教育部高等教育面向21世纪课程教材

普通高等学校机械工程类专业双语系列教材

MECHANICAL ENGINEERING CAD/CAM

机械CAD/CAM

胡红舟　钟志华　杨旭静　主编

WUHAN UNIVERSITY OF TECHNOLOGY PRESS

教育部高等教育面向21世纪课程教材

Mechanical Engineering CAD/CAM

(机械CAD/CAM)

主编　胡红舟　钟志华　杨旭静

Wuhan University of Technology Press
武汉理工大学出版社

ABSTRACT

This book gives an introduction to CAD/CAM techniques. It is organized in the following way: Chapter 1 introduces the basic concepts and a brief history of CAD/CAM. Chapter 2 to chapter 4 introduce the mathematical description of curves, surfaces and solids. Chapter 5 discusses geometry transformations and various visual techniques. Chapter 6 introduces some popular methods for graphical manipulations and editings provided by commercial CAD/CAM systems. Finally Chapter 7 describes basic technology in CAM.

图书在版编目(CIP)数据

机械 CAD/CAM/ 胡红舟编. —武汉:武汉理工大学出版社,2003.9
ISBN 7-5629-2129-6

Ⅰ.机… Ⅱ.胡… Ⅲ.①机械设计:计算机辅助设计-高等学校-教材-汉、英 ②机械制造:计算机辅助制造-高等学校-教材-汉、英 Ⅳ.TH122

中国版本图书馆 CIP 数据核字(2002)第 107048 号

出版者:武汉理工大学出版社(武汉市武昌珞狮路 122 号 邮政编码:430070)
印刷者:湖北地矿印业有限公司
发行者:各地新华书店
开 本:787×1092 1/16
印 张:10.375
字 数:260 千字
版 次:2004 年 6 月第 1 版
印 次:2004 年 6 月第 1 次印刷
书 号:ISBN7-2129-6/TH・64
印 数:1—3000 册
定 价:21.00 元

普通高等学校机械工程类专业双语系列教材
编审委员会

出版说明

随着经济全球化的发展，中国的经济必然要与世界接轨。由于近年来中国经济的快速增长，各发达国家的装备制造业纷纷向中国转移，中国将会成为世界制造业的中心。大力发展装备制造业是我国经济发展的一个重要方向，机电产品将是出口创汇的主要来源之一。中国的企业和产品必须面向世界市场，参与国际竞争。与此相适应，高等学校培养出来的人才，不管是到国外的企业（包括合资企业）工作，还是在国内的企业就业，用外语进行交流的机会将逐渐增多。因此，能熟练使用外语的学生在人才市场的竞争中将会具有更大的优势。

为了提高我国高等教育的国际竞争能力，教育部于2001年8月印发了《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），文件强调，“按照‘教育面向现代化、面向世界、面向未来’的要求，为适应经济全球化和科技革命的挑战，本科教育要创造条件使用英语等外语进行公共课和专业课教学。……力争三年内，外语教学课程达到所开课程的5%～10%。暂不具备直接用外语讲授条件的学校、专业，可以对部分课程先实行外语教材，中文授课，分步到位。”该文件还大力提倡编写、引进和使用先进教材。高等学校要结合学科的调整，加快教材的更新换代，鼓励有条件的高等学校编写具有特色的高水平教材。

双语教学（使用母语和英语等外语进行教学）对于提高学生的外语水平非常有利。因此，有计划地逐步推进双语教学，扩大双语教学的课程门数，提高双语教学的质量，是今后一个时期内高等学校必须重视的工作之一。机械工程类专业招生人数最多、就业面最广，而且随着我国装备制造业的发展，今后对能够熟练使用外语（主要是英语）的机械工程类人才的需求会越来越大。因此，在机械工程类专业中实施双语教学，具有更加现实的意义。

教材是教学的基础，对于双语教学来说尤其如此。要搞好机械工程类专业的双语教学工作，必须要有相应的英文教材，而机械工业类专业的原版英文教材与我国的教学大纲及教学体系差异较大，不太适合我国高校阶段的教学状况。此外，我国大学生现阶段的英语水平参差不齐，大多数学生的英语水平还不足以很好地理解英文原版教材的体系和内容，故英文原版教材现在还不可能在我国一般的高等院校大面积地推广。

许多高等学校的机械工业类专业，在开展双语教学的试点工作中，除了采用少量英文原版教材之外，还编写了部分英文讲义，经过试用后有的已经出版。但迄

今为止，各校出版的零星英文教材，还没有形成系列，还远远不能满足日益发展的双语教学的需要。为此，武汉理工大学出版社经过广泛、深入的调研，组织编写了这套面向全国普通高等学校机械工程类专业双语教学的系列教材。

本套教材集中了国内十多所大学从事过双语教学的专家、教授和有过留学经历的中青年骨干教师，承担教材编写和审校的任务；并且组织了以全国高校机械工程类专业教学指导委员会主任杨叔子院士为首的编审委员会，负责整套教材的策划和指导工作。

本套教材以机械工程类专业的学科基础课为主要对象，选择相应的优秀中文教材作为蓝本，同时广泛收集国外优秀的同类英文教材作为参考。各门课程都按照我国通用教学大纲的要求，用英文编写，并附有适当的中文注释和说明，在文字上力求规范、通俗易懂、繁简得当。本套教材分两批编写、出版，并逐步配齐相应的电子课件，以满足双语教学的需要。我们衷心希望广大读者多提宝贵意见，共同将这套教材建设成为机械工程类专业双语教学的精品。

武汉理工大学出版社

2004.3

PREFACE

It is widely recognized that the development of mechanical engineering technology nowadays depends strongly on computer technology. The development of computer aided design (CAD) and computer aided manufacturing (CAM) technology services as a typical result of application of computer technology in mechanical engineering. Despite the fact that more and more areas are being influenced by computer technology, CAD and CAM technologies consist of the most important fundamental knowledge for mechanical engineers and researchers. Thus, the basic topics on CAD/CAM should be of general interests to all students in mechanical engineering area no matter what kind of future they are looking for.

CAD/CAM technology in mechanical engineering has experienced a development history over thirty years. Great achievements have been made in both research and application of the technology. However, this book will not be written as a comprehensive textbook including all the topics for some reasons. First of all, the purpose of the book is to provide an introduction with reasonable depth and breadth for bilingual teaching. Secondly, the space of the book would not allow too many subjects with sufficient depth and breadth. In addition, the authors' knowledge and ability are also limited. Thus, selection of the topics of the book is based on the authors' judgement on basic needs for students in their immediate application after graduation.

Considering the fact that more people will be involved in CAD technology, much more efforts are focused on discussions of CAD technology. Of course, much of the basic knowledge in CAD technology is also fundamental to CAM technology. The book is organized in the following way: Chapter 1 introduces the basic concepts and a brief history of CAD/CAM; Chapter 2 to chapter 4 introduce the mathematical description of curves, surfaces and solids; Chapter 5 discusses geometry transformations and various visual techniques; Chapter 6 introduces some popular methods for graphical manipulation and editing provided by commercial CAD/CAM systems; Finally Chapter 7 describes some basic technology

in CAM.

During the writing of the book, it is kept in mind that the book is intended for bilingual teaching of a course on an introduction to CAD/CAM. Thus, relatively simple concepts and mathematics are used. Furthermore, efforts are made to use relatively simple language and expressions. For easy and better understanding, examples expressed in pictures, graphs and diagrams are used whenever desired. Some problems are given to help readers to test themselves on how much they have understood what discussed in the book. A list of keywords and fundamental concepts are provided at the end of each chapter with Chinese translation.

Although the authors have tried to make the book as good as possible, there is no doubt that deficiencies and even mistakes may exist in the book. Any comments and corrections are mostly welcome. The authors would like to take the opportunity to express sincere thanks to Wuhan University of Technology Press for making it possible to publish this textbook. The help from Ms Li Li is also gratefully acknowledged.

Authors in Changsha
Autumn, 2004

CONTENTS

CHAPTER 1

INTRODUCTION

This chapter gives a brief history of CAD/CAM, and an introduction to the basic hardware and software used in the CAD/CAM systems.

1.1 WHAT IS CAD/CAM

CAD[1] stands for Computer Aided Design. It refers to the design and technical drawing of various engineering applications on computers. A related term, CADD, stands for Computer Aided Drafting and Design.

CAD implementations have evolved dramatically over the last few decades. CAD was initially limited to produce drawings similar to hand drafted drawings at the beginning of its development history. Today's advances in CAD technology have allowed more skillful and complex applications in engineering.

The useful features of CAD include the ability to make changes in the design easily, and validate designs against design rules. CAD models can also be used to simulate designs without building a physical prototype.

CAM[2] stands for Computer Aided Manufacturing. The CAM has evolved from the technology of Numerical Controlled (NC) machines[3].

Early NC machines had their own on-board electronic control systems for their servo drives and motors, and were programmed by punched paper tape. Modern CAD/CAM systems automatically generate tool paths from 3D models, and can simulate the cutting action on-screen.

Integrating CAM with CAD systems produces quicker and more efficient manufacturing processes.

1.2 DEVELOPMENT HISTORY OF CAD/CAM TECHNOLOGY

1.2.1 1970s and Before

The first commercial numerical-control programming system was developed in 1957 by

Dr. Patrick J. Hanratty. The first CAD system was developed during the 1960s.

Several companies, such as MCS, were founded in the 1970s and they began to offer automated design/drafting systems in the early 1970s. During that period, most CAD/CAM systems were 2D and very expensive, and they were only available for experts. At the end of 1970s, the typical CAD system was a 16-bit minicomputer with a maximum memory of 512 kB and a 20 to 300 MB disk storage at a price of $125,000.

Some highlights in the 1970s are listed in the following.

1971: MCS was founded by Dr. Patrick J. Hanratty. MCS has had a reputation for technological leadership in mechanical CAD/CAM software.

1978: Computervision introduced the first CAD terminal using raster display technology.

1979: IGES (Initial Graphic Exchange Standard) was developed, which is a neutral file format, and becomes the industry standard format and the most widely accepted format for transferring complex surface information, such as NURBS curves.

1.2.2 The 1980s

A number of early CAM systems were introduced in the early 1980s to partially automate the manufacturing process by creating digital control tapes to drive machine tools. CAE (Computer Aided Engineering)[4] tools were introduced for complex design analysis.

In the mid-1980s, major technological advances, including feature-based parametric modelling systems, were introduced, which allowed CAD/CAM/CAE software products to become a more integral part of the product design process.

Parasolid geometry kernel was developed in 1980s. Parasolid is a very powerful B-rep solid modelling kernel that allows the boundaries and surfaces joining together as a solid.

The first PC was introduced by IBM in 1981. Due to the success of the IBM PC, PC based CAD/CAM systems became more and more established.

Most systems in 1980s were closed. Migrating software packages from one vendor's system to another's was difficult and required a lot of efforts.

Some highlights in the 1980s are listed here.

1981: Unigraphics introduced the first solid modelling system, UniSolid.

1983: The development work has started for STEP (Standard for the Exchange of Product model data). STEP can transfer CAD data and include complete details of product modelling, including materials and various design parameters.

1988: Shape Data Ltd. was acquired by Unigraphics for solids modelling, Parasolid.

1.2.3 The 1990s and Beginning of 2000s

During this period, CAD/CAM systems have been expanded dramatically. With the development of ACIS, Parasolid and other geometry formats, communications among CAD/CAM systems have been better and better. 3D modelling systems are used in engineering in a much bigger scale than before. Today most applications include data translation utilities like IGES, STEP, STL, ACIS, Parasolid, DXF and DWG as standard. 3D modelling CAD

systems using ACIS and Parasolid as the core are widely used in engineering.

As all systems are migrating toward Windows, the graphical user interfaces (GUI)[5] between different products are not only becoming easier and more intuitive, but they are similar to each other. This allows users to change from one system to another, with minimal training costs and less time to be productive. Feature based software[6] has been popular among CAD/CAM users, with the introduction of the feature/assembly tree, ease of use has improved dramatically.

CAD/CAM are more and more integrated with other engineering area such as CAE. Nearly all CAD/CAM packages include Application Programming Interfaces (API)[7]. These interfaces allow integration of powerful add-on analysis packages for doing finite element analysis (FEA)[8], kinematical simulations, animations and so on. Development on both the hardware and the CAD/CAM software provide great possibility to cut short the product development process.

Some highlights in the 1990s and at the beginning of 2000s are listed here.

1990: Spatial Technologies developed ACIS 1.0.

1995: There are over 350,000 users of generic CAD worldwide.

1999: CATIA Version 5 for native Windows NT and UNIX. CATIA V5 is based on:

① Next generation technologies (Native Windows implementation, powerful interface, Plug & Play extensibility, consistency with standards such as OLE)

② Windows Web metaphor to ensure a natural, productive and fun to use environment

③ Scalability to address all user profiles

④ Capture and reuse of the company know-how

2000: Unigraphics Solutions Inc. announced in May that its industry-leading kernel solid modelling product, Parasolid, had 500,000 active end-users.

1.3 BASIC CAD/CAM HARDWARE

1.3.1 Workstation and PC

A workstation[9] is a general purpose computer designed to be used by one person at a time and it offers higher performance than normally found in a personal computer, especially with respect to graphics, processing power and the ability to carry out several tasks at the same time.

A personal computer is an inexpensive microcomputer, originally designed to be used by only one person at a time, and is compatible with IBM PC (though it may sometimes refer to non-IBM compatible machines).

During the 1990s, the power of personal computers increased radically, blurring the formerly sharp distinction between personal computers and workstations. Today workstations often distinguish themselves from personal computers by greater reliability or greater ability on multitask, rather than by straight CPU power.

1.3.2 Input Device[10]

A keyboard is designed to enter data by manual depression on keys. Most keyboards have characters printed on the keys, they usually represent characters selected from some language alphabet, along with numbers and punctuation.

A mouse is a handheld input device for computers. It involves a small object fitted with several buttons and shaped to sit naturally under the hand. The mouse's motion is typically translated into the motion of a cursor in a monitor. A conventional mouse uses mechanical devices (e. g. a ball) to detect movements. An optical mouse, as shown in Fig. 1. 1, on the other hand, detects movements by an optical sensor on its underside, paired with a light emitting diode to illuminate the surface.

Figure 1. 1 An optical cordless mouse

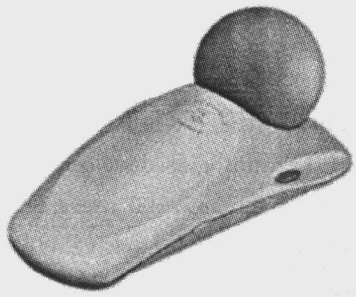
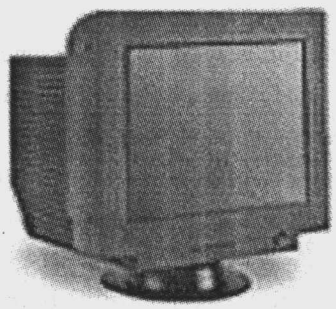


Figure 1. 2 A spaceball

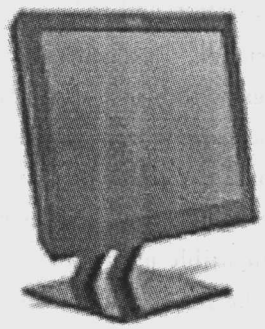
Besides, spaceball is used to pan, zoom and rotate 3D models, which is shown as Fig. 1. 2.

1.3.3 Output Device[11]

Computer monitors show still or moving images generated by a computer. It is driven by a graphics card and generally matches one or more display standards. As Fig. 1. 3 show, CRT (Cathode Ray Tube) and LCD (Liquid Crystal Display) monitors are the main two types.



Trinitron flat screen (IBM)



TFT active matrix LCD (IBM)

Figure 1. 3 Monitors

CRT monitors are standard, and almost used everywhere. They are less expensive and still provide better colors. However, CRT monitors take up considerable space and consume

more power. LCD monitors take less places while maintain large screen sizes, they also consume less power. Today the arrival of inexpensive (LCD) monitors and other flat-screen designs challenge CRTs' position.

Figure 1.4 shows a type of plotter, plotters are used primarily in drafting and CAD applications, where they have the advantage of working on very large sized paper while maintaining high resolution.

Figure 1.4 Synergix 8825 (Xerox)

1.4 COMMON CAD/CAM SOFTWARE

Software is created with programming languages and related utilities. CAD/CAM systems usually include a variety of software. In an open system, the software may come from a wide range of sources, including those purchased from a third party or developed from users.

The latest types of CAD/CAM software[12] are those with built-in intelligence, some of them are the following.

Parametric design software[13]: These packages represent geometry by parameters, which linked together by direct values or mathematical equations. When users change one parameter, the system will automatically update related areas. Parameter design software provides good possibility of alternative design study.

Feature based software: A feather based software uses predefined geometry or behaviour (e.g. a rounding operation) called feathers to generate CAD/CAM models. Features of the model are stored in the model database for later use.

Knowledge (expert) based software[14]: Systems contain a knowledge base of specialized information that the expert uses to do his or her job. This generally consists of data drawn from textbooks, technical papers plus information such as rules of thumb, wise guessing criteria. When a user provides specifications and constraints of a design, the expert systems give the user a design decision.

1.4.1 Basic Concepts

(1) Database

A database[15] is an information set organized for flexible searching and utilization. There are some popular database models such as:

Relational database: Data is stored in tables that are related to each other.

Hierarchical database: Data is represented by a tree structure. This model is, for example, used in CSG solid representations.

Network database: A network model database management system has a more flexible

structure than the hierarchical model or relational model, but its processing time is longer.

Object-oriented database: Storages in an object oriented database are design objects not individual records in the files.

(2) Data structure

A data structure[16] is a specialized format for organizing and storing data. Often a carefully chosen data structure will allow a more efficient algorithm to be used.

In the design of many types of programs, the choice of data structures is a primary design consideration. Experiences in building large systems have shown that the difficulty of implementation and the quality of the final result depend heavily on choosing data structure.

(3) Algorithm

Algorithm[17] is a computable set of steps to achieve a desired result. A computer program can be viewed as a complex algorithm.

(4) Raster[18]

A scanning pattern of parallel lines that forms the display of an image projected on a display screen.

(5) Raster graphics

A raster graphics[19] image, or bitmap, is a data file or structure that consists of a generally rectangular array of pixels on a computer monitor or other display device. Each pixel has a corresponding red, green, or blue value. These values are combined to determine the color displayed by that pixel.

(6) Vector graphics

Vector graphics[20] describe the use of geometrical primitives such as points, lines, curves and polygons to represent images in computer graphics. It is used by contrast to the term of raster graphics, which is the representation of images as a collection of pixels (dots). The term is mainly used in the context of two-dimensional graphics.

(7) Database management

A database management system (DBMS)[21] is a computer program designed to manage a database, a large set of structured data, and run operations on the data requested by numerous users.

(8) Networks

As the increasing dependence on communication and data exchange in engineering and manufacturing, system hardware is increasingly being tied together into networks. Networks allow systems to share data and software. The most common network is LAN (Local Area Network). Large geographic areas are handled by WAN (Wide Area Network).

1.4.2 Software Modules[22]

Most CAD/CAM systems are modular, and each module has its specific application area. Different modules are closely related in CAD/CAM systems, at the same time, any module may be run as a standalone module without the need for any other software. Modular

software also allows the users to purchase only the modules they need.

1.4.2.1 Part Module[23]

The part modelling environment allows users to construct geometry solid models. 3D-objects can be generated from 2D profiles via various techniques such as extrusion, revolution, loft etc., or by using Boolean operations among solid primitives provided by the CAD/CAM systems. In the part module, there are also many operations such as chamfer, rounding, cutout etc., available to build the model. Parts in Fig. 1.5 are created in the part module.

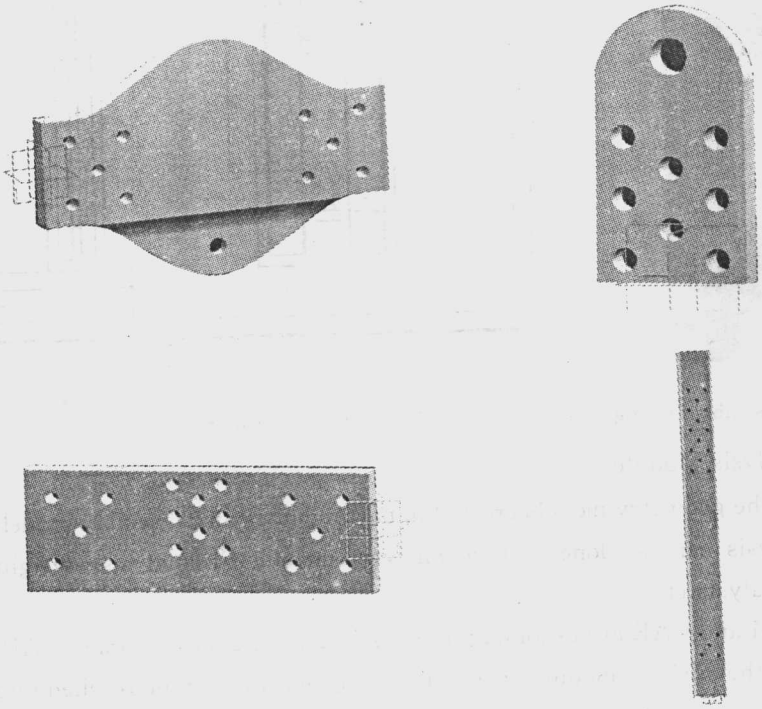


Figure 1.5 Modelling of geometry parts in part module

1.4.2.2 Assembly Module

The assembly module[24] fits parts together with natural assembly techniques, such as mate and align. As shown in Fig. 1.6, parts in an assembly are usually individually specified elsewhere, combined according to requirements, and physically connected. Both existing parts and subassemblies can be used to build a new assembly. The assembly module is tightly associated with the part module, which means that any change in the part module will be updated in the assembly module. In Fig. 1.5, the four parts created in the part module are fitted together in the assembly module.

1.4.2.3 Draft Module

Draft module[25] produces engineering drawings directly from a 3D part or an assembly