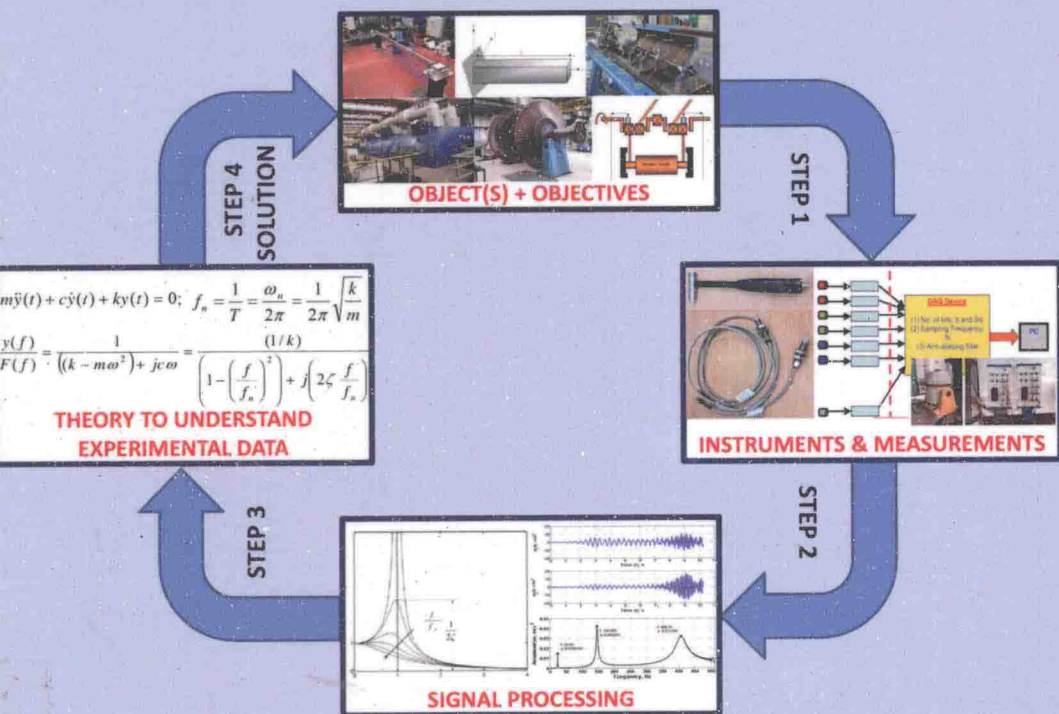


Vibration Analysis, Instruments, and Signal Processing



Jyoti Kumar Sinha



CRC Press
Taylor & Francis Group

Vibration Analysis, Instruments, and Signal Processing

Jyoti Kumar Sinha



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2015 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed on acid-free paper
Version Date: 20141110

International Standard Book Number-13: 978-1-4822-3144-1 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Sinha, Jyoti Kumar.
Vibration analysis, instruments, and signal processing / author, Jyoti Kumar Sinha.
pages cm
Includes bibliographical references and index.
ISBN 978-1-4822-3144-1 (hardback)
1. Vibration--Measurement. 2. Damping (Mechanics) I. Title.

TA355.S525 2014
620.3--dc23

2014032230

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

Preface

Over the past four decades, the technology in vibration instrumentation and measurements, signal processing, and analytical simulation using finite element (FE) methods has advanced significantly. There are several dedicated books that have recorded these advancements. However, it has been consistently observed that several persons (students, researchers, designers, and maintenance personnel in industry) involved in, say, vibration-related works or research, do not fully comprehend the interrelation between theory and experiments. These individuals can be grouped as (1) good in vibration data collection but may not be aware of the applicable basic theory, and vice versa, (2) good in signal processing but may not know the basics of either the theory or vibration data collection and measurement procedures, and (3) involved in dynamic qualifications (FE analysis and modal testing) using standard commercially available software without knowing much about the basic principles and methods. It is imperative that persons involved in vibration-based analysis have at least a basic understanding of the different processes so that they can more effectively solve vibration-related problems.

This book aims to communicate the fundamental principles of all three facets of vibration-based analysis (i.e., instruments and measurement, signal processing, and theoretical analysis) in a simplified tutorial manner, which is not readily available in literature. The unique content of this book will therefore be very useful for a diverse audience who are interested in vibration analysis. The target audience includes students (all levels), researchers, and engineers (involved in vibration-based condition monitoring). There are several chapters related to day-to-day requirements in vibration measurements and analysis so that the reader may become aware of the basics. He or she can then consult the many dedicated books in an area of interest if needed. A chapter is also added for real-life case studies relating the basic theory, types of measurements needed, and requisite signal processing that ultimately lead to effective fault diagnosis.

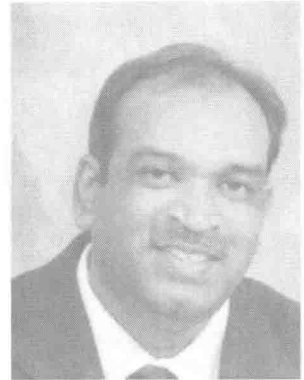
The author acknowledges his teachers and colleagues, particularly Prof. M.I. Friswell, Prof. Arthur Lees, Mr. K.K. Meher, Prof. R.I.K. Moorthy, Prof. P.M. Mujumdar, Mr. A. Rama Rao, Mr. R.K. Sinha, and Mr. B.C.B.N. Suryam. I am really thankful to Prof. R.I.K. Moorthy for his guidance at the beginning of my professional career and in research in the area of structural dynamics and vibration. I also acknowledge a number of the postgraduate students with industrial experience in the "Maintenance (Reliability) Engineering and Asset Management (MEAM/REAM)" MSc course and my diligent PhD students for their useful suggestions during the book's preparation.

Finally, I dedicate this book to my parents, Mr. Jagdish Prasad Sinha and Mrs. Chinta Sinha, my wife, Sarita Sinha, and my son, Aarambh Sinha. My parents stay miles away from me but give unconditional love to me every moment of my life. My wife and son are my real strength, with whom I share all the moments of my life.

Jyoti K. Sinha

About the Author

Dr. Jyoti K. Sinha joined the School of MACE, University of Manchester, in January 2007. He previously worked as a senior research scientist in the Bhabha Atomic Research Centre, India, for nearly 16 years. He also worked as a research fellow in Cranfield University, UK, for 18 months. He earned his bachelor's degree (Mech. Eng.) from BIT, Sindri (India), and master's degree (Aerospace Eng.) from IIT Bombay, Mumbai (India). He completed his PhD from the University of Wales Swansea (now Swansea University), UK.



His research area is in vibration and structural dynamics, using both experiments and analytical methods, including finite element (FE) model updating, vibration control, and health monitoring techniques. He is the recipient of the prestigious "Young Scientist (Boyscast) Fellowship" from the Department of Science and Technology, India, for his outstanding work in vibration diagnosis and structural dynamics related to the number of rotating machines and structural components of nuclear power plants (NPPs). Dr. Sinha has been extensively involved in a number of projects (nearly £2.5M) related to vibration and dynamics. He has also been instrumental in the development of a number of innovative techniques in his research area. He is the author of more than 60 technical reports and 135 technical papers in both international journals and conferences combined. He has delivered a number of invited lectures. Dr. Sinha is also the associate editor of two international journals, *Structural Health Monitoring: An International Journal* and *Advances in Vibration Engineering* (now *Journal of Vibration Engineering and Technology*), editorial board member of the journal *Structural Monitoring and Maintenance*, coauthor of two books, and a member of the Technical Committee on Rotor Dynamics, IFTOMM (2011 onward).

In academia, nine PhD and EngD students have completed their programs since January 2007 under Dr. Sinha's supervision in the different areas of vibration, rotordynamics, and signal processing. He has completed supervision of nearly 75 MSc dissertations, and he currently supervises a number of PhD students and MSc dissertations. Presently, Dr. Sinha is the principal investigator of different industrial projects related to steam and wind turbines in the areas of vibration-based condition monitoring, fault diagnosis, and life prediction.

Contents

Preface.....	xi
About the Author	xiii
1. Introduction	1
1.1 Introduction	1
1.2 Layout of the Chapters	2
1.2.1 Basic Theories and Analysis Methods.....	3
1.2.2 Instrumentations, Signal Processing, and Experimental Methods.....	3
1.2.3 Combined Analysis and Experimental Methods.....	4
1.2.4 Case Studies.....	4
2. Single Degree of Freedom (SDOF) System	5
2.1 A Single Degree of Freedom (SDOF) System	5
2.2 Equation of Motion	5
2.2.1 Example 2.1: SDOF System	7
2.2.2 Example 2.2: A Massless Bar with a Tip Mass.....	7
2.2.3 Example 2.3: A Massless Bar with a Disc	8
2.3 Damped SDOF System	9
2.3.1 Equation of Motion for Free Vibration.....	9
2.3.2 Critically Damped System: Case 1: Limiting Case When $DF = 0$	11
2.3.3 Overdamped System: Case 2: When $DF \geq 0$	12
2.3.4 Underdamped System: Case 3: When $DF \leq 0$	13
2.4 Forced Vibration.....	15
2.4.1 The System Vibration Behavior.....	19
2.5 Summary.....	21
3. Introduction to Finite Element Modeling.....	23
3.1 Basic Concept.....	23
3.1.1 Degree of Freedom (DOF)	23
3.1.2 Concept of Node, Element, and Meshing in the FE Model.....	24
3.1.3 Element Mass and Stiffness Matrices for a Spring	25
3.2 Modeling Procedure for Discrete Systems	29
3.2.1 Example 3.1: Three-DOF System.....	29
3.2.2 Example 3.2: Another Three-DOF System	31
3.3 Extension of FE Modeling Approach to Continuous Systems	32
3.3.1 Example 3.3: A Simple Continuous System of Steel Bar.....	32
3.3.2 Example 3.4: Beam Structure	33

3.4	Element Mass and Stiffness Matrices	34
3.5	Construction of Global Mass and Stiffness Matrices.....	37
3.6	Concept of the Formal FE Method	39
3.6.1	Element Shape Functions (ESFs).....	40
3.6.2	Generalized Mass and Stiffness Matrices	40
3.7	FE Modeling for the Beam in Example 3.4	41
3.7.1	Applying Boundary Conditions (BCs).....	42
3.7.1.1	Cantilever Condition at Node 1	42
3.7.1.2	Simply Supported (SS) Beam at Nodes 1 and 3 ...	42
3.7.1.3	Clamped–Clamped (CC) Beam at Nodes 1 and 3	43
3.8	Modal Analysis	43
3.8.1	Natural Frequencies and Mode Shape Estimation	44
3.8.2	Concept of Mode Shapes.....	46
3.9	Sensitivity of the Element Size	50
3.10	Damping Modeling	53
3.11	Summary	55
	References	55
4.	Force Response Analysis.....	57
4.1	Introduction	57
4.2	Direct Integration (DI) Method	58
4.2.1	Example 4.1: A SDOF System	59
4.2.2	Example 4.2: A Two-DOF System	61
4.2.3	Example 4.3: A Cantilever Beam	69
4.3	Mode Superposition (MS) Method	73
4.3.1	Example 4.4: A Two-DOF System	78
4.4	Excitation at the Base.....	86
4.5	Summary	89
	Reference	89
5.	Introduction to Vibration Instruments.....	91
5.1	Vibration Measurement.....	91
5.1.1	Typical Measurement Setups	92
5.1.2	Steps Involved in the Collection of Data	95
5.1.3	Instrument Calibration and Specifications	96
5.1.3.1	Specifications of Instruments/Sensors.....	97
5.2	Response Measuring Transducers.....	99
5.2.1	Sensor/Transducer Unit.....	99
5.3	Displacement Transducers.....	100
5.3.1	Proximity or Eddy Current Probe.....	101
5.3.2	Optical Sensor	102
5.4	Velocity Transducers	102
5.4.1	Seismometer	102
5.4.2	Laser Sensor	106

5.5	Acceleration Transducers.....	106
5.5.1	Technical Specifications of Accelerometer	109
5.5.2	Accelerometer Mounting	110
5.6	External Excitation Instruments	111
5.6.1	Instrumented Hammer	111
5.6.2	Portable Shaker.....	111
5.6.3	Payload Shaker	112
5.7	Data Collection and Storage	114
5.7.1	Digital Data Tape Recorder	114
5.7.2	PC-Based Data Acquisition and Storage.....	114
5.7.3	Precautions during Data Recording/Collection.....	115
5.8	Concept of Sampling Frequency, f_s	115
5.9	Aliasing Effect and the Selection of Sampling Frequency, f_s	118
5.9.1	Effect of Different Sampling Frequencies	118
5.9.2	Observations.....	121
5.10	DAQ Device Bit for ADC.....	122
5.10.1	Case 1: 2-Bit DAQ Device	123
5.10.2	Case 2: 16-Bit DAQ Device	126
5.10.3	Case 3: DAQ Card Bit, $b = 8$, FSIV = 10 V, $S_{dl} = 10/2^8 =$ 0.0391 V/bin	131
5.10.4	Summary of ADC	134
6.	Basics of Signal Processing	137
6.1	Introduction	137
6.2	Nyquist Frequency	137
6.3	Time Domain Signals	137
6.4	Filtering	139
6.4.1	Low-Pass (LP) Filter	140
6.4.2	High-Pass (HP) Filter.....	140
6.4.3	Band-Pass (BP) Filter.....	140
6.5	Quantification of Time Domain Data.....	142
6.5.1	RMS Value.....	142
6.5.2	Example 6.1: RMS Computation	143
6.5.3	Crest Factor (CF).....	144
6.5.4	Kurtosis (Ku).....	144
6.5.5	Example 6.2: Comparison between CF and Kurtosis	145
6.6	Integration of Time Domain Signals	146
6.6.1	Example 6.3: Data Integration	146
6.7	Frequency Domain Signal: Fourier Transformation (FT)	148
6.7.1	Fourier Series.....	148
6.7.2	Limitations for Experimental Data	150
6.7.3	Alternate Method.....	150
6.7.4	Computation of Fourier Transform (FT)	151
6.7.5	Example 6.4: Importance of Segment Size on FT Analysis	152

6.7.6	Leakage.....	154
6.7.7	Window Functions	157
6.8	Aliasing Effect	160
6.9	Averaging Process for the Spectrum Computation	165
6.9.1	Example 6.5: Averaged Spectrum.....	165
6.9.2	Concept of Power Spectral Density (PSD).....	166
6.9.3	Example 6.6: Comparison of the Averaged Spectra for the Signals with and without (i.e., No) Noise	168
6.9.4	Example 6.7: Averaged Spectrum for the Noisy Signal	170
6.9.5	Concept of Overlap in the Averaging Process.....	172
6.10	Short-Time Fourier Transformation (STFT).....	173
6.11	Correlation between Two Signals.....	175
6.11.1	Cross-Power Spectral Density (CSD)	175
6.11.2	Frequency Response Function (FRF)	176
6.11.3	Ordinary Coherence.....	177
6.11.4	Example 6.8: FRF and Coherence	178
6.12	Experiments on a SDOF System	180
	References	183
7.	Experimental Modal Analysis	185
7.1	Introduction	185
7.2	Experimental Procedure	185
7.2.1	Impulsive Load Input Using the Instrumented Hammer	186
7.2.2	Shaker Excitation	186
7.3	Modal Test and Data Analysis	187
7.4	Example 7.1: Peak Pick Method.....	188
7.4.1	Step 1: The Modal Testing Experiment.....	189
7.4.2	Step 2: Computation of the Amplitude Spectrum, FRF, and Coherence	189
7.4.3	Step 3: Identification of Natural Frequency from the FRF Plot.....	191
7.4.4	Step 4: Mode Shape Extraction.....	196
7.4.5	Step 5: Half-Power Point (HPP) Method for Estimation Modal Damping.....	196
7.5	Example 7.2: A Clamped–Clamped Beam.....	198
7.5.1	Step 1: The Modal Testing Experiment.....	198
7.5.2	Step 2: Computation of the Amplitude Spectra, FRFs, and Coherences	200
7.5.3	Step 3: Natural Frequency Identification from the FRF Plots.....	203
7.5.4	Step 4: Extraction of Mode Shapes	205
7.5.5	Step 5: Estimation Modal Damping	206

7.6	Industrial Examples.....	207
7.6.1	Example 7.3: Sparger Tube	209
7.6.2	Example 7.4: Shutoff Rod Guide Tube	210
7.6.3	Example 7.5: Horizontal Tank	214
7.7	Summary.....	217
	References	217
8.	Finite Element Model Updating	219
8.1	Introduction.....	219
8.2	Model Updating Methods	220
8.3	Gradient-Based Sensitivity Method	220
8.3.1	Steps Involved	221
8.3.2	Regularization.....	225
8.4	Example 8.1: A Simple Steel Bar.....	225
8.5	Example 8.2: An Aluminum Cantilever Beam	231
8.6	Summary.....	233
	References	233
9.	A Simple Concept on Vibration-Based Condition Monitoring	235
9.1	Introduction.....	235
9.2	Operational Personnel.....	236
9.2.1	Rotating Machines.....	236
9.2.2	Reciprocating Machines.....	237
9.2.3	Piping.....	237
9.2.4	Comparative Observations.....	237
9.3	Plant Maintenance Engineers	238
9.4	Vibration Experts	238
9.5	Condition Monitoring of Rotating Machines.....	238
9.5.1	Type of Vibration Transducers.....	240
9.5.2	Data Processing and Storage.....	241
9.6	Normal Operation Condition.....	242
9.6.1	Overall Vibration Amplitude	242
9.6.2	Vibration Spectrum	242
9.6.3	The Amplitude—Phase versus Time Plot	244
9.6.4	The Polar Plot	244
9.6.5	The Orbit Plot	244
9.7	Transient Operation Conditions	246
9.7.1	The 3D Waterfall Plot of Spectra.....	246
9.7.2	The Shaft Centerline Plot.....	246
9.7.3	The Orbit Plot	247
9.7.4	The Bode Plot.....	247
9.8	Instrumenting TG Sets for Condition Monitoring.....	248
9.9	Types of Faults	250

9.10	Identification of Faults	251
9.10.1	Mass Unbalance	251
9.10.2	Shaft Bow or Bend	252
9.10.3	Misalignment and Preloads	252
9.10.4	Crack	253
9.10.5	Asymmetric Shaft	254
9.10.6	Shaft Rub	256
9.10.7	Fluid-Induced Instability	257
9.10.8	Mechanical Looseness	259
9.10.9	Blade Vibration	259
9.10.10	General Comments	260
9.11	Condition Monitoring for Other Rotating Machines	261
9.11.1	Detection of Fault(s) in Antifriction Bearings	261
9.11.2	Characteristic Frequencies of a Ball Bearing	262
9.11.3	Concept of Envelope Analysis	263
9.12	Field Balancing	264
9.12.1	Single Plane Balancing—Graphical Approach	265
9.12.1.1	Example 9.1	265
9.12.1.2	Example 9.2	267
9.12.2	Single Plane Balancing—Mathematical Approach	267
9.12.3	Multiplane Balancing	272
9.13	Comments about Model-Based Fault Diagnosis (MFD)	273
	References	274
10.	Case Studies	277
10.1	Introduction	277
10.2	Roles and Philosophy of Vibration Diagnostic Techniques (VDTs)	277
10.3	Dynamic Qualification due to In-Service Load Condition	278
10.4	Seismic Qualification	280
10.4.1	Shake-Table Method	280
10.4.2	Railway Track-Induced Vibration Method	280
10.4.3	Direct Use of In Situ Modal Data	281
10.4.4	Updated FE Model Method	283
10.4.4.1	Experimental Setup and Modal Tests	283
10.4.4.2	Updated FE Model	284
10.4.4.3	The Reactor Conditions	285
10.4.4.4	Seismic Response Estimation	286
10.5	Machine Installation and Commissioning	286
10.5.1	High Vibration	287
10.5.2	Different Dynamic Behavior of Two Identical Pumps	289
10.5.3	Frequent Failure	292

- 10.6 Aging Management for Machines and Structural Components..... 294
 - 10.6.1 Structural Components: The Coolant Channels 294
 - 10.6.2 Machines 298
 - 10.6.2.1 A Centrifugal Pump 298
- 10.7 Summary..... 302
- References 302
- Index 305**

1

Introduction

1.1 Introduction

Vibration measurements, tests, and analyses are becoming popular tools for several applications, a few of which are listed below:

Design qualification and optimization

Machine installation

Health monitoring

 Mechanical and civil structures

 Machines

 Human body, electrical panels, etc.

Over the decades, a significant advancement has been made in the experimental facilities and capabilities in terms of vibration instruments, sensors, and the computation power to analyze the experimental data. However, to achieve the requirements listed above, one needs a better understanding of dynamics and vibration behavior by both the experiments and theory. The correlation of the experimental observations with the theory is essential to suggesting a simple but effective and reliable solution. It has been observed that the following four aspects are very important to tackle any problem:

1. Understand the object(s) (e.g., structures, machines) and the objectives.
2. What kind of vibration instruments and experiments are required for measurements? This depends on the history of previous failures, malfunctioning in case of machinery, etc.
3. What kind of data processing is required for the measured vibration signals?

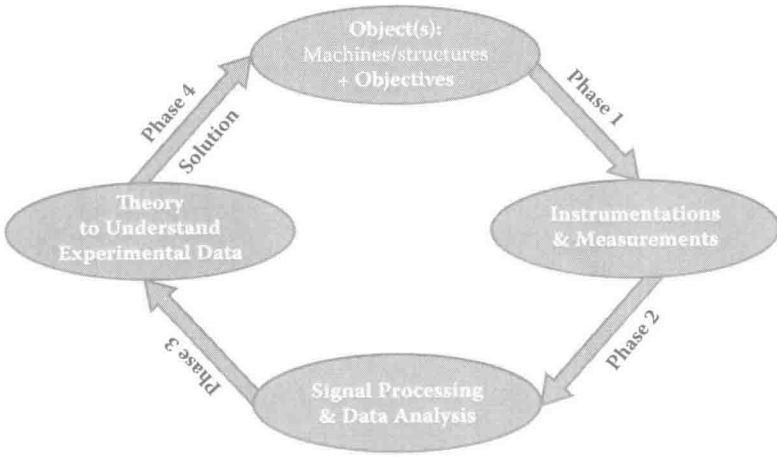


FIGURE 1.1
Typical abstract representations of different steps for analyzing any dynamic system.

4. Meet the expectation of an easy remedial suggestion (solution). In fact, it is always observed and experienced that a kind of “magic solution” is expected. It is only possible if the measurements, data processing, and their correlation to the theory are fully understood.

This book aims to communicate the above facets in a simplified tutorial manner, which is not readily available in a book. An abstract form of representation of the above facets is also illustrated in Figure 1.1 for better understanding.

1.2 Layout of the Chapters

The complete book is presented in 10 chapters (including Chapter 1) and aims to address a number of topics often useful for many day-to-day analyses and experiments in an illustrative and tutorial style, so the basic concept can be understood in a much better way. Although the book is divided into 10 chapters, it can be grossly classified into the following four categories.

1. Basic theories and analysis methods
2. Instrumentations and signal processing methods
3. Combined analysis and experimental approaches
4. Case studies relating 1 to 3

1.2.1 Basic Theories and Analysis Methods

Chapters 2 to 4 provide the basic understanding and concept of the vibration theory, mathematical modeling of structures and machines using the finite element (FE) method, and the vibration response computation using the FE model for the load applied.

Chapter 2 discusses a simplified vibration theory through a single degree of freedom (SDOF) system of a mass and a spring. A better understanding of vibration theory on a simplified system like a spring-mass system is often useful to understand several complex problems related to structures and machines.

Chapter 3 is on finite element (FE) modeling. This chapter introduces the concept of FE modeling at a very basic level through a few simple examples. This may provide a better concept and understanding even when developing an FE model using the commercial FE codes. The concept of the theoretical modal analysis using the FE model and eigenvalues and eigenvectors analysis is also discussed to introduce the concept of the mode shape at a natural frequency.

Chapter 4 is related to the use of the FE model discussed in Chapter 3. It discusses how the equation of motion in matrix form for any system can be integrated to solve for the responses (displacement, velocity, and acceleration) at all DOFs due to the time-varying external loadings. Broadly, two different approaches, the direct integration (DI) method and the mode superposition (MS) method, are used in practice and discussed in this chapter. The step-by-step concepts through a few examples are used to explain both methods. The Newmark- β method is used as the integration method for solving the dynamic equation of motion in matrix form for both the DI and MS methods to compute the responses.

1.2.2 Instrumentations, Signal Processing, and Experimental Methods

This book contains three exclusive chapters related to instrumentation, signal processing, and modal experiments, respectively. These are important elements for any vibration experiment.

Chapter 5 introduces the basic concept and working principles of different vibration sensors that include the proximity probes for displacement measurement, seismometers, accelerometers, and force sensors with their specifications. The concept of the experimental setup for the vibration measurements, experiments, and data collection is explained systematically for any experimental work. The basic understanding of the analogue-to-digital conversion (ADC) and the sampling frequency are discussed through the aid of a number of examples. The data acquisition (DAQ) device used to collect the experimental data in digital form from the analogue signals from the different sensors is also discussed so that appropriate DAQ and setting selection is possible for the experimental data collection.

Chapter 6 focuses on signal processing. It is a very important step to get the meaningful outputs from the measured vibration signals. Signal processing

generally used in vibration, in both time and frequency domains, is explained through a number of vibration signals. A simplified concept for the fast Fourier transformation (FFT) and its use in the spectrum, cross-spectrum, frequency response function (FRF), and coherence are discussed. The use of the window function and averaging process while estimating the spectrum, FRF, etc., is explained through the aid of a number of signals. The usefulness of filters and the aliasing effect during data collection is also explained in this chapter.

Chapter 7 deals with experimental modal testing and analysis. Conducting modal experiments on any structure, machine, or equipment may be a straightforward procedure, but the data analysis needed to extract the natural frequencies, mode shapes, and modal damping accurately is a complex process. A number of modal analysis software codes are already available commercially to do such data analysis. In this chapter, a very simplified test procedure and the data analysis based on the theory of a SDOF system are outlined to extract the modal properties. It is generally observed to be an effective practical approach for many applications, including industrial structures and machines.

1.2.3 Combined Analysis and Experimental Methods

FE model updating and vibration-based condition monitoring and diagnosis require the knowledge of both analysis (Section 1.2.1) and experiments (Section 1.2.2). These are presented in the following chapters. The basic theories are explained through examples.

Chapter 8 describes the FE model updating method. The development of an FE model (Chapter 3) for any structure or machine is generally based on the material properties, physical dimensions, and ideally assumed boundary conditions. Such an a priori FE model may not be a true reflection of in situ dynamic behavior, and hence the FE model needs to be updated to get the model close to in situ behavior. The FE model updating approach uses the experimental modal parameters to update the model using updating parameters. The step-by-step procedure of this updating method is explained through a few simple laboratory examples and a case study.

Chapter 9 is dedicated to vibration-based condition monitoring, which is one of the most popular topics for monitoring the health of any structure or machine. A simplified concept about the requisite instrumentation, data collection, data analysis, diagnosis features, and the related International Organization for Standardization (ISO) codes is discussed in the chapter, mainly related to rotating machines.

1.2.4 Case Studies

Chapter 10 is exclusively on a few case studies, from laboratory examples to industrial examples, in order to provide a clear concept for analyzing different problems and the usefulness and relation of Sections 1.2.1 to 1.2.3 in each case study, and then how to achieve the magic solution to any problem.