands that will be necessary to make use of this facility. At the end of Chapter 4, where the first extensive calculations with finite difference and Runge-Kutta were made, the MATLAB method is demonstrated with parallel computations for comparison.

Systems with two or more degrees of freedom, introduced in Chapter 5, offers a logical opportunity to present the matrix notation. The Mass and the Stiffness Matrices are defined here and the digital computation in Fortran has been completely replaced by MATLAB. The importance of normal mode vibration is emphasized in this chapter and free vibrations are demonstrated to be composed of normal modes with specified initial conditions. Forced vibrations are again presented in terms of frequency ratio of forced to normal modes, and the important application of vibration absorbers and dampers is retained unchanged.

Chapter 6, "Properties of Vibrating Systems," remains essentially unchanged. Stiffness of framed structures is again presented to bring out the introductory basics of the finite element method presented later in Chapter 10. Orthogonality of eigenvectors, the modal matrix and its orthonormal form enable concise presentation of basic equations for the diagonal eigenvalue matrix that forms the basis for the computation of the eigenvalue-eigenvector problem. They also provide a background for the normal mode summation method. The chapter concludes with the modal damping and examples of equal roots and degenerate systems.

Chapter 7 presents the classic method of Lagrange, which is associated with virtual work and generalized coordinates. Included in this chapter is the method of assumed modes, which enables the determination of eigenvalues and eigenvectors of continuous systems in terms of smaller equations of discrete system equations. The Lagrangian method offers an all-encompassing view of the entire field of dynamics, a knowledge of which should be acquired by all readers interested in a serious study of dynamics.

Chapter 8, "Computational Methods," examines the basic methods of computation that are utilized by the digital computer. Most engineering and science students today acquire knowledge of computers and programming in their freshman year and, given the basic background for vibration calculation, they can generally follow computer programs for eigenvalues and eigenvectors. Covered in this chapter are the following subjects; Polynomial method, Gauss elimination, Matrix iteration, the Dynamic matrix, Standard computer form, Cholesky Decomposition, Jacobi Diogonalization, and the QR Decomposition. As stated earlier, for those who feel intimidated by the somewhat difficult mathematics may ignore these sections or even skip the entire Chapter 8 and still acquire the skills of using these newer computer programs. The former computations made by Fortran are now replaced and plotted by MATLAB.

Chapter 9, "Vibration of Continuous Systems," Rods and beams of uniformly distributed mass and stiffness represent continuous systems of infinite degrees of freedom. To analyse the vibration of such system requires the use of partial differential equation, presented in the first part of this chapter. As example of how these solutions can be adopted to more complex structures, an example of the vibration of the Tacoma Narrows suspension bridge is presented. When the continuous structure is discretized into repeated identical sections, simple analytic expressions are available for the natural frequencies and mode shapes by the use of difference equations. Here the method demonstrates the technique of matching boundary conditions.

Chapter 10, "Introduction to the Finite Element Method," remains unchanged except that the computing is done entirely by MATLAB. A few helpful hints have been injected in some places, and the section on generalized force proportional to displacement has been substantially expanded by detailed computation of rotating helicopter blades. Brought out by this example is the advantage of forming equal element sections of length $l = 1$ (all l's can be arbitrarily equated to unity inside of the mass and stiffness matrices when the elements are of equal lengths) for the compiling of the mass and stiffness matrices and converting the final results to those of the original system only after the computation is completed.

Chapters 11 and 12: These two chapters, "Mode Summation Procedures for Continuous Systems," and "Classical Methods" have been retained as in the previous edition. Being essentially computing methods, MATLAB has been advantageously used. Holzer and Myklestad methods have been placed into MATLAB files for available use.

Chapter 13. "Random Vibrations": Random vibration became of interest to the engineer with the development of jet engines for airplanes. It is a nondeterministic phenomena which require a probabilistic solution. The presentation of the subject here is mainly from the mathematical treatment to familiarize the students with the new terminology. Progress in this field is largely through instruments developed to make measurements useful to engineering design.

Chapter 14, "Nonlinear Vibrations", can be described as a behavior which cannot be solved mathematically by superposition. The understanding of its behavior is best studied by means of the phase-plane. Presented in this chapter are some terminology for nonlinear systems, its stability and limit cycle and the computer programs of Runge-Kutta used for its digital solution. A number of problems suitable for the computer are listed in the problem section and marked with a capital M.

Finally I wish to acknowledge my appreciation to my coauthor and to Dr. Igor Mezic of our Mechanical Engineering Department, who corrected and assembled the Solutions Manual for the fifth edition and added several new problems throughout the text.

William T. Thomson
Marie Dillon Dahleh

Note: To find the M files referenced in the text log on to the Prentice Hall's World Wide Web site at: http://www.prenhall.com and access the ftp files either via the down load libraries on the authors' catalog page or under the Help topic or directly at FTP://ftp.prenhall.com.

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