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# 机械工程设计 (第七版 改编版)

## Mechanical Engineering Design (Seventh Edition)

原著 Joseph E. Shigley, Charles R. Mischke, Richard G. Budynas

改编 刘向锋 高 志

 高等教育出版社

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# 机械工程设计

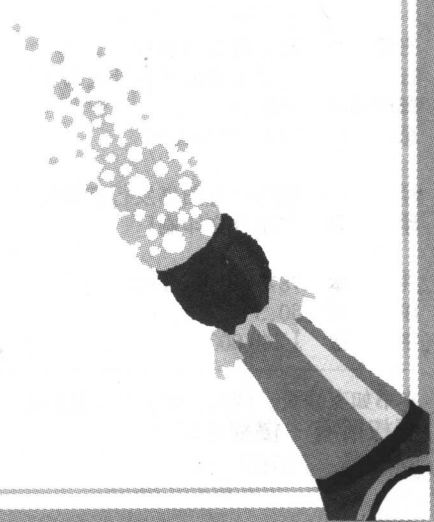
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图字: 01 - 2005 - 2297

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Mechanical Engineering Design, Seventh Edition

ISBN: 0 - 07 - 123270 - 2

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### 图书在版编目(CIP)数据

机械工程设计:第7版:改编版:英文/(美)希格力  
(Shigley, J. E.), (美)米施卡(Mischke, C. R.),  
(美)布迪纳斯(Budynas, R. G.)著;刘向锋,高志改编.  
—北京:高等教育出版社,2007.4  
ISBN 978-7-04-020757-6

I. 机… II. ①希…②米…③布…④刘…⑤高…  
III. 机械设计-高等学校-教材-英文 IV. TH122

中国版本图书馆 CIP 数据核字(2007)第 032925 号

出版发行 高等教育出版社  
社 址 北京市西城区德外大街 4 号  
邮政编码 100011  
总 机 010-58581000

经 销 蓝色畅想图书发行有限公司  
印 刷 北京外文印刷厂

开 本 787×1092 1/16  
印 张 50.5  
字 数 1 240 000

购书热线 010-58581118  
免费咨询 800-810-0598  
网 址 <http://www.hep.edu.cn>  
<http://www.hep.com.cn>  
网上订购 <http://www.landaco.com>  
<http://www.landaco.com.cn>  
畅想教育 <http://www.widedu.com>

版 次 2007 年 4 月第 1 版  
印 次 2007 年 4 月第 1 次印刷  
定 价 62.00 元

本书如有缺页、倒页、脱页等质量问题,请到所购图书销售部门联系调换。

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物料号 20757-00

## 出版说明

为进一步适应高等教育教学改革发展的趋势,加速培养具有国际竞争力的高素质优秀人才,教育部在《关于加强高等学校本科教学工作提高教学质量的若干意见》的通知(教高[2001]4号)中提出:“本科教育要创造条件使用英语等外语进行公共基础课和专业课教学。”目前,按照教育部教高[2001]4号文件的精神,我国各类高校都以不同的形式全面展开英语或“双语”教学,教师们在“双语”教学实践中积累了一些经验,同时也对双语教学提出了不同的意见与看法。教材是教学内容与教学方法的知识载体,是教师教学、学生学习的基本工具,也是深化教学改革、提高教学质量的重要保证。因此,一本优秀的“双语”教学教材无疑将对高校开展“双语”教学产生积极的推动作用。许多老师在实践中体会到,没有国外原版教材,“双语”教学犹如无本之木、无源之水,而直接使用国外教材作为“双语”教学的教材在实际授课中也存在诸多弊病。尤其是在机械类课程的教学中,不仅存在着工程标准不同的问题,而且存在着课程内容与课程体系的差异。许多教师在授课过程中采用不同的教材作参考,根据授课的需要将所需的资料拼凑到一起,以解决上述教学中存在的矛盾。因此,由于缺乏合适的双语教材,使双语教学缺乏进入机械类课程课堂教学的基础。

高等教育出版社在发展壮大过程中积极实施国际化的战略,从世界范围内发掘优秀教育资源服务于我国高校的教育教学与人才培养,为我国高等教育的持续发展提供精工细作的食粮。针对我国高校开展“双语”教学的现状,我社积极开展与 Pearson Education、John Wiley & Sons、McGraw-Hill 以及 Thomson Learning 等国外大型教育出版集团合作,以不同的方式将国外优秀教材输送到我国高等教育的第一线。针对机械类课程的特点及我国高校机械类课程开展“双语”教学存在的问题,我社与国内外的专家一道,努力打造适合国内教学的“双语”教学教材。为此,我社积极组织国内外专家,展开了改编国外优秀教材,为我国机械类课程“双语”教学量体裁衣的尝试。

首先,精选教材。我们广泛了解我国高校机械类课程开展“双语”教学的情况,了解高校广大师生在开展“双语”教学的过程中对教材的需求。然后,我们与多家国外出版公司进行了广泛接触,经推荐并在国内专家的协助下,精选了涉及机械、材料、能源动力、工程图学等学科专业领域的优秀教材几十种之多。我们聘请了国内高校一线教师、专家学者参与这些原版教材的评介工作,从中遴选出了一批优秀教材进行改编,并组织出版。



这批教材普遍具有以下特点：(1) 基本上是近几年出版的，在国际上被广泛使用，在同类教材中具有相当的权威性；(2) 高版次，历经多年教学实践检验，内容翔实准确，反映时代要求；(3) 各种教学资源配套整齐，为师生提供了极大的便利；(4) 插图精美、丰富，图文并茂，与正文相辅相成；(5) 语言简练、流畅，可读性强，比较适合非英语国家的学生阅读。

其次，慎选改编者。教材的优劣将直接影响到教学质量的高低，而一位学识渊博、治学严谨的作者必然编写出高水平的精品教材。我们与国内众多高等院校的专家学者进行了广泛的接触和细致的协商，几经酝酿，最终确定下来改编者。大多数改编者都是有国外留学背景的中青年学者，他们既有相当高的学术水平，又热爱教学，活跃在教学第一线。他们能够承担此任，不单是因为他们了解引进版教材的知识结构、表达方式和写作方法，更重要的是他们有精力、有热情，愿意付出，有的甚至付出了比写一本新教材更多的劳动。我们向他们表示最真诚的谢意。

在努力降低引进教材售价方面，高等教育出版社做了大量和细致的工作，这套引进改编的教材体现了一定的权威性、系统性、先进性和经济性等特点。

改编国外优秀教材，就是在保留国外原版教材风格的基础上，使之满足国内教学的实际需要，这样，不仅加强了学生的英语实际应用能力，引进了国外优秀教材所包含的先进的科技知识，而且引进了先进的教育理念、教学思想。我们希望这套教材能够为我国高校“双语”教学的教材建设带来启示，同时也对推进我国高校机械类课程“双语”教学有所裨益。

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# 前言

为了加快培养具有国际竞争力的高水平技术人才,加快我国高等教育改革的步伐,教育部近来出台了一系列倡导高校开展英语或双语教学、引进原版教材的政策。引进国外优秀原版教材,在有条件的学校推动开展英语授课或双语教学,自然也引进了先进的教学思想和教学方法,这对提高我国自编教材的水平,加强学生的英语实际应用能力,使我国的高等教育尽快与国际接轨,必将起到积极的推动作用。

*Mechanical Engineering Design* 为美国密歇根大学 Joseph E. Shigley 教授等著,是美国大学广泛使用的一本机械工程设计教材,具有极高的权威性。1956 年,Joseph E. Shigley 教授独自开始编写机械工程设计教材,后逐渐发展成为目前的机械工程设计教材。Joseph E. Shigley 于 1994 年 5 月去世,其合作者仍然以 Joseph E. Shigley 教授的名义出版修订版至目前的第七版。修订版继续沿用原教材的基本内容和编写体系,可见该教材深受美国业内人士的广泛认同和欢迎。书中内容涵盖了设计过程、工程力学与材料、静载荷与动载荷下的防止失效、典型机械零部件设计等内容,提供了大量解决工程实际问题的方法和实例。该教材一直受到我国从事机械设计教学和研究人员的高度重视。作为国外权威性教材,高等教育出版社曾组织该书第三版(1980 年)和第四版(1988 年)的翻译出版工作,从而使国内同行深入了解和掌握美国机械设计相关课程的教学内容、体系、方法和发展,取得了很好的效果。机械工业出版社于 2002 年出版了该书(第六版)的英文影印版,为国内机械设计课程的双语教学起到了积极的推动作用。

本书由清华大学刘向锋(第 1 至 7 章、附录)、高志(第 8 至 13 章)改编,在对原书内容进行筛选和改编的过程中,清华大学精密仪器与机械学系设计工程研究所的许多老师提出了许多宝贵的建设性意见,在此致以衷心的感谢!

引进和精选国外原版教材是一项艰苦而细致的工作,将其内容、体系等改编成为适宜中国学生学习的教材还仅仅是初步尝试,加之改编者水平有限,误漏欠妥之处在所难免。欢迎广大同仁和读者批评指正。

改编者

2006 年 10 月于清华园

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# 1

## Introduction

### Chapter Outline

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This chapter introduces a number of ideas, many of which are new to you either in context or substance. Mechanical design is a complex undertaking, requiring many skills. A vocabulary that allows large relationships to be subdivided into a series of simple tasks is needed. The complexity of the subject suggests a sequence in which ideas are introduced and revisited. Toward this end, we consider a number of topics briefly in this chapter to serve as an orientation. Later these topics are developed in detail, their bones fleshed out, and they will become part of you.

We first address the nature of design in general, then mechanical engineering design in particular. Design is an iterative process with many interactive phases. Learning and mastering is an ongoing process as you finish your formal education and throughout your career. Many resources exist to support the designer, including sources of information such as the Internet and an abundance of computational design tools. There are roles to be played by codes and standards, ever-present economics, safety, and considerations of product liability.

Then the focus of the chapter narrows, and the primal skill of the designer—adequacy assessment—is considered. Matters of uncertainty have been ever-present in engineering design, and methods have been evolved that draw on growing knowledge. Attention is given to stress and strength and to the distinction between design factor and factor of safety. Reliability is considered, as are units, preferred units, calculations, and significant figures.

Decision-making processes are common to all disciplines in the field of engineering design—not just to mechanical engineering design. But, since our subject is mechanical engineering design, we will use mechanical engineering as the vehicle for understanding these decision-making processes and for applying them to practical situations.

## 1 – 1 Design

To design is either to formulate a plan for the satisfaction of a specified need or to solve a problem. If the plan results in the creation of something having a physical reality, then the product must be functional, safe, reliable, competitive, usable, manufacturable, and marketable. These terms are defined as follows:

- *Functional*: The product must perform to fill its intended need and customer's expectation.
- *Safe*: The product is not hazardous to the user, bystanders, or surrounding property. Hazards that cannot be “designed out” are eliminated by guarding (a protective enclosure). If that is not possible, appropriate directions or warnings are provided.
- *Reliable*: Reliability is the conditional probability, at a given confidence level, that the product will perform its intended function satisfactorily or without failure at a given age.
- *Competitive*: The product is a contender in its market.
- *Usable*: The product is “user friendly,” accommodating to human size, strength, posture, reach, force, power, and control.



- *Manufacturable*: The product has been reduced to a “minimum” number of parts, suited to mass production, with dimensions, distortion, and strength under control.

- *Marketable*: The product can be bought, and service (repair) is available.

To remind us that designs are constrained, and have to exhibit qualities known at the outset, a *design imperative* can be expressed as follows:

Design

(subject to certain problem-solving constraints)

a component, system, or process

that will perform a specified task

(subject to certain solution constraints)

optimally.

The parenthetical expressions refer to qualifications placed on the design. The solution methodology is constrained by what the designer knows, or can do; the solution, in addition to being functional, safe, reliable, Competitive, usable, manufacturable, and marketable, must also be legal and conform to applicable codes and standards.

It is important that the designer begin by identifying exactly how he or she will recognize a satisfactory alternative, and how to distinguish between two satisfactory alternatives in order to identify the better. From this kernel, optimization strategies can be formed or selected. Then, the following tasks are unfolded:

- Invent alternative solutions.
- Establish key performance metrics.
- Through analysis and test, simulate and predict the performance of each alternative, retain satisfactory alternatives, and discard unsatisfactory ones.
- Choose the best satisfactory alternative discovered as an approximation to optimality.
- Implement the design.

The characterization of a design task as a design *problem* can introduce the idea that, as a problem, it has a solution. This may not be so. The design space may be empty. Some situations may simply have to be endured. To relieve the absence of solutions, some constraint(s) may have to be renegotiated in order to admit solutions. Then again, even when solutions are possible, the designer may not be creative enough, inventive enough, to conceive of them. This admits to the design problem the necessity of individual talent or skill in this area.

There is usually more than one solution, and distinguishing among them to choose the best may require the ability to handle a large number of solutions without being overwhelmed. Solutions, if they exist, can be characterized as satisfactory, some better than others, some clearly good, and one, the best by some criterion. Solutions can have a time dependency, for what is acceptable today may not be so tomorrow, and vice versa.



Design is an innovative and highly iterative process. It is also a decision-making process. Decisions sometimes have to be made with too little information, occasionally with just the right amount of information, or with a surfeit of partially contradictory information. A man with a watch knows what time it is; with two watches, he is never sure. Decisions are sometimes made tentatively, reserving the right to adjust as more becomes known. The point is that the engineering designer has to be personally comfortable with a decision-making, problem-solving role. It should be a satisfying and welcomed activity. If it is not, there can be personal ramifications (such as stress) that can interfere, even threatening the designer's health.

Design is a communication-intensive activity in which both words and pictures are used, and written and oral forms are employed. Engineers have to communicate effectively and work with people of many disciplines who know more than they do, or less than they do. These are important skills, and an engineer's success depends on them.

A designer's personal resources of creativeness, communicative ability, and problemsolving skill are intertwined with knowledge of technology and first principles. Engineering tools (such as mathematics, statistics, computer, graphics, and language) are combined to produce a plan, which, when carried out, produces a product that is functional, safe, reliable, competitive, usable, manufacturable, and marketable, regardless of who builds it or who uses it.

## 1 - 2 Mechanical Engineering Design

Mechanical engineers are associated with the production and processing of energy and with providing the means of production, the tools of transportation, and the techniques of automation. The skill and knowledge base are extensive. Among the disciplinary bases are mechanics of solids and fluids, mass and momentum transport, manufacturing processes, and electrical and information theory. Mechanical engineering design involves all the disciplines of mechanical engineering.

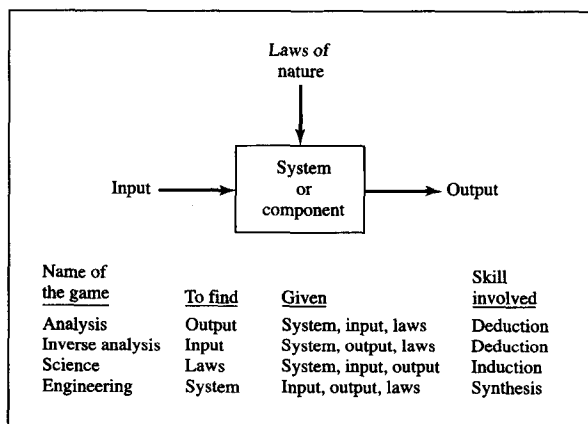
Problems resist compartmentation. A simple journal bearing involves fluid flow, heat transfer, friction, energy transport, material selection, thermomechanical treatments, statistical descriptions, and so on. A building is environmentally controlled. The heating, ventilation, and air-conditioning considerations are sufficiently specialized that some speak of *heating, ventilating, and air-conditioning design* as if it is separate and distinct from mechanical engineering design. Similarly, *internal-combustion engine design*, *turbomachinery design*, and *jet-engine design* are sometimes considered discrete entities. The leading adjectival string of words preceding the word *design* is merely a product-descriptive aid to the communication process. There are phrases such as *machine design*, *machine-element design*, *machine-component design*, *systems design*, and *fluid-power design*. All of these phrases are somewhat more focused examples of mechanical engineering design. They all draw on the same bodies of knowledge, are similarly organized, and require similar skills.





In the academic world, with its clustering of knowledge into efficient learning groups, we encounter subjects, courses, disciplines, and fields. Curricula consist of sequences of courses. The arrangement of courses present the opportunity to study machine elements and machines earlier than the last semester. Thus machine design often represents the student's first serious design experience with a substantial knowledge base. Some, but not many machine elements can be understood without a complete thermofluid base, but before you know it, we are into mechanical engineering design.

Science explains what *is*; engineering creates what *never was*. Mathematics is neither science nor engineering. Physics and chemistry are science, but not engineering.



**Figure 1-1**

The name(s) of the game(s).

Note distinctions between analysis, science, and engineering and the significant skills involved.

As suggested in Fig. 1-1, it takes one kind of talent to be a scientist and a different talent to create what never was. Engineers and scientists know something of each other's work, but only in rare cases are both talents developed in an individual. It takes talent and ability to create and innovate, talent to be a consistently successful problem solver and decision maker, and talent to be an effective communicator. Preparation, you see, is the developing and polishing of talent, whatever the endeavor.

### ***Rational Decision Making***

Designers have to make decisions, few or many, some a priori, some in concert. Rational design making is a systematic design process involving the following key elements.

#### **Key 1: Suitability, Feasibility, Acceptability**

When the military establishment recognized the importance of clear thinking and rational decision making for its general officers, it sought engineers' advice on how to proceed. The military reasoned that engineers commit enormous resources to large projects, with no possibility of starting over. The advice offered can be distilled to the following:

- A contemplated action is *suitable* if its adoption will indeed accomplish the intended purpose.
- A contemplated action is *feasible* if the action can be carried out with the knowledge, personnel, money, and material at hand, or if it can be assembled in time.