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HARRIS'  
SHOCK AND  
VIBRATION  
HANDBOOK  
FIFTH EDITION

CYRIL M. HARRIS  
ALLAN G. PIERSOL

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# HARRIS' SHOCK AND VIBRATION HANDBOOK

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## ABOUT THE EDITORS

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**Cyril M. Harris**, one of the world's leading authorities on shock, vibration, and noise control, currently lectures at Columbia University where he is the Charles Batchelor Professor Emeritus of Electrical Engineering. Dr. Harris has received many honors for his scientific and engineering achievements, including membership in both the National Academy of Sciences and the National Academy of Engineering. He has been the recipient of the Gold Medal and the Sabine Medal of the Acoustical Society of America, the Franklin Medal of the Franklin Institute, the Gold Medal of the Audio Engineering Society, and the A.I.A. Medal of the American Institute of Architects.

He received his Ph.D. degree in physics from M.I.T. and has been awarded honorary doctorates by Northwestern University and the New Jersey Institute of Technology. Among books written or edited by Dr. Harris are the following McGraw-Hill publications: *Handbook of Acoustical Measurements and Noise Control*, Third Edition (1991); *Noise Control in Buildings* (1994); *Dictionary of Architecture and Construction*, Third Edition (2000); and *Handbook of Utilities and Services for Buildings* (1990).

**Allan G. Piersol** is a professional engineer in private practice specializing in the analysis of and design for shock, vibration, and acoustical environments. He received an M.S. degree in engineering from UCLA and is licensed in both mechanical and safety engineering. Mr. Piersol is a Fellow of the Acoustical Society of America and the Institute of Environmental Sciences and Technology, and a recipient of the latter organization's Irvin Vigness Memorial Award. He is the co-author with Julius S. Bendat of several books published by John Wiley & Sons, the most recent being *Engineering Applications of Correlation and Spectral Analysis*, Second Edition (1993), and *Random Data: Analysis and Measurement Procedures*, Third Edition (2000). He is also a co-author of NASA-HDBK-7005, *Dynamic Environmental Criteria* (2001), and a contributor to numerous other engineering handbooks.

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# PREFACE

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The first edition of the *Shock and Vibration Handbook* in 1961 brought together for the first time a comprehensive survey of classical shock and vibration theory and current applications of that theory to contemporary engineering practice. Edited by Cyril M. Harris and the late Charles E. Crede, the book was translated into several languages and became the standard reference work throughout the world. The Second Edition appeared in 1976, the Third Edition in 1988, and the Fourth Edition in 1996.

There have been many important developments in the field since the Fourth Edition was published, including advances in theory, new applications of computer technologies, new methods of shock and vibration control, new instrumentation, and new materials and techniques used in controlling shock and vibration. Many new standards and test codes have also been enacted. These developments have necessitated this Fifth Edition, which covers them all and presents a thorough, unified, state-of-the-art treatment of the field of shock and vibration in a single volume that is approximately 10 percent longer than its predecessor edition. A new co-editor, highly regarded as an author in his own right, has collaborated with an original editor in this endeavor. The book brings together a wide variety of skills and expertise, resulting in the most significant improvements in the Handbook since the First Edition.

New chapters have been added and many other chapters updated, revised, or expanded to incorporate the latest developments. Several chapters written by authors who are now deceased have been revised and updated by the editors, but the credits to the original authors are retained in recognition of their outstanding contributions to shock and vibration technology. (For convenience, and to retain as closely as possible the chapter sequence of prior editions, several chapters have been designated Part II or III of an associated chapter.) The editors have avoided duplication of content between chapters except when such repetition is advisable for reasons of clarity. In general, chapters in related areas are grouped together whenever possible. The first group of chapters presents a theoretical basis for shock and vibration. The second group considers instrumentation and measurement techniques, as well as procedures for analyzing and testing mechanical systems subjected to shock and vibration. The third group discusses methods of controlling shock and vibration, and the design of equipment for shock and vibration environments. A final chapter presents the effects of shock and vibration on human beings, summarizing the latest findings in this important area. Extensive cross-references enable the reader to locate relevant material in other chapters. The Handbook uses uniform terminology, symbols, and abbreviations throughout, and usually both the U.S. Customary System of units and the International System of units.

The 42 chapters have been written by outstanding authorities, all of them experts in their fields. These specialists come from industrial organizations, government and university laboratories, or consulting firms, and all bring many years of experience to their chapters. They have made a special effort to make their chapters as accessible

as possible to the nonspecialist, including the use of charts and written explanations rather than highly technical formulas when appropriate.

Over the decades, the Handbook has proven to be a valuable working reference for those engaged in many areas of engineering, among them aerospace, automotive, air-conditioning, biomedical, civil, electrical, industrial, mechanical, ocean, and safety engineering, as well as equipment design and equipment maintenance engineering. Although this book is not intended primarily as a textbook, it has been adopted for use in many universities and engineering schools because its rigorous mathematical basis, combined with its solutions to practical problems, are valuable supplements to classroom theory.

We thank the contributors to the Fifth Edition for their skill and dedication in the preparation of their chapters and their diligence in pursuing our shared objective of making each chapter the definitive treatment in its field; in particular, we thank Harry Himmelblau for his many helpful suggestions. We also wish to express our appreciation to the industrial organizations and government agencies with which many of our contributors are associated for clearing for publication the material presented in their chapters. Finally, we are indebted to the standards organizations of various countries—particularly the American National Standards Institute (ANSI), the International Standards Organization (ISO), and the International Electrotechnical Commission (IEC)—as well as to their many committee members whose selfless efforts have led to the standards cited in this Handbook.

The staff members of the professional book group at McGraw-Hill have done an outstanding job in producing this new edition. We thank them all, and express our special appreciation to the production manager, Tom Kowalczyk, for his support.

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