Mechanical Engineers' Handbook
Third Edition

Instrumentation, Systems, Controls, and MEMS

Edited by
Myer Kutz



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To Bill and Judy, always there

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Preface

The second volume of the third edition of the *Mechanical Engineers' Handbook* (''ME3'') is comprised of two major parts: Part 1, Instrumentation, with eight chapters, and Part 2, Systems, Controls, and MEMS, with 13 chapters. The two parts are linked in the sense that most feedback control systems require measurement transducers. Most of the chapters in this volume originated not only in earlier editions of the *Mechanical Engineers' Handbook* but also in a book called *Instrumentation and Control,* which was edited by Chester L. Nachtigal and published by Wiley in 1990. Some of these chapters have been either updated or extensively revised. Some have been replaced. Others, which present timeless, fundamental concepts, have been included without change.[1] In addition, there are chapters that are entirely new, including Digital Integrated Circuits: A Practical Application (Chapter 8), Neural Networks in Control Systems (Chapter 19), Mechatronics (Chapter 20), and Introduction to Microelectromechanical Systems (MEMS): Design and Application (Chapter 21).

The instrumentation chapters basically are arranged, as they were in the Nachtigal volume, in the order of the flow of information in real measurement systems. These chapters start with fundamentals of transducer design, present transducers used by mechanical engineers, including strain gages, temperature transducers such as thermocouples and thermistors, and flowmeters, and then discuss issues involved in processing signals from transducers and in acquiring and displaying data. A general chapter on measurement fundamentals, updated from the second edition of *Mechanical Engineers' Handbook* (''ME2''), as well as the chapter on digital integrated circuits have been added to the half-dozen *Instrumentation and Control* chapters in this first part.

The systems and control chapters in the second part of this volume start with three chapters from ME2, two of which have been updated, and move on to seven chapters from Nachtigal, only two of which required updating. These ten chapters present a general discussion of systems engineering; fundamentals of control system design, analysis, and performance modification; and detailed information about the design of servoactuators, controllers, and general-purpose control devices. This second part of Vol. II concludes with the chapters, all of them new to the handbook, on what are termed ''new departures''—neural networks, mechatronics, and MEMS. These topics have become increasingly important to mechanical engineers in recent years.

[1] A new edition of *Instrumentation and Control* has been sought after but has never appeared. Because several chapters had numerous contributors, it proved impossible to update or revise them or even to find anyone to write new chapters on the same topics on the schedule that other contributors could meet. Because the material in these chapters was outdated, they have been dropped from this edition, but may be revised for future editions.

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Vision for the Third Edition

Basic engineering disciplines are not static, no matter how old and well established they are. The field of mechanical engineering is no exception. Movement within this broadly based discipline is multidimensional. Even the classic subjects on which the discipline was founded, such as mechanics of materials and heat transfer, continue to evolve. Mechanical engineers continue to be heavily involved with disciplines allied to mechanical engineering, such as industrial and manufacturing engineering, which are also constantly evolving. Advances in other major disciplines, such as electrical and electronics engineering, have significant impact on the work of mechanical engineers. New subject areas, such as neural networks, suddenly become all the rage.

In response to this exciting, dynamic atmosphere, the *Mechanical Engineers' Handbook* is expanding dramatically, from one volume to four volumes. The third edition not only is incorporating updates and revisions to chapters in the second edition, which was published in 1998, but also is adding 24 chapters on entirely new subjects as well, incorporating updates and revisions to chapters in the *Handbook of Materials Selection,* which was published in 2002, as well as to chapters in *Instrumentation and Control,* edited by Chester Nachtigal and published in 1990.

The four volumes of the third edition are arranged as follows:

Volume I: *Materials and Mechanical Design*—36 chapters
- Part 1. Materials—14 chapters
- Part 2. Mechanical Design—22 chapters

Volume II: *Instrumentation, Systems, Controls, and MEMS*—21 chapters
- Part 1. Instrumentation—8 chapters
- Part 2. Systems, Controls, and MEMS—13 chapters

Volume III: *Manufacturing and Management*—24 chapters
- Part 1. Manufacturing—12 chapters
- Part 2. Management, Finance, Quality, Law, and Research—12 chapters

Volume IV: *Energy and Power*—31 chapters
- Part 1: Energy—15 chapters
- Part 2: Power—16 chapters

The mechanical engineering literature is extensive and has been so for a considerable period of time. Many textbooks, reference works, and manuals as well as a substantial number of journals exist. Numerous commercial publishers and professional societies, particularly in the United States and Europe, distribute these materials. The literature grows continuously, as applied mechanical engineering research finds new ways of designing, controlling, measuring, making and maintaining things, and monitoring and evaluating technologies, infrastructures, and systems.

Most professional-level mechanical engineering publications tend to be specialized, directed to the specific needs of particular groups of practitioners. Overall, however, the mechanical engineering audience is broad and multidisciplinary. Practitioners work in a variety of organizations, including institutions of higher learning, design, manufacturing, and con-

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sulting firms as well as federal, state, and local government agencies. A rationale for an expanded general mechanical engineering handbook is that every practitioner, researcher, and bureaucrat cannot be an expert on every topic, especially in so broad and multidisciplinary a field, and may need an authoritative professional summary of a subject with which he or she is not intimately familiar.

Starting with the first edition, which was published in 1986, our intention has always been that the *Mechanical Engineers' Handbook* stand at the intersection of textbooks, research papers, and design manuals. For example, we want the handbook to help young engineers move from the college classroom to the professional office and laboratory where they may have to deal with issues and problems in areas they have not studied extensively in school.

With this expanded third edition, we have produced a practical reference for the mechanical engineer who is seeking to answer a question, solve a problem, reduce a cost, or improve a system or facility. The handbook is not a research monograph. The chapters offer design techniques, illustrate successful applications, or provide guidelines to improving the performance, the life expectancy, the effectiveness, or the usefulness of parts, assemblies, and systems. The purpose is to show readers what options are available in a particular situation and which option they might choose to solve problems at hand.

The aim of this expanded handbook is to serve as a source of practical advice to readers. We hope that the handbook will be the first information resource a practicing engineer consults when faced with a new problem or opportunity—even before turning to other print sources, even officially sanctioned ones, or to sites on the Internet. (The second edition has been available online on knovel.com.) In each chapter, the reader should feel that he or she is in the hands of an experienced consultant who is providing sensible advice that can lead to beneficial action and results.

Can a single handbook, even spread out over four volumes, cover this broad, interdisciplinary field? We have designed the third edition of the *Mechanical Engineers' Handbook* as if it were serving as a core for an Internet-based information source. Many chapters in the handbook point readers to information sources on the Web dealing with the subjects addressed. Furthermore, where appropriate, enough analytical techniques and data are provided to allow the reader to employ a preliminary approach to solving problems.

The contributors have written, to the extent their backgrounds and capabilities make possible, in a style that reflects practical discussion informed by real-world experience. We would like readers to feel that they are in the presence of experienced teachers and consultants who know about the multiplicity of technical issues that impinge on any topic within mechanical engineering. At the same time, the level is such that students and recent graduates can find the handbook as accessible as experienced engineers.

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