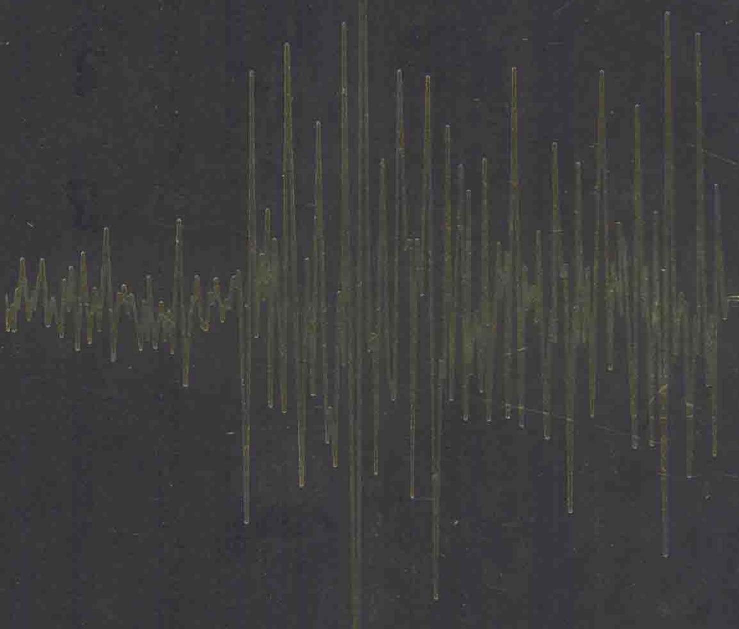
VIBRATION FOR ENGINEERS



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Vibration for Engineers

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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 19th Century. At that time, in the 1870's, 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 authors who, having been practicing engineers for a lifetime, would not have anything to add to the 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 original 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 in libraries 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 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, SIMULAB is a vehicle that provides the reader with simulated experience aiming 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 reach the 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 possibility 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 vibration 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 10 years between editions of a book is certainly a very long time. Thus source code is not included in the text, but the basic algorithms are written in pseudocode for easy implementation in the high-level language of the reader's preference.

In recent years, engineers have realized the importance of using vibration analyses to monitor and diagnose machinery conditions for more effective predictive maintainance. Chapters 13 and 14 were written as an introduction to this methodology.

Since this is a completely rewritten new edition, the authors will be obliged if the readers help in the identification of misprints, errors, and points of ambiguity in the text, the problems, or the software.

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Historical Introduction

1 THE ORIGINS OF VIBRATION THEORY

The development of vibration theory, as a subdivision of mechanics, came as a natural result of the development of the basic sciences it draws from, mathematics and mechanics. These sciences were founded in the middle of the first millennium B.C. by the ancient Greek philosophers. Of course, people were using the underlying principles in their everyday life long before that, sometimes in a systematic way. For example, geometry and other branches of mathematics were used extensively during the second and third millennia B.C. in Mesopotamia and Egypt in problems such as land surveying. The rules they developed and used were generally empirical in nature and no attempt was made to deduct these rules from fundamental principles in a rigorous way.

The scientific method of dealing with nature started with the Ionian school of natural philosophy, whose leader was Thales of Miletos (640–546 B.C.), the first of the seven wise men of antiquity. He is perhaps better known for his legendary discovery of the electrical properties of yellow amber (electron) and introduction

*Notes for the Historical Introduction appear, as numbered, at the end of the chapter.