高等学校“十一五”规划教材
机械设计制造及其自动化系列

ADVANCED MANUFACTURING TECHNOLOGY

先进制造技术

主编　施　平

哈爾濱工業大學出版社

内容提要

先进制造技术(Advanced Manufacturing Technology)是国际上20世纪80年代末提出的一门综合性、交叉性前沿学科。本书介绍了先进制造技术的基本内容,其中包括:计算机辅助设计、制造、检验、成本估算,并行工程,快速原型制造,数字化制造,数控,机器人,机械量测量和现代制造技术,如:涂层刀具、高速切削、硬态切削、干式切削、缓进给磨削、微细加工、纳米技术等。

本书采用英文编写。在文字上力求规范,通俗易懂,繁简得当,以满足双语教学的要求。本书可以作为机械设计制造及自动化、机械电子工程、航空宇航制造工程、工业工程等专业高年级本科生和硕士研究生的教学参考书,亦可作为专业英语教材。

图书在版编目(CIP)数据

先进制造技术 = Advanced Manufacturing Technology/施平主编.—哈尔滨:哈尔滨工业大学出版社,2006.8

ISBN 7-5603-2334-0

Ⅰ.先…　Ⅱ.施…　Ⅲ.①机械制造工艺 - 高等学校 - 教材 - 英文　Ⅳ.TH16

中国版本图书馆 CIP 数据核字(2006)第013261号

责任编辑　潘　鑫
封面设计　卞秉利
出版发行　哈尔滨工业大学出版社
社　　址　哈尔滨市南岗区复华四道街10号　邮编150006
传　　真　0451 - 86414749
网　　址　http://hitpress.hit.edu.cn
印　　刷　黑龙江省地质测绘印制中心印刷厂
开　　本　787mm×1092mm　1/16　印张11　字数265千字
版　　次　2006年8月第1版　2006年8月第1次印刷
印　　数　1~4 000
定　　价　18.80元

高等学校"十一五"规划教材

机械设计制造及其自动化系列

总　序

自1999年教育部对普通高校本科专业设置目录调整以来，各高校都对机械设计制造及其自动化专业进行了较大规模的调整和整合，制定了新的培养方案和课程体系。目前，专业合并后的培养方案、教学计划和教材已经执行和使用了几个循环，收到了一定的效果，但也暴露出一些问题。由于合并的专业多，而合并前的各专业又有各自的优势和特色，在课程体系、教学内容安排上存在比较明显的"拼盘"现象；在教学计划、办学特色和课程体系等方面存在一些不太完善的地方；在具体课程的教学大纲和课程内容设置上，还存在比较多的问题，如课程内容衔接不当、部分核心知识点遗漏、不少教学内容或知识点多次重复、知识点的设计难易程度还存在不当之处、学时分配不尽合理、实验安排还有不适当的地方等。这些问题都集中反映在教材上，专业调整后的教材建设尚缺乏全面系统的规划和设计。

针对上述问题，哈尔滨工业大学机电工程学院从"机械设计制造及其自动化"专业学生应具备的基本知识结构、素质和能力等方面入手，在校内反复研讨该专业的培养方案、教学计划、培养大纲、各系列课程应包含的主要知识点和系列教材建设等问题，并在此基础上，组织召开了由哈尔滨工业大学、吉林大学、东北大学等9所学校参加的机械设计制造及其自动化专业系列教材建设工作会议，联合建设专业教材，这是建设高水平专业教材的良好举措。因为通过共同研讨和合作，可以取长补短、发挥各自的优势和特色，促进教学水平的提高。

会议通过研讨该专业的办学定位、培养要求、教学内容的体系设置、关键知识点、知识内容的衔接等问题，进一步明确了设计、制造、自动化三大主线课程教学内容的设置，通过合并一些课程，可避免主要知识点的重复和遗漏，有利于加强课程设置上的系统性、明确自动化在本专业中的地位、深化自动化系列课程内涵，有利于完善学生的知识结构、加强学生的能力培养，为该系列教材的编写奠定了良好的基础。

本着“总结已有、通向未来、打造品牌、力争走向世界”的工作思路，在汇聚多所学校优势和特色、认真总结经验、仔细研讨的基础上形成了这套教材。参加编写的主编、副主编都是这几所学校在本领域的知名教授，他们除了承担本科生教学外，还承担研究生教学和大量的科研工作，有着丰富的教学和科研经历，同时有编写教材的经验；参编人员也都是各学校近年来在教学第一线工作的骨干教师。这是一支高水平的教材编写队伍。

这套教材有机整合了该专业教学内容和知识点的安排，并应用近年来该专业领域的科研成果来改造和更新教学内容、提高教材和教学水平，具有系列化、模块化、现代化的特点，反映了机械工程领域国内外的新发展和新成果，内容新颖、信息量大、系统性强。我深信：这套教材的出版，对于推动机械工程领域的教学改革、提高人才培养质量必将起到重要推动作用。

蔡鹤皋

哈尔滨工业大学教授

中国工程院院士

2005年8月10日

前言

先进制造技术(Advanced Manufacturing Technology)自20世纪80年代末被提出之后,受到了各国的重视。先进制造技术是各种现代制造技术的总称,被称为面向21世纪的技术。其主要特征是强调实用性,以提高企业的综合经济效益为目的。因此,被认为是提高制造业竞争能力的主要手段,对促进国民经济的发展有着重要的影响。

近年来,先进制造技术这门课程成为了国内外高等工科院校机械工程学生们的一门专业课,可以为他们今后从事技术工作或管理工作打下基础。

中国加入世贸组织后,各发达国家的机械制造业纷纷向中国转移。这对中国的机械制造业来说,既是机遇也是挑战。与此同时,也对机械工程各专业学生的专业知识和专业英语水平提出了更高的要求。

双语教学(使用中文和英语进行专业课程的教学)可以培养学生以英语为工具交流专业信息的能力。教材是教学的基础。为了能够搞好先进制造技术这门课程的双语教学,我们参考了大量近年出版的有关的英文原版专著、教材和期刊杂志,编写出这本英文版教材,力求吸取国内外最新技术成果,满足机械工程各专业的教学要求。

本书由施平主编,梅雪副主编,参加编写工作的还有李越、丁印成,由陈时锦主审。由于水平有限,书中难免有不足和欠妥之处,恳请广大读者批评指正。

编者

2006年1月

Contents

Chapter 1 Computer-Aided Engineering

Over the last twenty years the term computer-aided engineering (CAE) has had several meanings. To some, it implied software that worked with CAD files to analyze geometric designs; others considered CAE as the umbrella covering all computer software used in design and manufacturing. Recently, the term CAx has been used to indicate that many operations in manufacturing are computer aided; you would supply the applicable capital letter/initial for the x. As a result of the past confusion, the study of computer-aided engineering should start with a definition:

CAE is the analysis and evaluation of the engineering design using computer-based techniques to calculate product's operational, functional, and manufacturing parameters which are too complex for classical methods.

Study of the form, fit, and function of products is covered by the terms "operational" and "functional" in the definition, while an examination of the match between the design requirements and the production capability is included in the phrase "manufacturing parameters." The expression "too complex for classical methods" indicates that the process performed by CAE software could be performed manually, but the quantitative difficulty, the number of the computations, or time required for analysis would be prohibitive.

CAE fits into the design process at the synthesis, analysis, and evaluation levels and is also consistent with the concurrent engineering (CE) principles. At the synthesis level, the primary CAE activity is focused on manufacturability using design for manufacturing and assembly principles. The output from the CAE operation at the analysis and evaluation levels is used by the CE team to determine the quality of the product design. Based on this CAE data, the product design is cycled through the steps in the design process until an optimum solution is generated.

Computer-aided engineering provides productivity tools to aid the production engineering area as well. Software to support group technology (GT), computer-aided process planning (CAPP), and computer-aided manufacturing (CAM) are grouped under the broad heading of CAE. The level and variety of CAE software used, however, depends on the amount of concept and repetitive design practised in the company and the type of manufacturing systems present. In the sections that follow, we describe the type of CAE software commonly used throughout the design process and in the production engineering area.

1.1 Computer-Aided Design and Engineering Design Process

Many people believe that the parallel developments in electronics and digital computers constitute the most profound innovations in the history of human progress. Certainly, the development of computer technology was a major milestone whose impact is still unfolding. The first generation of digital computers, even though relatively clumsy and unreliable, permitted scientists and engineers to perform computations at speeds that were orders of magnitude greater than was possible with mechanical calculators. As vacuum tubes gave way to transistors, speed and reliability increased significantly. Interactive, on-line programming became possible through the development of greater memory sizes, remote communication capabilities, and sophisticated operating systems that could accommodate multiple users simultaneously.

Computer technology continued its progress through the development of sophisticated database management systems, mass storage systems, and ever-improving input/output capabilities. Of particular significance was the development of interactive graphics and supporting software.

Supporting the developments in computer technology were significant advancements in electronics. Some of the important developments were integrated circuits, printed circuit boards, LSI (large-scale integrated circuits), VLSI (very large scale integrated circuits), and programmable controllers. These advancements have culminated in the microelectronics revolution, which has literally made "computer chips" a household term. Computer chip technology pervades practically every aspect of our lives. Numerous chips are found in household appliances, automobiles, watches, credit cards, and even in greeting cards!

Modern computer technology also pervades our factories. In later sections of this chapter, we will see some of these applications. There is no question that computers and electronics are changing dramatically the way products are designed, manufactured, distributed, and serviced. This is forcing companies to rethink the way work is organized and performed and the way people relate to each other in our manufacturing facilities. A second industrial revolution is, indeed, well under way.

1.1.1 Computer-Aided Design

Computer-aided design (CAD) involves the use of computers to create design drawings and product models. Computer-aided design systems are powerful tools and are used in the mechanical design and geometric modeling of products and components.

In CAD, the drawing board is replaced by electronic input and output devices. When using a CAD system, the designer can conceptualize the object to be designed more easily on the graphics screen and can consider alternative designs or modify a particular design quickly to meet the necessary design requirements or changes.

Draft productivity rises dramatically. When something is drawn once, it never has to be drawn again. It can be retrieved from a library, and can be duplicated, stretched, sized, and changed in many ways without having to be redrawn. Cut and paste techniques are used as labor-saving aids.

CAD makes possible multiview 2-D drawings, and the drawings can be reproduced at different levels of reduction and enlargement. It gives the mechanical engineer the ability to magnify even the smallest of components to ascertain if assembled components fit properly. Parts with different characteristics, such as movable or stationary, can be assigned different colors on the display. Designers have even more freedom with the advent of 3-D modeling. They can create 3D parts and manipulate them in endless variations to achieve the desired results.

Using the tools of CAD at a graphics terminal, an engineer defines a part shape, analyzes stresses and other factors, simulates mechanical performance, and (if desired) automatically generates an engineering drawing. This process results in a design database, consisting of geometric (shape) data and nongeometric data such as bills of materials, tooling requirements, and other data useful to the user of the design database. The categories of computer-aided design are as follows:

1. Design Development

The design image is created on a graphics terminal from a library of basic geometric elements, such as lines, points, cones, and spheres that are added, subtracted, intersected, or otherwise transformed to construct the geometric shape desired.

2. Design Analysis

On the design just created, the engineer now performs a series of analyses. Software packages accessible from the graphics workstation are used to calculate properties of the design (weight, volume, center of gravity, surface area, etc.) and to analyze stresses, heat transfer properties, and other factors of interest. Finite element analysis software is one of the more common packages available to perform design analysis. Using this technique, the component is subdivided into a network of simple elements that the computer uses to calculate stresses, deflections, and other structural characteristics. In this manner, the engineer can observe how the proposed component would behave and modify it if necessary to obtain the desired behavior. Thus the engineer avoids the building of costly physical models and prototypes.

3. Design Simulation

The design analysis procedure described above can be extended to a complete system model and the performance of a total product can be evaluated. Simulation and animation software routines are employed to examine the paths of moving parts and to analyze more complete mechanisms.

4. Design Review and Evaluation

After the design has been analyzed and simulated, several aspects of design accuracy can be checked on the CAD graphics terminal. Interference checking is one useful procedure for design review that helps reduce the risk that two or more components of an assembled system are trying to occupy the same space at the same time. Dimension and tolerance checking routines are available to help reduce the possibility of dimensioning errors. Software packages are becoming available that assist in assessing manufacturability of a particular design.

5. Automated Drafting

Most CAD systems will automatically generate, upon command, hard-copy engineering drawings for use in process planning and in manufacturing. Some of the features available in automated drafting systems are automatic dimensioning, generation of specific sectional views, crosshatching, and scaling of the drawing.

6. Design Retrieval and Modification

Engineering designs undergo frequent modification. CAD databases allow specific designs to be retrieved for modification, improvement, further analysis, and so on. If a group technology type of parts classification and coding system has been incorporated into the CAD/CAM system, designers can use the classification and coding system to retrieve an existing part design for possible consideration for a new part design. Perhaps the existing design can be modified slightly to serve the function required of the new part.

The CAD system consists of both hardware and software. The CAD hardware will normally include a computer, one or more graphics design terminals, keyboards, a digital tablet, a light pen, a large disk storage device, and a plotter. The computer may be a large mainframe serving as a host to many design terminals, it may be a powerful minicomputer serving four to six design terminals, or it may be a stand-alone CAD design workstation. The CAD software typically consists of special computer graphics packages and a wide variety of application software programs, depending on the type of manufacturing involved, the nature of the product lines, and customer requirements.

1.1.2 The Engineering Design Process

Engineering design is one of the processes normally associated with the entire business or enterprise, from receipt of the order or product idea, to maintenance of the product, and all stages in between. The design process requires input from such areas as customer needs, materials, capital, energy, time requirements, and human knowledge and skills. An example of human knowledge input is an engineer's knowledge of graphics, mathematics, and the sciences. Such knowledge is used by the engineer to analyze and solve problems.

An engineering design involves both a process and a product. A process is a series of continuous actions ending in a particular result. A product is anything produced as a result of some process. As the design of a product or process is developed, the design team applies engineering principles, follows budgetary constraints, and takes into account legal and social issues.

Graphics is an extremely important part of the engineering design process, which uses graphics as a tool to visualize possible solutions and to document the design for communications purpose.

1. Traditional Engineering Design

Traditional engineering design is divided into a number of steps. For example, a design process might be divided into six steps: problem identification, preliminary ideas, refinement, analysis, documentation, and implementation. The design process moves through each step in a sequential manner; however, if problems are encountered, the process may return to a previous step. This repetitive action is called iteration or looping. Many industries use the traditional engineering design process; however, a new process is developing, which combines some features of the traditional process with a team approach that involves all segments of a business.

2. Concurrent Engineering Design

Modern design, analysis, and communications techniques are changing the traditional role of engineers. The design process is shifting from a segmented activity of the traditional design process to a team activity, involving all areas of business and using computers as the tool. This new way of designing, with its integrated team approach, is called concurrent engineering (Further details on concurrent engineering are described in Section 1.7). Concurrent engineering involves coordination of the technical and nontechnical functions of design and manufacturing within a business. This design shift has resulted in a major change in the way engineers do their jobs.

Engineers and technologists must be able to work in teams. They must be able to design, analyze, and communicate using powerful CAD systems, and they must possess a well-developed ability to visualize, as well as the ability to communicate those visions to nontechnical personnel. Typically, design engineers in many industries today work in teams to create conceptual designs, with rapid-fire communication back and forth at every stage of the design process.

Many companies are finding that concurrent engineering practices result in a better, higher-quality product, more satisfied customers, fewer manufacturing problems, and a shorter cycle time between design initiation and final production.

Figures 1.1 and 1.2 represent the concurrent approach to engineering design, based on 3-D modeling. In Figure 1.1, the concurrent engineering model shows how every area in an enterprise is related, and the CAD database is the common thread of information between areas. In Figure 1.2, the three intersecting circles represent the three activities that are a major part of the concurrent engineering design process: ideation, refinement, and implementation, which all share the same 3-D CAD database. These three activities are further divided into smaller segments, as shown by the items surrounding the three circles. The three intersecting circles also represent the concurrent nature of this design approach. For example, in the ideation phase, design engineers interact with service technicians to ensure that the product will be easily serviceable by the consumer or technician. This type of interaction results in a better product for the consumer.

The center area in Figure 1.2 represents the 3-D computer model and reflects the central importance of 3-D modeling and graphics knowledge in engineering design and production. With the use of a modeling approach, everyone in the team can have access to the current design through a computer terminal. This data sharing is critically important to the success of the design process.

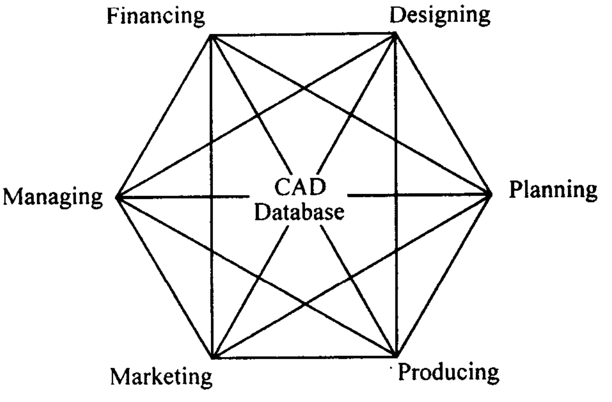

Figure 1.1 Sharing the CAD database.

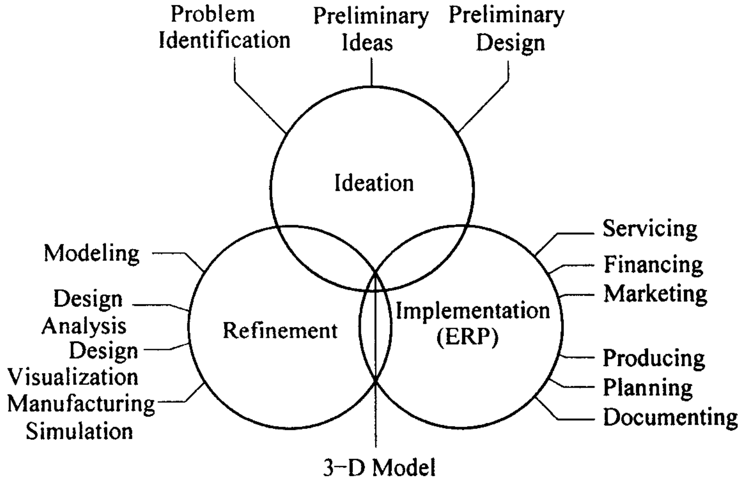

Figure 1.2 Concurrent engineering design.

Through the sharing of information, often in the form of a database, it is possible for all areas of the enterprise to work simultaneously on their particular needs as the product is being developed. For example, a preliminary 3-D model could be created by the design engineers early in the ideation phase. A mechanical engineer could use the same 3-D model to analyze its thermal properties. The information gained from this preliminary analysis could then be given to the design engineers, who could then make any necessary changes early in the ideation phase, minimizing costly changes later in the design process.

3. Design Teams

The actual members of a design team will vary according to the complexity and type of design. In small companies, design teams may be only a few individuals, such as a design engineer, a drafter, and a manufacturing engineer. A typical team in a concurrent engineering design process will include individuals from design, manufacturing, quality, materials, vendors, and managers. Team members rotate in and out and involvement levels rise and fall as the design moves from concept to manufacturing. Daily meetings are common during critical times in the design process, although weekly meetings of the design team are more common.

The coordination of the design team is critical to the success of the design and in meeting deadlines. Communications becomes a very important element for successful design. The use of computers in the design process can facilitate good communication between members of the design team. Global design teams are possible through the use of the web and other Internet-based tools. It is now possible to share design information, including CAD models, across the web.

1.1.3 Other Engineering Design Methods

1. Knowledge-Based Engineering (KBE)

Knowledge-based engineering (KBE) systems complement CAD by adding the engineering knowledge necessary for a product's design. KBE allows the development of a true virtual prototype. A KBE system is programmed by defining the "rules" or engineering criteria for the design. For example, a rule can relate to the type and strength of the specific material needed, and the programming can require that several materials be examined in order to determine which one is most suitable for the design being developed. The product information is contained in a comprehensive model composed of the engineering design rules specific to that product, the general rules for product design, and standard engineering design practices.

KBE systems can be used to create initial designs for engineering evaluation; compare proposed designs to previous ones; evaluate designs; and produce drawings, bills of material, cost analyses, and process plans. KBE systems thus promote concurrent engineering, reduce time to market, and capture the design knowledge of experienced engineers.

2. Reverse Engineering

Reverse engineering is a method of taking an existing product, accurately evaluating it, and putting the information into a CAD database. The measurements of a product are taken using a coordinate measuring machine (CMM). A CMM is an electromechanical device, with a probe on one end, that accurately measures objects and then inputs the 3-D data into a CAD system. The 3-D model can then be modified or checked for accuracy.

3. Web-Based Design

Before the Internet became popular, design information was shared through face-to-face meetings, telephone calls, faxes, and mailings of drawings. Geographic distances were a hindrance to the sharing of design information. Now with the Internet available to virtually any civilized location on earth, it is possible to share design information in a new way. Physical presence is no longer necessary for the people doing the design or the documents used to support the design process.

Internet-based companies are developing web sites that allow design teams to establish project-specific web sites called Extranets that allow the sharing of a wide variety of data almost instantaneously. This allows designers, suppliers, marketing, sales, and others to collaborate electronically through the design process regardless of their locations. Typically, design team members can view CAD drawings and models, sketches, photographs, specifications, and other documents on a restricted access web site. Different levels of access to the site can be specified so some users can only view drawings while others can red-line the drawings. Web-based design can speed up the design review process and reduce costs.

Web-based design can also allow access of 2-D and 3-D database libraries. It is estimated that as much as 70 percent of major product design consists of standard components such as fasteners, valves, motors, etc. The use of standard parts is essential for the design and assembly of products. As much as 25 percent of an engineer's time is spent searching for standard parts used in the design of products. Many standard part libraries are available over the web and through business-to-business (B-to-B) web sites.

1.2 Design for Manufacturing and Assembly

The synthesis stage in the design process enriches the product by adding basic geometric detail and reshapes the product by applying design for manufacturing and assembly (DFMA) guidelines and constraints. The DFMA process answers the question: Is the design optimum for manufacturing and assembly? DFMA is defined as follows: