

# MECHANICAL ENGINEERS' HANDBOOK

Volume

Manufacturing and  
Management »

3

**MYER KUTZ** EDITOR

FOURTH EDITION

**WILEY**

# **Mechanical Engineers' Handbook**

## **Fourth Edition**

# **Manufacturing and Management**

**Edited by**  
**Myer Kutz**

**WILEY**

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# **Mechanical Engineers' Handbook**

*To Alan and Nancy, now and forever*

# Preface

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The third volume of the fourth edition of the *Mechanical Engineers' Handbook* comprises two parts: Manufacturing and Management. Each part contains 12 chapters. Contributors include business owners, consultants, lawyers, librarians, and academics from all around the United States.

Part 1 opens with a chapter from the second edition on Product Design for Manufacturing and Assembly (DFM&A). The centerpiece of Part 1 includes the chapters that in earlier editions of the handbook have been called "the handbook within the handbook."

Developed by a team at Louisiana State University and the University of Louisville, these six chapters, which have been updated, span manufacturing topics from production planning, production processes and equipment, metal forming, shaping, and casting, statistical quality control, computer-integrated manufacturing, to material handling. The chapter on classification systems remains unchanged from earlier editions; the chapter on mechanical fasteners has been revised extensively. Part 1 has three chapters entirely new to the handbook: a chapter on physical vapor deposition, one on environmentally conscious manufacturing, and one on a new approach to dealing with process technology in the context of design, tooling, manufacturing, and quality engineering. The latter chapter is indicative of how much contributors can give of themselves. Its content is the lifeblood of its author's consulting practice.

Part 2 covers a broad array of topics. The 12 chapters can be broken down into four groups. The first two chapters cover project and people management. The first of these chapters, on project management, deals with a subject that has appeared in previous editions, but the chapter is entirely new, to reflect advances in this field. The people management chapter has been revised. The following three chapters deal with fundamentals of financial management and are unchanged. The next three chapters, contributed by a team led by Jack ReVelle, treat a set of management issues, including total quality management; registrations, certifications, and awards; and safety engineering. Two chapters cover legal issues of interest to engineers, including patents. The final two chapters cover online and print information sources useful to mechanical engineers in their daily work. The chapter on online sources is a new version of the chapter that appeared originally in 1998.

# Vision for the Fourth Edition

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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, keep evolving. 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 expanded dramatically, from one to four volumes for the third edition, published in November 2005. It not only incorporated updates and revisions to chapters in the second edition, published seven years earlier, but also added 24 chapters on entirely new subjects, with updates and revisions to chapters in the Handbook of Materials Selection, published in 2002, as well as to chapters in Instrumentation and Control, edited by Chester Nachtigal and published in 1990, but never updated by him.

The fourth edition retains the four-volume format, but there are several additional major changes. The second part of Volume I is now devoted entirely to topics in engineering mechanics, with the addition of five practical chapters on measurements from the Handbook of Measurement in Science and Engineering, published in 2013, and a chapter from the fifth edition of Eshbach's Handbook of Engineering Fundamentals, published in 2009. Chapters on mechanical design have been moved from Volume I to Volumes II and III. They have been augmented with four chapters (updated as needed) from Environmentally Conscious Mechanical Design, published in 2007. These chapters, together with five chapters (updated as needed, three from Environmentally Conscious Manufacturing, published in 2007, and two from Environmentally Conscious Materials Handling, published in 2009) in the beefed-up manufacturing section of Volume III, give the handbook greater and practical emphasis on the vital issue of sustainability.

Prefaces to the handbook's individual volumes provide further details on chapter additions, updates and replacements. The four volumes of the fourth edition are arranged as follows:

- Volume 1: Materials and Engineering Mechanics—27 chapters
  - Part 1. Materials—15 chapters
  - Part 2. Engineering Mechanics—12 chapters
- Volume 2: Design, Instrumentation and Controls—25 chapters
  - Part 1. Mechanical Design—14 chapters
  - Part 2. Instrumentation, Systems, Controls and MEMS —11 chapters
- Volume 3: Manufacturing and Management—28 chapters
  - Part 1. Manufacturing—16 chapters
  - Part 2. Management, Finance, Quality, Law, and Research—12 chapters
- Volume 4: Energy and Power—35 chapters
  - Part 1: Energy—16 chapters
  - Part 2: Power—19 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, as well as 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 consulting firms, as well as federal, state, and local government agencies. A rationale for a 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, published in 1986, my intention has always been that the Mechanical Engineers' Handbook stand at the intersection of textbooks, research papers, and design manuals. For example, I 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 fourth edition, I have continued to produce 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. Its chapters offer design techniques, illustrate successful applications, or provide guidelines to improving performance, life expectancy, effectiveness, or 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 handbook is to serve as a source of practical advice to readers. I 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. 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? I have designed 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. I 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.



# Contributors

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Kate D. Abel  
Stevens Institute of Technology  
Hoboken, New Jersey

William E. Biles  
University of Louisville  
Louisville, Kentucky

Benjamin D. Burge  
Intel Americas, Inc.  
Chantilly, Virginia

David A. Burge  
David A. Burge Company  
Cleveland, Ohio

Martin S. Chizek  
Weinstein Associates International  
Delray Beach, Florida

Robert L. Crane  
Air Force Research Laboratory  
Wright Patterson Air Force Base  
Dayton, Ohio

Giles Dillingham  
Brighton Technologies Group  
Cincinnati, Ohio

Fritz Dusold  
Mid-Manhattan Library Science  
and Business Department (Retired)  
New York, New York

Banu Ekren  
University of Louisville  
Louisville, Kentucky

Keith M. Gardiner  
Lehigh University  
Bethlehem, Pennsylvania

Kasper Hallenborg  
University of Southern Denmark  
Odense, Denmark

Martin Hardwick  
Rensselaer Polytechnic Institute &  
STEP Tools, Inc.  
Troy, New York

Sunderesh S. Heragu  
University of Louisville  
Louisville, Kentucky

Jeremy S. Knopp  
Air Force Research Laboratory  
Wright Patterson Air Force Base  
Dayton, Ohio

Alan Kemerling  
Ethicon, Inc.

Myer Kutz  
Myer Kutz Associates, Inc.  
Delmar, New York

Anthony Luscher  
Ohio State University  
Columbus, Ohio

Allan Matthews  
Sheffield University  
Sheffield, United Kingdom

James E. McMunigal  
MCM Associates  
Long Beach, California

Ruth E. McMunigal  
MCM Associates  
Long Beach, California

Walter W. Olson  
University of Toledo  
Toledo, Ohio

Thomas G. Ray  
Louisiana State University  
Baton Rouge, Louisiana

Jack B. ReVelle  
Revelle Solutions, LLC  
Santa Ana, California

Murray J. Roblin  
California State Polytechnic University  
Pomona, California

Suzanne L. Rohde  
Infinidium, LLC  
Steamboat Spring, Colorado

Cynthia M. Sabelhaus  
Raytheon Missile Systems Company  
Tucson, Arizona

Bhaba R. Sarker  
Louisiana State University  
Baton Rouge, Louisiana

Robert N. Schwarzwald, Jr.  
Stanford University  
Stanford, California

Michael Slocum  
Breakthrough Management Group  
Longmont, Colorado

Bruce M. Steinetz  
NASA Glenn Research Center at Lewis Field  
Cleveland, Ohio

Eric H. Stapp  
Raytheon Missile Systems Company  
Tucson, Arizona

Hans J. Thamhain  
Bentley University  
Waltham, Massachusetts

Steve W. Tuszynski  
Algoryx, Inc.  
Los Angeles, California

Steven Ungvari  
Strategic Product Innovations, Inc.  
Columbus, Ohio

Dennis B. Webster  
Louisiana State University  
Baton Rouge, Louisiana

Alvin S. Weinstein  
Weinstein Associates International  
Delray Beach, Florida

Magd E. Zohdi  
Louisiana State University  
Baton Rouge, Louisiana

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**PART 1**

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# **MANUFACTURING**



# CHAPTER 1

## ORGANIZATION, MANAGEMENT, AND IMPROVEMENT OF MANUFACTURING SYSTEMS

Keith M. Gardiner  
Lehigh University  
Bethlehem, Pennsylvania

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### 1 INTRODUCTION: WHAT IS THIS CHAPTER ABOUT?

There are many books, pricey consultants, guides, expensive courses, and magazine articles telling us how to improve. Improvers tell us how to do everything from diet, exercise, staying healthy, relaxing, sleeping, investing, fixing our homes, and growing vegetables to bringing up our children—there are recommended fixes available for every human condition! This trend is



nowhere more prevalent than in business and industry and most especially in manufacturing. The challenge for this chapter is to deliver meaningful content that, if applied diligently, will enable readers to improve their manufacturing systems.

We must go beyond the acronyms and buzzwords, and here there are strong parallels with self-improvement. To be successful, self-improvement and a diet or exercise regimen first requires admission, recognition, and consciousness of the necessity for improvement. The next step required is to realize that improvement is possible; then there must be a willingness and eager enthusiasm to meet the challenges and commence the task or tasks; this can be very difficult. It is too easy for managers or erstwhile change agents to place placards by the coffee and soda machines and in the cafeteria with messages like "Learn today and be here tomorrow." Inspirational posters, T-shirts, and baseball caps with logos and slogans are often made available as promotional incentives. This is ignorant folly and can rapidly turn any improvement project into a cliché and workplace joke.

A leading slogan (maybe some slogans are unavoidable) is continuous improvement. Here the models from sports or the arts are appropriate. Athletes and musicians practice, learn, and train, almost as a way of life. Similar approaches and habits must be introduced to the manufacturing regimen. Here, management must lead by example and act as coaches while at the same time accepting that they also must be engaged in continuing endeavors to improve. Commitment and the enthusiasm of management, accompanied by visible participation, are essential. In fact, no improvement initiative should be launched without a prior thoroughgoing and preferably independent objective analysis to assess the morale of the whole operation or enterprise. Incorrect assumptions by leadership will result in poor planning, possibly inappropriate emphasis, and ineffective implementation. As a consequence there could be negative effects on workplace morale, and the initiative could be destined for failure.

Beyond this it is wise to recognize that any initiative will inevitably have a life cycle.<sup>1</sup> Thus, planning and implementation must be very careful and deliberate. Initiatives of this nature should not be considered as once and done. There must be long-range plans for continuation, revitalization, and refreshment. To be successful, the improvement initiative(s) must become embedded into the culture and practices of the enterprise. It must become a habit, and resources must be allocated to support successful implementation and on-going maintenance.

Improvement can be an abstract notion, but any improvement must be accompanied by a thorough analysis and understanding of exactly what is to be improved. An athlete has many performance metrics, such as resting pulse, heart and lung capacities, treadmill and weight performances, times for standard tests, and ultimately, of course, competitive results. Practice and training regimens are developed to focus on areas of weakness and to develop greater capabilities in zones of opportunity. Time is spent in counseling, measuring, and planning with development of very specific exercises on a continuing basis. It is rare to discover this kind of detailed attention being paid to the improvement of individuals, teams, or their performance in manufacturing enterprises. Nevertheless this is an essential concomitant to any improvement regions.

## 2 NATURE OF MANUFACTURING SYSTEM: ARENA FOR OUR IMPROVEMENT

Systems for manufacture, or production, have evolved appreciably in the last 4000 or so years. The achievements of the Egyptians, Persians, Greeks, Romans, and others must not be ignored. They were able to leave us countless superbly manufactured artifacts and equip their military as efficient conquerors. It is interesting and worthwhile to define the production or manufacturing system in this context. Our system can be viewed as "a system whereby resources (including materials and energy) are transformed to produce goods (and/or services) with generation of wealth."<sup>2</sup> Our current systems, recent developments, and, particularly, prejudices can be best appreciated and understood by taking a brief glance back in time to review the nature, management, and characteristics of some of these early production systems.

Most early systems were directed and under the control of local rulers. In many locations these pharaohs, princes, chieftains, or tribal leaders levied taxes for defense and other purposes of state and also to support their military, social, and manufacturing systems. In Europe, after the fall of the Roman Empire, a distributed regional, state, or manorial system arose that was hierarchical. The local earls, dukes, princes, or lords of the manor owed allegiance and paid taxes to the next levels, the church, and/or threatening despots. This manorial system relied on a tiered dependent and subservient vassal or peasant society. The manor, district, or local manager (or seigneur) gave protection and loans of land to the vassals proportional to perceptions of their contribution to the unit.<sup>3</sup> Products required for daily living, agriculture, clothing, food, meat, and fuel were produced as ordered, assuming weather and other conditions were satisfactory.

Major large-scale projects to meet architectural, marine, defense, societal, and funereal purposes (harbors, fortifications, aqueducts, and memorial structures) involved substantial mobilization of resources and possibly the use of slaves captured in wars. Smaller artifacts were made by single artisans or by small groups working collectively; agricultural production was also relatively small scale and primarily for local markets. In these early days the idea of an enterprise was synonymous with the city or city-state itself. When the armies needed equipment, swords, and armor, orders were posted and groups of artisans worked to fill them. Organization during these periods was hierarchical and devolved around the state and a ruling class. Religion also played a major role in structuring the lives of the populace.

The artisan groups organized themselves into guilds establishing standards for their craft, together with differentiation, fellowship, and support for those admitted to full membership. There was training for apprentices and aid for widows and orphans when a member died. Guilds participated actively in the religious life of the community, built almshouses, and did charitable works.<sup>4</sup> It can be surmised that guild leaders of the miners in Saxony, for example, would have the power, experience, and qualifications to negotiate working conditions with the lord of the manor or leader of the principality and mine owner. The guild would also claim some share in the revenues of the mining and metal winning operations. Mining and manufacturing operations in Saxony were described extensively in *De Re Metallica*, a notable text by Agricola in 1556 translated into English by the Hoovers.<sup>5</sup>

The guild workplaces, mines, smelters, waterwheel-powered forges, hammers (described by Agricola), grist mills, and the like were the early factories. The existence of a water-powered paper mill in England is recorded as early as 1494. The printing operations of Gutenberg in what was to become Germany and of Caxton in England in 1454 and 1474, respectively, were small factories. Early armorers must have worked in groups supported by cupolas, furnaces, hearths, and power systems. A most renowned early factory was the Arsenale (arsenal) in Venice. This was a dockyard operated by the city-state that opened around the eighth century, with major new structures (Arsenale Nuovo) started in 1320. At its height in the sixteenth century, the arsenal was capable of producing one ship per day using an assembly line with mass production methods, prefabrication of standardized parts, division of labor, and specialization.<sup>6</sup> Power sources during these periods were limited to levers, winches, and cranes driven by human or animal power, wind, or water. To a large extent these systems were reasonably sustainable but were vulnerable to unpredictable social, climatic, or other disasters.

During the period marked as the Industrial Revolution, available power densities increased markedly. Improvements in engineering and materials increased the efficiency and size of waterwheels and their associated transmission systems. There is a tendency, certainly in the United Kingdom and United States, to mark the improvement of the steam engine by Boulton and Watt and the discussions of the Lunar Society as the inception of the Industrial Revolution.<sup>7</sup> In fact, effective production systems were already extant and evolving as the result of global influences. The scale and scope increased as a result of this major change in available power density. Factories grew up around sources of power, materials, and potential employees.