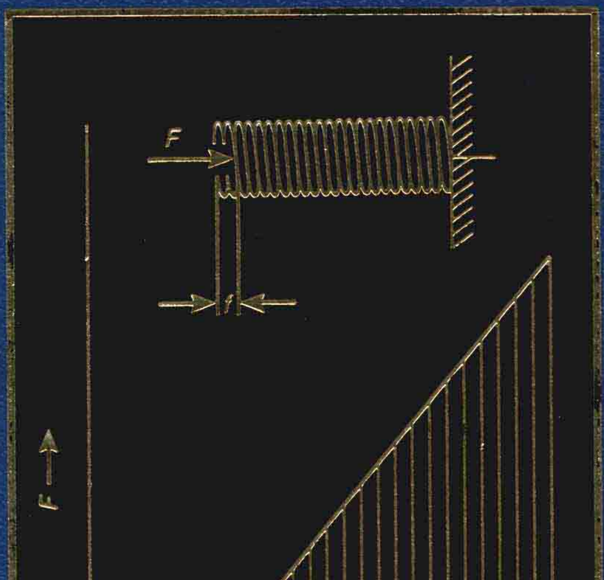
VIBRATION FOR ENGINEERS

SECOND EDITION



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Vibration for Engineers

To the unknown engineer
who contributed to this book
more than words can acknowledge

Preface

Speed of rotating machines has changed very little from the time of the muscle-powered machines of the Stone Age to the water- and air-powered ones of the classical and medieval times and finally to the Watts engine. Rotating speeds were, in general, below 1000 rpm at the end of the nineteenth century. At that time, in the 1870s, Dr. Gustaf Patrik de Laval, a Swedish engineer, invented the milk separator, which had to work at 6000 to 10,000 rpm. De Laval's first units were horse-wheel or hand-driven with geared step-up of speed. He soon saw the need for a direct drive and the steam turbine was born. The day that de Laval presented his marine steam turbine to the World Columbian Exposition, opened in 1893 in Chicago by President Cleveland, marks the beginning of the era of high speeds. De Laval turbines worked to 42,000-rpm speeds, way above the critical speed. In a few years, there was a 40-fold increase in rotating speed, which was equivalent to a 1600-fold increase in the unbalance forces. It was the time that the brilliant solutions in vibration theory developed by the great mathematicians from Newton to Poincaré would find problems to be applied to. Sound and vibration became a separate branch of physics and Lord Rayleigh's *Theory of Sound* appeared. Subsequently, mechanical vibration became an engineering discipline and W. Hort's *Technische Schwingungslehre* was published in 1910 by Julius Springer.

Most vibration topics taught to undergraduate students were developed in the time period between the work of Newton and that of Lord Rayleigh by mathematicians who had very little to do with applications. On the other hand, our century may be labeled the era of vibration applications, and they are too numerous to put in one book. Therefore, such a textbook should include the basic theory and some notable or pedagogically useful applications. The balance, in the sense introduced by Truesdell in his *Six Lectures on Natural Philosophy,* is one of the manifestations of the taste of the author who, having been a practicing engineer for a lifetime, would not have anything to add to

Leonardo da Vinci's dictum: "O students, study mathematics, and do not build without foundations. . . ."

During the past 50 years, most engineering authors have omitted the orignal references, replacing them with recent textbooks or references. A practical reason was posed for this practice—that more recent references are easier to find for further study. This, of course, is not exactly true. It is much easier to locate Newton's *Principia mathematica* or Lagrange's *Mécanique analytique,* perhaps in English translations, in libraries than it is to find many recent references. Moreover, no student of modern poetry would consider his or her education complete without reading Homer or Shakespeare, although they may have very little in common with Howard Nemerov's poetry. Yet very few engineering students have read Newton or Euler, despite the fact that most of the material they learn was written by them. Finally, every engineer should take seriously the counsel of Leibnitz: "It is most useful to trace the sources of memorable inventions. . . . That is so because such knowledge helps not only the history of letters give each his own and encourage others to pursue like glory but also, when method is disclosed by shining examples, the art of discovery graten." Of course, to revive the accurate referencing, nearly forgotten for so long and controversial, is not easy. Suggestions and comments by readers will be of great help.

In C. Truesdell's words, "experiment is necessary to see for yourself if something you read is true but also to find something you have not already read." We have no control over the availability of laboratory facilities to readers while they study this book. However, VIBLAB is a vehicle that provides the reader with simulated experience aimed at making the computer screen an observation window into a laboratory where most of the principles described here can be demonstrated. This, of course, is not a substitute for laboratory experience. In its absence, however, it can provide the reader with an alternative route to gain understanding of the subject. The reader can practice on his or her computer, viewed as a laboratory window, using the keyboard as a control console.

Desegregation of design in all engineering science courses has been advocated as an alternative to specific design courses in engineering education, in the tradition of schools such as the Ecole Polytechnique. In this sense, major emphasis is placed on design, not in the form of providing ample "design formulas" but using examples and design problems in most chapters, which are true case studies and truly open ended, with the belief that this can contribute to the dissemination of design to the engineering curricula instead of its segregation into design courses. This offers the possiblity for teaching a vibrations course as a design course.

In an earlier edition, this book, entitled *Vibration Engineering,* was one of the first in engineering to include a rather complete set of FORTRAN code for analysis. We have decided not to include it here in printed form but in the form of electronically recorded software, not only in the interest of space but to allow for debugging and upgrading the code as new hardware and software become available. With the contemporary rate of change in computers, the average of ten years between editions is certainly a very long time. Thus, program code is not included. Instead pseudocode is presented for those readers who might want to test their programming skills. For those readers that might want to use existing computer programs, a reduced version of MELAB is available as shareware program and includes several executable programs. Moreover, MATHEMATICA code is introduced throughout the book for those readers who want to use symbolic processing.

In this second edition, in addition to correcting misprints and errors:

1. Additions and changes were made to improve understanding, consistency, and clarity. Several sections were completeley rewritten and several new sections were added. Moreover, trends in teaching and accreditation practices dictated an increase in design content. Concurrently, an effort was made to separate the material for an entry-level undergraduate course in vibration in the first six chapters of the book and organize the material for a second course in vibration, with emphasis on design, in Chapters 7 to 15. Depending on the readers' background and the particular curriculum, instructors might want to cross the boundaries of these two parts of the book.
2. Drill exercises were added for each section, in particular in the introductory chapters, to allow for concept understanding before the reader would try to solve complex engineering problems and obtain numerical results.
3. To facilitate utilization of the book in a second course in vibration with design emphasis, tables with mass, damping, and stiffness properties of engineering materials encountered in vibration analysis were added in an appendix. Moreover, the open-ended design problems were expanded and better defined. These problems can be discussed also in a framework of a capstone design course.
4. The author does not share the view of many that design involves merely a quick search for handbook solutions to produce component sizing. The designer should be equally interested with the theoretician in proofs and questions of convergence, numerical accuracy, assumptions behind an analytical method, and so on. Emphasis on design should also mean emphasis on the fundamentals. Thus, almost all results in the book are derived from fundamentals so that the reader understands the physics of the problem, the underlying assumptions, and the limitations of the solution.
5. Symbolic processing was introduced that might not directly contribute to the understanding of the subject but it might help the reader obtain quick solutions and their plots that otherwise could require tedious work. However, for an entry-level course the instructor might want to skip symbolic processing and computer simulation and stress understanding of the fundamentals instead. Computer programs and symbolic processing are not integral parts of the book in the sense that their use is not required in following the text, understanding the subject, or solving problems. For those readers and instructors who, in addition to the basic understanding of the subject, want numerical solutions, this material of the book would become useful.

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