Handbook of Acoustical Measurements and Noise Control, Third Edition

Cyril M. Harris, Editor

Originally published in 1991; Reprinted in 1997

TABLE OF CONTENTS

Robert S. Gales, Consultant, formerly Head, Airborne Acoustics Branch, Naval Ocean Systems Center, San Diego, CA 92109

Chapter 18. Hearing Loss from Noise Exposure

William Melnick, Ph.D., Professor, Department of Otolaryngology, Ohio State University, Columbus, OH 43210

Chapter 19. Hearing Evaluation

Maurice H. Miller, Ph.D., Professor of Speech-Language Pathology and Audiology, New York University; Chief, Center for Communications Disorders, Lenox Hill Hospital New York, NY 10021

Laura Ann Wilber, Ph.,D., Professor of Audiology and Hearing Impairment, Northwestern University, Evanston, IL 60208

Chapter 20. Hearing Loss; Legal Liability

Allen L. Cudworth, Sc.D., Vice President, Liberty Mutual Insurance Co., Boston, MA 02117

Chapter 21. Hearing Protection Devices

Charles W. Nixon, Ph.D., Chief, Bioacoustics and Biocommunications, Armstrong Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45433

Elliott H. Berger, M.S. Manager, Acoustical Engineering, Cabot Safety Corp., Indianapolis, IN 46268

Chapter 22. Hearing Conservation Programs

Larry E. Royster, Ph.D., Professor of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC 27695

Julia Doswell Royster, Ph.D., President, Environmental Noise Consultants, Inc., Raleigh, NC 27622

Chapter 23. Noise-Induced Annoyance of Individuals and Communities

Sanford Fidell, Lead Scientist, BBN Systems & Technologies (a division of Bolt Beranek and Newman, Inc.), Canoga Park, CA 91304

David M. Green, Ph.D., Professor of Psychology, University of Florida, Gainesville, FL 32611

Chapter 24. Human Performance and Noise

Dylan M. Jones, Ph.D., University Reader, School of Psychology, University of Wales College at Cardiff, Cardiff, CF1 3YG, United Kingdom

Donald E. Broadbent, C.B.E., Sc.D., F.R.S., External Staff, Medical Research Council, Department of Experimental Psychology University of Oxford, Oxford, OX1 3UD, England

Chapter 25. Physiological Effects of Noise

Gerd Jansen, Dr. Med., Dr. Phil., University Professor of Occupational Medicine, Istitut für Arbeitmedizin der Universität Düsseldorf, Düsseldorf D-4000, Germany

Chapter 26. Criteria for Noise and Vibration Exposure

Henning E. von Gierke, D. Eng., Director Emeritus, Biodynamics and Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45433; Clinical Professor, School of Medicine, Wright State University, Dayton, OH 45401

W Dixon Ward, Ph.D., D. Sc., Professor, Departments of Communication Disorders, Otolaryngology and Environmental Health, University of Minnesota, Minneapolis, MN 55414

Chapter 27. Vibration Control Principles

Cyril M. Harris, Ph.D.,Charles Batchelor Professor Emeritus of Electrical Engineering and Professor Emeritus of Architecture, Columbia University, New York, NY 10027

Chapter 28. Vibration Control Techniques

Eric E. Ungar, Eng., Sc.D., Chief Consulting Engineer, Bolt Beranek and Newman, Inc., Cambridge, MA 02138

Douglas H. Sturz, Senior Consultant, Acentech Incorporated (a Bolt Beranek and Newman Company), Cambridge, MA 02140

Chapter 29. Part 1: Types and Characteristics of Vibration Isolators

Romulus H. Racca, Principal Engineer, Barry Wright Corporation, Watertown, MA 02172

Chapter 29. Part 2: Selection and Applications of Vibration Isolators Harry L. Hain, Staff Engineer

John J. Heintzel, Staff Engineer

Charles J. Leingang, Staff Engineer

Lord Corp., Eric, PA 16506

Chapter 30. Sound-Absorptive Materials

Ron Moulder, Principal Research Scientist, Battelle Memorial Institute, Columbus, OH 43201

Chapter 31. Airborne Sound Insulation

A.C.C. Warnock, Ph.D., Senior Research Officer

J.D. Quirt, Head

Acoustics Section, Institute for Research in Construction, National Research Council of Canada, Ottawa, ON KIA OR6, Canada

Chapter 32. Structureborne Sound Isolation

Isivan L. Ver, Ph.D., Principal Consultant, Bolt Beranek and Newman, Inc., Cambridge, MA 02138

Douglas H. Sturz, Senior Consultant, Acentech Incorporated (a Bolt Beranek and Newman Company), Cambridge, MA 02140

Chapter 33. Noise Control in Buildings

A.C.C. Warnock, Ph.D., Senior Research Officer

J.D. Quirt, Head
Acoustics Section, Institute for Research in Construction, National Research Council of Canada, Ottawa, ON K1A OR6, Canada

Chapter 34. Electric Motor Noise

James B. Moreland, M.B.A., Director, Totl Quality, Westinghouse Science and Technology Center, Pittsburgh, PA 15235
Douglas H. Cashmore, B. Sc. (Hons.), M. Sc., Principal Engineer, Centrilift (a Baker Hughes Company), Claremore, OK 74017

Chapter 35. Transformer Noise

James B. Moreland, M.B.A., Director, Total Quality, Westinghouse Science and Technology Center, Pittsburgh, PA 15235
Ramses S. Girgis, Ph.D., ABB T&D Company, Power Transformer Division, Muncie, IN 47307

Chapter 36. Gear Noise

William D. Mark, Ph.D., Principal Scientist, Bolt Beranek and Newman, Inc., Cambridge, MA 02138 (now at Pennsylvania State University, Applied Research Laboratory, University Park, PA 16802)

Chapter 37. Bearing Noise

F.P. Wardle, Ph.D., C. Eng., M.I. Mech, E, RHP Ltd., Bodegraven 2411 PK, The Netherlands

Chapter 38. Measurement and Analysis of Machinery Noise

Richard H. Lyon, Ph.D., President
Richard G. Cann, P.E., Corporate Consultant
David L. Bowen, Senior Consultant
RH Lyon Corp, Cambridge, MA 02138

Chapter 39. Condition Monitoring of Machinery

Joëlle Courrech, D. Eng., Senior Applications Engineer, Bruel and Kjaer, Naerum, DK-2850, Denmark

Chapter 40. Control of Machinery Noise

Colin G. Gordon, President, Colin Gordon and Associates, San Mateo, CA 94402
Robert S. Jones, M.E., Acoustical Consultant, Acentech Incorporated, Rio Rancho, NM 87124

Chapter 4l. Fan Noise

J. Barrie Graham, P.E., Consultant, Graham Consultants, Santa Fe, NM 87501
Robert M. Hoover, Acoustical Consultant, Hoover & Keith, Inc., Houston, TX 77082

Chapter 42. Noise Control in Heating, Ventilating, and Air-Conditioning Systems

Robert M. Hoover, Acoustical Consultant, Hoover & Keith, Inc., Houston, TX 77082
Warren E. Blazier, Jr., Principal Consultant, Warren Blazier Associates, Inc., San Francisco, CA 94109

Chapter 43. Noise Control Criteria for Heating, Ventilating, and Air-Conditioning Systems

Warren E. Blazier, Jr., Principal Consultant, Warren Blazier Associates, Inc., San Francisco, CA 94109

Chapter 44. Ventilating Systems for Small Equipment

George C. Maling, Jr., Ph.D., P.E., Senior Physicist, IBM Corporation, Poughkeepsie, NY 12602
Andrew K, Boggess., Jr., M. Sc., Principal Engineer, EG&G Rotron, Woodstock, NY 12498

Chapter 45. Control of Plumbing Noise in Buildings

John J. Van Houten, P.E., Principal Consultant, J.J. Van Houten & Associates, Inc., Anaheim, CA 92805

Chapter 46. Rail Transportation Noise and Vibration

Carl E. Hanson, Ph.D., Vice President
Hugh J. Saurenman, Ph.D., P.E., Senior Consultant
David A. Towers, P.E., Senior Consultant
Harris Miller Miller & Hansen, Lexington, MA 02173

Chapter 47. Aircraft Noise

John Philip Raaney, Ph.D., P.E., former Head of Aircraft Noise Prediction Office
Jimmy M. Cawthorn, former Aerospace Technologist
NASA Langley Research Center, Hampton, VA 23665

Chapter 48. Highway Noise Prediction and Control

William Bowlby, Ph.D., P.E., Associate Professor of Civil Engineering, Vanderbilt University, Nashville, TN 37235

Chapter 49. Noise Assessment of Building Sites

George E. Winzer, Principal, Winzer Associates, Acoustical & Environmental Consultants, Rockville, MD 20855

Chapter 50. Community Noise Measurements

Dwight E. Bishop, President, Acoustical Analysis Associates, Inc., Canoga Park, CA 9l303
Paul D. Schomer, Ph.D., P.E., Chief-Acoustics/Environmental Noise Research, U.S. Army Construction Engineering Research Laboratory, Champaign, IL 61824

Chapter 51. Noise and the Law

Albert J. Rosenthal, Maurice T. Moore Professor Emeritus of Law and Dean Emeritus of Law, Columbia University, New York, NY 10027

Chapter 52. Aircraft Noise Litigation: Case Law Review

Ricarda L. Bennett, J.D., Attorney-at-Law; Principal, Heliport Consultants, Westlake Village, CA 91361
Gary Hoover, J.D., Gatzke, Mispagel & Dillon, Carlbad, CA 92009 (now Assistant District Attorney, County of San Diego, San Diego, CA 92101)

Chapter 53. Aircraft Noise Regulation
Richard J Linn, Senior Coordinator, Environmental Planning, American Airlines, Dallas/Fort Worth Airport, TX 75261
Richard N. Tedrick, Ph.D., Federal Aviation Administration, Washington, DC 20591
Chapter 54. Environmental Impact Statements
Henning E. von Gierke, D. Eng., Director Emeritus, Biodynamics and Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45433; Clinical Professor, School of Medicine, Wright State University, Dayton, OH 45401
Kenneth M. Eldred, Director, Ken Eldred Engineering, Concord, MA 01742
Robert K. Break, J.D., Partner, Latham & Watkins, Attorneys, Costa Mesa, CA 92626

Preface

At the time the first edition of the *Handbook of Noise Control* was published in 1957, various aspects of noise control were treated in specialized scientific journals and in reports of government agencies and industrial organizations. This information was not always easily accessible. Furthermore, there was a need for an authoritative work covering the entire field. The *Handbook* met this need and was also the first book on noise control published in the U.S.A. It included considerable technical information not previously available and defined the term *noise control* for the first time: *Noise control is the technology of obtaining an acceptable noise environment, at a receiver, consistent with economic and operational considerations; the receiver may be a person, a group of people, an entire community, or a piece of equipment whose operation is affected by noise.*

In the years that followed, many countries enacted noise control legislation, and noise became a matter of increasing social and economic importance, leading to new engineering methods of control. Accordingly, the *Handbook of Noise Control* was updated in 1979 to reflect these important changes.

More recently, technical innovations such as microminiaturization and the practical application of digital techniques have made possible innovative measurement techniques and the application of engineering methods that were not economically feasible a generation earlier. These changes have given rise to the need for a completely revised and enlarged handbook. Because there is now much greater emphasis on acoustical measurements throughout the text, the book has been retitled *Handbook of Acoustical Measurements and Noise Control*.

The *Handbook* employs uniform terminology, symbols, and abbreviations that probably represent as close to an international consensus as is possible to obtain at this time. Both the International System of units and the U.S. Customary System of units are used throughout.

Each of the chapters in the *Handbook* is written by an expert in his or her special area. Technical information has been made accessible by the use of simple charts and written explanations in place of highly technical formulas without lowering the substantive level of the *Handbook's* contents. This has required much effort on the part of the authors of the various chapters, and I am deeply grateful to them for their skill and patience.

The chapters of the *Handbook* are grouped as follows: properties and propagation of sound waves in the open air and in enclosures; measurement instrumentation, measurement techniques, the analysis of sound and vibration, and standards; hearing characteristics, hearing loss from noise exposure, hearing evaluation, hearing protection devices, hearing conservation programs, and liability for hearing loss; effects of noise on speech communication, annoyance, human performance, and physiology; criteria for noise and vibration exposure; methods of measuring, evaluating, and controlling noise and vibration in buildings; machinery and equipment noise (its characteristics, measurement, analysis, monitoring, and methods of control); the measurement and control of noise in heating, ventilating, and air-conditioning (HVAC) systems—including noise control criteria for use in designing HVAC systems and in assessing the noise produced by such systems; transportation noise; community noise; and noise legislation and regulations (including litigation and environmental impact statements).

The wealth of technical information contained in this book has been collected from many sources. Material has been reproduced, by permission, from books as well as copyrighted publications of a number of technical societies, primarily the Acoustical Society of America, the Institute of Noise Control Engineering, and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Some of the contributors are employed by the government of the United States. Material included in their chapters has been released for publication, but because these are personal contributions, the contents do not necessarily reflect the official view of the relevant department or agency.

Other valuable sources include publications of the standards organizations of various countries and publications of international organizations—particularly the International Organization for Standardization and the International Electrotechnical Commission. Copies of these publications may be obtained by writing the appropriate organizations at the addresses listed in Chapter 15. The standards cited in the text have resulted from the selfless efforts of members of various national and international committees, to whom we owe a debt of gratitude.

Special thanks are due Harold B. Crawford, editor in chief of engineering and technical books at McGraw-Hill, Inc.; Margaret Lamb, editing manager in McGraw-Hill's Professional Publishing Group; and especially Laura Givner, editing supervisor in the Professional Publishing Group.

Cyril M. Harris

Active Noise Control. Some Practical Suggestions. 18 Acoustics of Listening Rooms. Playback Criteria. Peculiarities of Small-Room Acoustics. Room Size and Proportion. Reverberation Time.Â Master Handbook of Acoustics. About the Authors. F. Alton Everest was a leading acoustics consultant. He was cofounder and director of the Science Film Production division of the Moody Institute of Science, and was also section chief of the Subsea Sound Research section of the University of California. Ken C. Pohlmann is well known as an audio educator, consultant, and author.Â Master Handbook of Acoustics. F. Alton Everest Ken C. Pohlmann. Fifth Edition. New York Chicago San Francisco Lisbon London Madrid Mexico City. Milan New Delhi San Juan Seoul Singapore Sydney Toronto. Noise control for buildings. Guidelines for acoustical problem solving. 1. â€œThe technology of noise control both inside and outside buildings. is well developed today. The problem is that it is too seldom used.â€Â Still, little was known about the physical science and measurement of sound until Sir Isaac Newton. He demonstrated that sound waves travel through any medium â€” solid, liquid, or gaseous â€” and that the speed with which they propagate depends upon the elasticity and density of the medium. In 1866, the fundamental nature of sound waves was vividly demonstrated by a German scientist, Charles Kundt.