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机械设计过程

The Mechanical Design Process

(美) 大卫 G.乌尔曼(David G.Ullman) 著

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这套教材出版后，我们将根据各高校的双语教学计划，及时地将其推荐给各高校选用。希望高校师生在使用教材后及时反馈意见和建议，使我们更好地为教学改革服务。

机械工业出版社

2010年1月

序

机械工业出版社在2006年出版了美国大卫 G·乌尔曼(David G. Ullman)所著《机械设计过程》第3版的中文翻译本，几年以后我们又见到了该书英文原版的第4版，这一版在保留原有特色的基础上有了较大的改进，反映了机械设计近年来的一些重要的发展和研究成果。

本书明确提出了“产品设计”的设计原理，是针对产品设计的设计思想、理论、技术和方法的总结，而对于那些针对“机构”和“零件结构”的设计手段，只作为基础知识介绍。同时，本书全面、具体地给出了“设计学”的基本内容，详细地引出了设计的典型步骤，每一个步骤的任务和目标，应考虑的主要问题和常用的解决方法，对产品设计具有很好的指导作用。本书的主要特点是：

1. 针对各章节知识点给出了计算机设计用的表格，供设计者参考。
2. 给出了更多的设计实例和照片。
3. 各章前面给出了“要点问题”(Key questions)，使读者阅读时目标更加明确。
4. 更新了参考资料，使本书更加实用。
5. 调整了内容，例如新增了山地自行车的设计实例。

总之，本书比第3版有了较大的改进，特别是加强或增加了计算机在机械设计中应用的内容。读者不但在内容方面可以看到本门学科的发展，而且可以发现本书在教材编写方面有较大的特色：语言生动，条理清晰，旁征博引。其引用的名言或实例恰到好处，使读者更好理解，获益更多。这种方式，对机械设计教学的改进有较大的启发。此外，机械工业出版社在出版《机械设计过程》第3版的中文翻译本以后，出版该书第4版的英文版，也是一种新的尝试，这将有利于引导教师和学生，把不同版本的中英文教材互相参照，进而直接阅读英文教材，起到阶梯和辅助作用。

希望这本英文教材的出版，给读者学习和工作提供更多的帮助。

吴宗泽

于清华大学

PREFACE

I have been a designer all my life. I have designed bicycles, medical equipment, furniture, and sculpture, both static and dynamic. Designing objects has come easy for me. I have been fortunate in having whatever talents are necessary to be a successful designer. However, after a number of years of teaching mechanical design courses, I came to the realization that I didn't know how to teach what I knew so well. I could show students examples of good-quality design and poor-quality design. I could give them case histories of designers in action. I could suggest design ideas. But I could not tell them what to do to solve a design problem. Additionally, I realized from talking with other mechanical design teachers that I was not alone.

This situation reminded me of an experience I had once had on ice skates. As a novice skater I could stand up and go forward, lamely. A friend (a teacher by trade) could easily skate forward and backward as well. He had been skating since he was a young boy, and it was second nature to him. One day while we were skating together, I asked him to teach me how to skate backward. He said it was easy, told me to watch, and skated off backward. But when I tried to do what he did, I immediately fell down. As he helped me up, I asked him to tell me exactly what to do, not just show me. After a moment's thought, he concluded that he couldn't actually describe the feat to me. I still can't skate backward, and I suppose he still can't explain the skills involved in skating backward. The frustration that I felt falling down as my friend skated with ease must have been the same emotion felt by my design students when I failed to tell them exactly what to do to solve a design problem.

This realization led me to study the process of mechanical design, and it eventually led to this book. Part has been original research, part studying U.S. industry, part studying foreign design techniques, and part trying different teaching approaches on design classes. I came to four basic conclusions about mechanical design as a result of these studies:

1. The only way to learn about design is to do design.
2. In engineering design, the designer uses three types of knowledge: knowledge to generate ideas, knowledge to evaluate ideas and make decisions, and knowledge to structure the design process. Idea generation comes from experience and natural ability. Idea evaluation comes partially from experience and partially from formal training, and is the focus of most engineering education. Generative and evaluative knowledge are forms of domain-specific knowledge. Knowledge about the design process and decision making is largely independent of domain-specific knowledge.
3. A design process that results in a quality product can be learned, provided there is enough ability and experience to generate ideas and enough experience and training to evaluate them.

4. A design process should be learned in a dual setting: in an academic environment and, at the same time, in an environment that simulates industrial realities.

I have incorporated these concepts into this book, which is organized so that readers can learn about the design process at the same time they are developing a product. Chaps. 1–3 present background on mechanical design, define the terms that are basic to the study of the design process, and discuss the human element of product design. Chaps. 4–12, the body of the book, present a step-by-step development of a design method that leads the reader from the realization that there is a design problem to a solution ready for manufacture and assembly. This material is presented in a manner independent of the exact problem being solved. The techniques discussed are used in industry, and their names have become buzzwords in mechanical design: quality function deployment, decision-making methods, concurrent engineering, design for assembly, and Taguchi's method for robust design. These techniques have all been brought together in this book. Although they are presented sequentially as step-by-step methods, the overall process is highly iterative, and the steps are merely a guide to be used when needed.

As mentioned earlier, domain knowledge is somewhat distinct from process knowledge. Because of this independence, a successful product can result from the design process regardless of the knowledge of the designer or the type of design problem. Even students at the freshman level could take a course using this text and learn most of the process. However, to produce any reasonably realistic design, substantial domain knowledge is required, and it is assumed throughout the book that the reader has a background in basic engineering science, material science, manufacturing processes, and engineering economics. Thus, this book is intended for upper-level undergraduate students, graduate students, and professional engineers who have never had a formal course in the mechanical design process.

ADDITIONS TO THE FOURTH EDITION

Knowledge about the design process is increasing rapidly. A goal in writing the fourth edition was to incorporate this knowledge into the unified structure—one of the strong points of the first three editions. Throughout the new edition, topics have been updated and integrated with other best practices in the book. Some specific additions to the new edition include:

1. Improved material to ensure team success.
2. Over twenty blank templates are available for download from the book's website (www.mhhe.com/ullman4e) to support activities throughout the design process. The text includes many of them filled out for student reference.
3. Improved material on project planning.

4. Improved sections on Design for the Environment and Design for Sustainability.
5. Improved material on making design decisions.
6. A new section on using contradictions to generate ideas.
7. New examples from the industry, with new photos and diagrams to illustrate the examples throughout.

Beyond these, many small changes have been made to keep the book current and useful.

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CONTENTS (目录)

CHAPTER 1

Why Study the Design Process?

KEY QUESTIONS

- What can be done to design quality mechanical products on time and within budget?
- What are the ten key features of design best practice that will lead to better products?
- What are the phases of a product's life cycle?
- How are design problems different from analysis problems?
- Why is it during design, the more you know, the less design freedom you have?
- What are the Hanover Principles?

1.1 INTRODUCTION

Beginning with the simple potter's wheel and evolving to complex consumer products and transportation systems, humans have been designing mechanical objects for nearly five thousand years. Each of these objects is the end result of a long and often difficult design process. This book is about that process. Regardless of whether we are designing gearboxes, heat exchangers, satellites, or doorknobs, there are certain techniques that can be used during the design process to help ensure successful results. Since this book is about the *process* of mechanical design, it focuses not on the design of any one type of object but on techniques that apply to the design of all types of mechanical objects.

If people have been designing for five thousand years and there are literally millions of mechanical objects that work and work well, why study the design process? The answer, simply put, is that there is a continuous need for new, cost-effective, high-quality products. Today's products have become so complex that most require a team of people from diverse areas of expertise to develop an idea into hardware. The more people involved in a project, the greater is the need for assistance in communication and structure to ensure nothing important is overlooked and customers will be satisfied. In addition, the global marketplace has fostered the need to develop new products at a very rapid and accelerating pace. To compete in this market, a company must be very efficient in the design of its products. It is the process that will be studied here that determines the efficiency of new product development. Finally, it has been estimated that 85% of the problems with new products not working as they should, taking too long to bring to market, or costing too much are the result of a poor design process.

The goal of this book is to give you the tools to develop an efficient design process regardless of the product being developed. In this chapter the important features of design problems and the processes for solving them will be introduced. These features apply to any type of design problem, whether for mechanical, electrical, software, or construction projects. Subsequent chapters will focus more on mechanical design, but even these can be applied to a broader range of problems.

Consider the important factors that determine the success or failure of a product (Fig. 1.1). These factors are organized into three ovals representing those factors important to product design, business, and production.

Product design factors focus on the product's function, which is a description of what the object does. The importance of function to the designer is a major topic of this book. Related to the function are the product's form, materials, and manufacturing processes. Form includes the product's architecture, its shape, its color, its texture, and other factors relating to its structure. Of equal importance to form are the materials and manufacturing processes used to produce the product. These four variables—function, form, materials, and manufacturing processes—

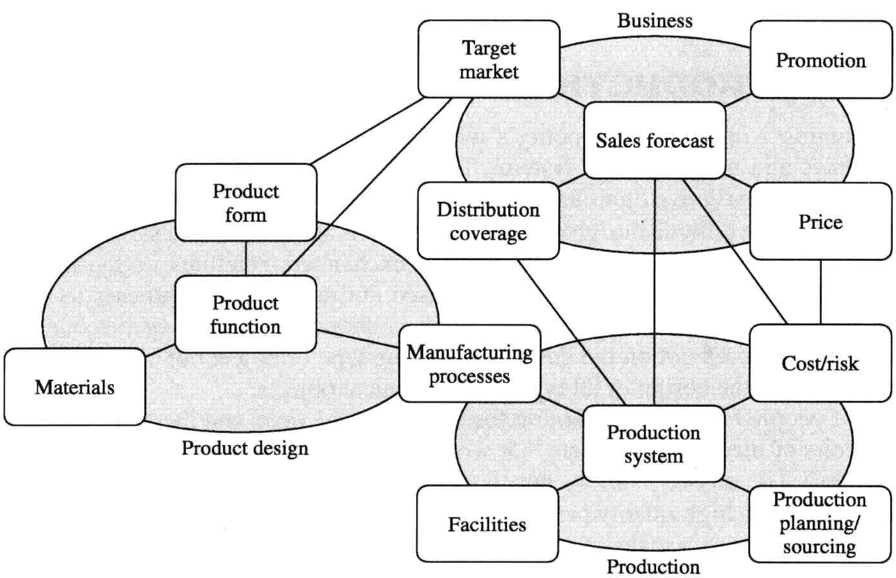

Figure 1.1 Controllable variables in product development.

are of major concern to the designer. This product design oval is further refined in Fig. 9.3.

The product form and function is also important to the business because the customers in the target market judge a product primarily on what it does (its function) and how it looks (its form). The target market is one factor important to the business, as shown in Fig. 1.1. The goal of a business is to make money—to meet its sales forecasts. Sales are also affected by the company's ability to promote the product, distribute the product, and price the product, as shown in Fig. 1.1.

The business is dependent not only on the product form and function, but also on the company's ability to produce the product. As shown in the production oval in Fig. 1.1, the production system is the central factor. Notice how product design and production are both concerned with manufacturing processes. The choice of form and materials that give the product function affects the manufacturing processes that can be used. These processes, in turn, affect the cost and hence the price of the product. This is just one example of how intertwined product design, production, and businesses truly are. In this book we focus on the product design oval. But, we will also pay much attention to the business and production variables that are related to design. As shown in the upcoming sections, the design process has a great effect on product cost, quality, and time to market.

1.2 MEASURING THE DESIGN PROCESS WITH PRODUCT COST, QUALITY, AND TIME TO MARKET

The three measures of the effectiveness of the design process are product cost, quality, and time to market. Regardless of the product being designed—whether it is an entire system, some small subpart of a larger product, or just a small change in an existing product—the customer and management always want it cheaper (lower cost), better (higher quality), and faster (less time).

The actual cost of designing a product is usually a small part of the manufacturing cost of a product, as can be seen in Fig. 1.2, which is based on data from Ford Motor Company. The data show that only 5% of the manufacturing cost of a car (the cost to produce the car but not to distribute or sell it) is for design activities that were needed to develop it. This number varies with industry and product, but for most products the cost of design is a small part of the manufacturing cost.

However, the effect of the quality of the design on the manufacturing cost is much greater than 5%. This is most accurately shown from the results of a detailed study of 18 different automatic coffeemakers. Each coffeemaker had the same function—to make coffee. The results of this study are shown in Fig. 1.3. Here the effects of changes in manufacturing efficiency, such as material cost, labor wages, and cost of equipment, have been separated from the effects of the design process. Note that manufacturing efficiency and design have about the same influence on the cost of manufacturing a product. The figure shows that