Vibration Problems in Machines: Diagnosis and Resolution

Arthur W. Lees
CRC Press, Boca Raton, FL, (2015),
332 pp., Hardbound, 159.95 USD, ISBN 9781498726740

This book is a very practical examination of rotating machine problems, with emphasis on the problems arising with the highest likelihood of occurrence, examined from theoretical, numerical and empirical perspectives. The author has a unique and admirable biographical combination of real-world, practical electric plant and academic research/teaching experience in the field of rotating machinery and that dual-pronged practical and pedagogical emphasis pervades and enhances the book. In fact, a similar balanced utilization of actual measured machine data needed to improve theoretical or physics-based computational analyses and to gain additional insight is a major theme of the book.

It should be noted that the book is not, nor is it intended to be, an exhaustive general treatment of the dynamics of rotating machines. The author himself frequently refers to other more comprehensive texts on basic rotating machine dynamic theory, including his own 2010 text co-authored along with Michael I. Friswell et al., for more thorough discussions. Rather, this book, as the title states, is focused more towards increasing the understanding, diagnosis and resolution of vibration *problems* in rotating machines.

While not immediately obvious when examining the many equations derived and explained throughout the book, the author puts a very strong reliance on the use of the finite element method (FEM) and other numerical modeling and simulation solution approaches in much of the book. This is not at all meant as a criticism since the FEM is certainly an important and highly useful approach to analyzing more complex real-world, rotating machinery. I mention this merely for the information and benefit of the potential reader to note that most of the book's equations are in matrix form meant to be solved in a numerical or computational manner.

To that end, the author also strongly leverages the MathWorks MATLAB software in a supplementary manner in the book. Specifically, readers are directed to a website containing large library or toolbox of MATLAB scripts, interfaces, examples, etc. that nicely complement the theories and techniques discussed in the book. After a thorough review of the website, it is believed that these additional accompanying routines, user interfaces and other commonly used task scripts offer the potential to significantly aide in the practical applications of the book's material by the reader and further enhances their learning experience.

Chapter 1 of the book is a relatively short introduction to the subject matter of monitoring, diagnosis, modeling and classification of rotating machines. It includes brief discussions on monitoring and diagnosis of machines, including the measurement and utilization of standard parameters such as vibration, pressure, fluid flow rates, temperature, electrical current and voltage, and acoustic radiation. This first chapter also introduces (a) the concepts of fault localization, root cause and remaining life in rotating machines, (b) the use of mathematical models (both analytic and numerical; both expanded in much more detail in Chapter 3), (c) machine classification and (d) monitoring schemes.

This book's second chapter contains a brief yet informative treatment of each of a variety of data presentation formats including time and frequency plots, waterfall plots, scatter plots, shaft orbit shape plots, polar plots and spectragrams. I particularly liked the manner of the discussion as it related the relative advantages/disadvantages and usefulness of each plot format to the others regarding shedding additional light towards the response of a rotating machine.

Chapter 3 introduces the fundamentals of modeling machines in both analytical and physics-based computational numerical forms. After a short general discussion on the necessity for theoretical models, this chapter includes a brief yet hands-on example treatment of the finite element method. Chapter 3 also discusses several analysis methods that can be utilized once the FEM matrices have been assembled to further examine faults in rotating machinery. Examples of analysis methods discussed include imbalance response, Campbell diagrams, analysis of damped systems, the root locus and stability method, and determination of the overall forced response behavior of systems subjected to harmonic excitation. The chapter concludes with a discussion on applying both vibrational mode shapes and also perturbation techniques to enhance understanding gained from models on rotating machine response behavior and its sensitivity to small changes in various system parameters.

Having laid a foundation in the book regarding the applicability and approaches to employing numerical models to predict the response behavior of rotating machines, the author then devotes the book's mid-section in Chapters 4–6 to discussions of the most common problems or "faults" in rotating machines. Chapter 4 is devoted to detailed treatment of the most predominant source of problems in rotating machinery, the subject of rotor imbalance. While the majority of the chapter rightly delves into mass imbalance as the main cause of rotor imbalance, the chapter ends with a discussion of the assumptions of rigid versus flexible or elastic rotors and briefly considers synchronous vibration caused by rotor bending. The chapter also includes a number of approaches to improving rotor balancing, including both single- and two-plane balancing as well as the modal balancing

method for the reduction of flexible rotor imbalance-related vibration.

Continuing on the discussion of the most prevalent rotating machine problems, Chapter 5 begins with a fairly detailed coverage of the second most common fault source, misalignment. This discussion includes misalignment in both flexible and solid couplings in addition to misalignment inherent to the vibrational excitation. This chapter also briefly outlines other complicated and less understood machine problems including cracked rotors, torsion, nonlinear systems, as well as the system-level, interrelated conditions of both synchronous and asynchronous excitation and vibration.

Chapter 6 concentrates on the major effects that rotor–stator interaction and clearances can have on rotating machine system dynamics, particularly clearances that are very small, direct contact and/or those in which lubrication of some other heavy internal fluid is involved. Examples covered include interaction of rotating machine rotors and stators through a number of different types of bearings, bushes and seals, and in the worst case, direct rotor–stator dynamic contact.

Moving on from specific rotating machine faults, Chapters 7 and 8 cover the more general and higher-level concepts of machine identification and more specialized system analysis methods, respectively. Chapter 7 discusses opportunities for future progress in rotating machine identification and characterization along with more conceptual and mathematical approaches to updating and improving the fidelity of purely physics-based dynamic models using actual measured system data. Several recent methods and techniques for examining and analyzing system data are treated in Chapter 8. These include non-deterministic methods such as artificial neural networks (ANNs) and their incorporation with physics-based models, kernel density estimations, Hilbert and wavelet transforms, and both mathematical and empirical decomposition techniques. This chapter further emphasizes the author's overall belief on the importance and benefits of using existing data to provide fundamental understanding and insight into a system's response behavior.

As an excellent presentation and attestation to the usefulness of the theories, methods and techniques covered in the earlier chapters of this book, Chapter 9 contains a wide-ranging collection of five real-world case studies originally examined by the author and others in the literature. In all cases, a rotating machinery system contained a fault (or faults) of some kind and documentation of the system description, investigative analysis and conclusions are presented and periodically tied back to specific sections and/or equations covered earlier in the book. Chapter 9 represents a nice addition to this book and provides a helpful and interesting practical treatment of the subject.

Chapter 10, titled "Overview and Outlook," is a short and more hypothetical, forward-looking, concluding chapter to the book. In addition to attempting to bring the reader up to the present in advances in instrumentation, data analysis, data handling and modeling, the author also takes the opportunity in this final chapter to speculate to a degree on what kinds of things are potentially possible in the future in the analysis and particularly the control of rotating machines. For example, more futuristic topics such as expert systems, so-called smart machines that can automatically detect, diagnose and apply "corrective" action, advanced magnetic and electrorheological bearings, and active piezoelectric actuation of rotating shafts are discussed as areas for future development in the solution of vibration problems in rotating machines.

This book would be most useful as a teaching instrument in the classroom. There are approximately five or six limited but insight-provoking homework problems at the conclusion of each chapter. All of the solutions to those problems, along with additional helpful comments for each one, are contained in back of book. The examples in each chapter are illustrative, clear, but unfortunately limited in number. The number of examples for each earlier chapter averages on the order of two to three, while some later chapters have none. It would benefit later editions of this book to include more examples since they are well done and informative. However, it should be noted that the aforementioned online MATLAB toolbox does also contain several hands-on numerical examples for Chapter's 5–7. Lastly, references are somewhat judiciously included but generally are from useful and helpful sources.

In closing, I very much enjoyed this book by Lees and found it to offer useful practical theories, techniques and approaches to diagnosing and resolving vibration problems in rotating machines in an easy-to-read and instructive manner. Because of its interesting combined theoretical and practical approach, the book should be helpful and informative to a broad spectrum of practitioners and researchers interested in examining and solving undesirable vibration levels occurring within rotating machinery.

Robert M. Koch
Naval Undersea Warfare Center
Newport, RI 02841-1708, USA
Robert.M.Koch@navy.mil