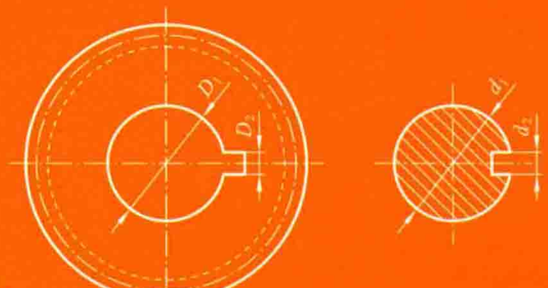
普通高等学校机械专业卓越工程师教育培养计划系列教材

机械CAD/CAM

Mechanical CAD/CAM

文国军 主编



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机械 CAD/CAM
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主编　文国军
参编　刘德刚　石欣雨

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内 容 简 介

本书重点讲述机械工程领域中与CAD/CAM相关的基础知识与理论、关键应用技术和软件系统开发技术等。主要内容包括:CAD/CAM技术基础、CAD/CAM软硬件系统、几何变换、三维实体建模技术、反求工程、参数化编程、有限元技术、虚拟样机技术、虚拟现实技术、先进制造技术、计算机辅助制造、CAD/CAM软件系统开发等。

本书注重理论与实践的结合,在参考国内外大量文献资料的基础之上,将CAD/CAM的基础知识与理论、软件系统(包含SolidWorks、SolidCAM、ANSYS、ADAMS等)与工程机械设计、钻机设计自动化、数控切割CAM系统开发等实际应用结合在一起,突显了实用性,有利于感兴趣的读者自学和教师讲授。

本书采用英文撰写,可作为普通高等院校机械工程专业本科生与研究生的双语教学课程的教材,也可供从事CAD/CAM系统研究与开发的工程技术人员参考。

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策划编辑:俞道凯
责任编辑:王 晶
封面设计:刘 卉
责任校对:邹 东
责任监印:张正林
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前　言

CAD/CAM是伴随着计算机技术的发展而形成的一门新兴技术,已广泛地应用于各个工程领域。毫无疑问,未来的机械设计与制造系统都将全面而系统地使用CAD/CAM的理论和技术,尽可能地减少人的参与,真正实现设计自动化与制造自动化。

本书充分结合编者自身十余年来教学与科研的经验,历经多次修改,内容丰富,在讲述机械CAD/CAM相关的基础知识与理论的同时,又阐述了与机械行业密切相关的CAD/CAM关键应用技术和软件系统开发技术,兼顾了理论基础和实际应用。

本书内容采用英文撰写,主要是为了满足大学生国际化和双语教学的时代需求,使大学生在学习CAD/CAM专业知识的同时,又充分锻炼其在专业领域内应用英语的能力。

本书主要内容由文国军编写,刘德刚编写了基于ObjectARX的AutoCAD参数化编程和CNC切割机的CAM软件开发部分,石欣雨编写了以非开挖钻机为例进行三维建模的SolidWorks软件应用实例部分。

本书从内部讲义到正式出版历时近十年,参考了大量的国内外文献,有些在参考文献中已明确列出,但还有少量由于未及时做好参考记录,现在一时无法找到出处,在此一并表示感谢。

由于编者水平有限,书中难免有不足之处,敬请广大读者批评指正。

编　者

2015年1月

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Chapter 1 Introduction to CAD/CAM

Computer-aided design/computer-aided manufacturing (CAD/CAM) is affecting almost every area of engineering. This skyrocketing technology is the result of years of development in which computer systems have continually evolved. Most experts agree that increasing CAD/CAM installations will continue to do what computer systems have always done: free engineers from the tedious, time-consuming tasks that have nothing to do with technical ingenuity. Experience shows that CAD/CAM speeds the engineering process, stripping away the drudgery and paper-work that inhibits productivity and creativity.

Throughout the history of industrial society, many inventions have been patented and whole new technologies have evolved. Whitney's concept of interchangeable parts, Watt's steam engine, and Ford's assembly line are only a few developments that are most noteworthy during our industrial period. Each of these developments has impacted manufacturing as we know it, and has earned these individuals deserved recognition in our history books.

Up to now, however, it is no doubt that the single development that has impacted manufacturing more quickly and significantly than any previous technology is the digital computer. Since the advent of computer technology, manufacturing professionals have wanted to automate the design process and use the database developed therein for automating manufacturing processes by using computers, which is so called computer-aided design/ computer-aided manufacturing (CAD/CAM). When successfully implemented, it should remove the "wall" that has traditionally existed between the design and manufacturing components.

As the heart of automated and integrated manufacturing, CAD/CAM itself can be described as a broader and more inclusive term. It almost encompasses the entire range of product development and manufacturing activities with all the functions being carried out with the help of dedicated software packages.

1.1 Historical Perspective of CAD/CAM

The historical time line in Figure 1-1 illustrates the significant developments of the CAD/CAM technology.

The historical development of CAD/CAM has followed close behind the development of computer technology and has paralleled the development of ICG (interactive computer graphics) technology. The significant developments leading to CAD/CAM began in the late 1950s and early 1960s. The first of these was the development, at Massachusetts Institute of Technology (MIT), of the automatically programmed tools (APT) computer programming language.

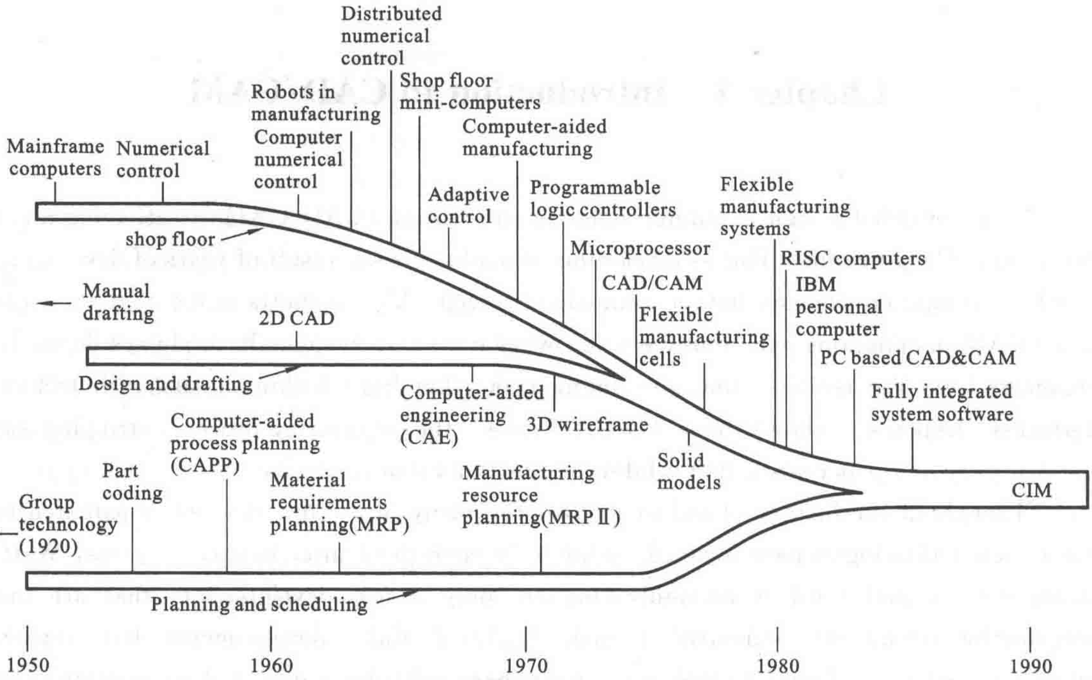

Figure 1-1 Historical time line of CAD/CAM development

The purpose of APT was to simplify the development of parts programs for numerical control machines. It was the first computer language to be used for this purpose. The APT language represented a major step toward automation of manufacturing processes.

Another significant development in the history of CAD/CAM followed close behind APT, also developed at MIT, was called the Sketchpad project. With this project, Ivan Sutherland gave birth to the concept of ICG. The Sketchpad project was the first time a computer was used to create and manipulate graphic images on a CRT display in real time.

Throughout the remainder of the 1960s and 1970s, CAD continued to develop and several vendors made names for themselves by producing and marketing turnkey CAD systems. These were complete systems including hardware, software, maintenance and training sold as a package. These early systems were configured around mainframe and minicomputers. As a result, they were too expensive to achieve wide-scale acceptance by small to medium manufacturing firms.

By the late 1970s, it became clear that the microcomputer would eventually play a role in the further development of CAD/CAM. However, early microcomputers did not have the processing power, memory, or graphic capabilities needed for ICG. Consequently, early attempts to configure CAD/CAM systems around a microcomputer failed.

In 1983, IBM(International Business Machines Corporation) introduced the IBM-PC, the first microcomputer to have the processing power, memory, and graphic capabilities to be used in CAD/CAM. This led to a rapid increase in the number of CAD/CAM vendors. By 1989, the number of CAD/CAM installations based on microcomputer equaled the number based on mainframe and minicomputers.

The 1990s witnessed the maturing of the PC(personal computer) for CAD software delivery. The processor chips produced by Intel Corporation provided processing power that approached the low end of the RISC market, and the NT(network termination) operating system from Microsoft Corporation became the de facto standard for PC industrial software development.

1.2 Benefit of CAD/CAM

The benefit of CAD/CAM is similar to that used to justify any technology-based improvement in manufacturing. It grows out of a need to continually improve productivity, quality, and competitiveness. There are some main benefits facilitating a company to make a conversion from manual processes to CAD/CAM—increased productivity, better quality, better communication, common database with manufacturing, reduced prototype construction costs, and faster response to customers.

1.2.1 Increased Productivity

Productivity in the design process is increased by CAD/CAM. Time-consuming tasks such as mathematical calculations, data storage and retrieval, and design visualization are handled by the computer, which gives the designer more time to spend on conceptualizing and completing the design. In addition, the amount of time required to document a design can be reduced significantly with CAD/CAM. All of these taken together are instrumental to shorten the design cycle, lessen the overall project completion time, and improve the level of productivity.

1.2.2 Better Quality

Since CAD/CAM allows designers to focus more on actual design problems rather than the time-consuming, and nonproductive tasks, the product quality improves greatly. With CAD/CAM, the designers can examine a wider range of design alternatives (e.g., product features) and analyze each alternative more thoroughly before making final decision. In addition, because the computer performs labor-intensive tasks, fewer design errors occur. These all are helpful to better the product quality.

1.2.3 Better Communication

Design documents such as drawings, parts lists, bills of material, and specifications are tools used to communicate the design to those who will manufacture it. The more uniform, standardized, and accurate these tools are, the better the communication will be. Because CAD/CAM leads to more uniform, standardized, and accurate documentation, it improves communication.

1.2.4 Common Database

This is one of the most important benefits of CAD/CAM. With CAD/CAM, the data generated during the design of a product can be used in producing the product. This sharing of a common database helps to eliminate the age-old "wall" separating the design and manufacturing functions.

1.2.5 Reduced Prototype Costs

During manual design process, all models and prototypes must be made and many actual tests must be done on them, thus increasing the cost of the finished product. With CAD/CAM, 3-D computer models can reduce and, in some cases, eliminate the need for building expensive prototypes. Such CAD/CAM capabilities as solids modeling allow designers to substitute computer models for prototypes in many cases.

1.2.6 Faster Response to Customers

Response time is critical in manufacturing. How long does it take to fill a customer's order? The shorter the time, the better it is. A fast response time is one of the keys to being more competitive in an increasingly competitive marketplace. Today, the manufacturer with the fastest response time is likely to win a contract with the lowest bid. By shortening the overall design cycle and improving communication between the design and manufacturing components, CAD/CAM can improve a company's response time.

1.3 CAD/CAM Database

In a CAD/CAM environment the total integration of operations is achieved by a common database linking various designs, manufacturing and other related activities.

In essence, the successful implementation of CAD/CAM lies in the efficient way relevant data is shared among the different segments of CAD/CAM.

The information required for manufacturing is complex covering a wide range of disciplines and serving a multitude of inter-related yet vastly differing needs. The CAD/CAM database comprises basically four classes of data:

(1) Product data: Data about parts to be manufactured. It includes text and geometry data.

(2) Manufacturing data: The information as to how the parts are to be manufactured is available in production data.

(3) Operational data: Closely related to manufacturing data but describes the things specific to production, such as lot size, schedule, assembly sequence, qualification scheme etc.

(4) Resource data: This is closely related to operational data but describes the resources involved in operations, such as materials, machines, human resources and money.

Product design and manufacturing process increasingly requires access to substantial technical information in various stages like design, analysis and manufacturing as well as smooth coordination among the many functions constituting an enterprise. Manufacturing organizations may waste a considerable portion of their resources due to delayed or error-prone communication from one segment to another. It would therefore be desirable to have one single central database that would contain all information.

A database can be defined as a collection of data in a single location designed to be used by different programmers for a variety of applications. The term database denotes a common base of data collection designed to be used by different programmers. More specifically it is a collection of logically related data stored together in a set of files intended to serve one or more applications in an optimal fashion. A database must also have a predetermined structure and organization suitable for access, interpretation, or processing either manually or automatically. A database not only stores the data but also provides several ways to view the data depending upon the needs of the user. There are several classifications of data.

(1) Physical data: It is the data stored in the computer's storage device. The volume of data required by a manufacturing company is so large that secondary storage devices such as hard discs, CD-ROMs, and other digital storage devices of several gigabyte capacities will be used.

(2) Logical data: This indicates how a user views the physical data. The distinction between the physical data and the corresponding logical view is that the user conceptualizes certain meaningful relationships among the physical data elements.

For example, we may have a set of items and quantities recorded in files. The logical view or interpretation of these sets of data can be that the items represent components available in stores and that the quantities recorded correspond to their inventory.

(3) Data independence: Database management systems (DBMS) are used by the users to manage the physical data. DBMS makes a distinction between the two namely, the user and the physical data. Changes in the organization of physical data and/or in the storage device parameters are absorbed by DBMS and therefore do not affect the user or more accurately, the application program. This flexibility is absent in the traditional file systems.

1.4 CAD/CAM Selection Criteria

Selecting the best hardware and software for a given CAD/CAM setting can be difficult, but it is critical to the success of CAD/CAM. For the inexperienced, the turnkey approach is recommended. This means purchasing a CAD/CAM system that comes with everything necessary for implementation, including hardware, software, installation, and training. The best system will vary, depending on the needs and intended applications of the individual company.

Before contacting vendors, it is a good idea to develop an applications checklist. This is a comprehensive list of everything the system is expected to do. For example, if an electronics firm were to develop an applications checklist, it might include the design documentation and supportive documentation.

The design documentation includes the schematic diagrams, circuit diagrams, logic diagrams, wiring diagrams, integrated circuit diagrams, printed circuit board drawings, bill of materials preparation, design rules checking, etc.

The supportive documentation includes the specifications, technical manuals, charts and graphs, flow charts, etc.

These are only a few of items that might be included on the applications checklist of an electronics-manufacturing firm. A complete checklist would be much more comprehensive. In putting together such a checklist, it is important to convene a team of experienced personnel who are thoroughly knowledgeable of the company's needs.

Once the applications checklist is completed, vendors may be contacted for bids or quotes. The first step, of course, is to rule out systems that cannot satisfy all functional requirements on the checklist. Once the list of vendors is narrowed down those with appropriate systems, the next step can be taken. In this step, more criteria of initial costs, ongoing costs, services and support, quality, delivery and installation, should be used to select the system to be purchased.

1.5 Application of CAD/CAM

Early CAD/CAM systems consisted of roomfuls of equipment costing several million dollars and required operators skilled in programming and related computer tasks. As a result, only the giant aerospace and automotive industries could afford them. And some of the most sophisticated CAD/CAM systems are still at these large companies.

With the skyrocketing computing power and plummeted size and cost, there has been a rapid proliferation into general industry of relatively inexpensive stand-alone equipment on which users can perform highly sophisticated design, analysis and manufacturing functions. This allows the user to reap the benefits of the computer without training in programming and related tasks. Consequently, although the most sophisticated systems remain at the large companies, many smaller companies that a few years ago could not afford CAD/CAM are now using it.

The major incentive for using CAD/CAM, of course, is increased productivity. Rising costs forced aircraft manufactures to start implementing CAD/CAM years ago as a way to produce airplanes economically. Likewise, the automotive industry also embraced the technology as the best way to design and manufacture automobiles. CAD/CAM has been carrying over into general industry, where it is used for a wide range of products.

1.5.1 Aerospace Industry

CAD/CAM is used in the aircraft industry more than in any other. And the Boeing Co. is unquestionably one of the leaders, having been heavily involved in the development and utilization of CAD/CAM since the early days of the technology. In the late 1950s, Boeing's manufacturing division used the APT (automatically programmed tools) language on a limited base to describe part geometries for generating numerical control tapes. In the early

1960s, they relied more heavily on NC(numerical control) in the production of machine parts for the 727 aircraft.

By the mid-1960s, Boeing was developing the 737 and had established itself as one of the largest users of NC equipment. Boeing engineers not only used NC technology to make parts, but also to define mathematically the complex exterior surface for developing the 737. In the early 1970s, they used APT to generate engineering drawings on the primary wing and body structure of the YC-14 Advance Tactical Transport. This early work showed the effectiveness of using a computer system to both design and manufacture a complex mechanical structure.

In the mid-1970s,Boeing installed interactive computer-graphics systems for production of the 747 and heavily used NC in computer-controlled manufacturing equipment such as giant riveting machines that move along the aircraft, automatically punching and reaming holes in the skin and then setting and trimming rivets.

The Boeing Co. has been now extending CAD/CAM capabilities for its all production. All engineering has accessed to the same huge database through interactive graphics terminals, which allow engineers at various location in the world to communicate design and analysis data instantaneously through the network. As a result, time has being drastically reduced for solving problems, integrating and completing design and analysis, and communicating project progress.

All the major aircraft producers as well as the U. S. Air Force presently have been expanding their use of CAD/CAM. The most concentrated Air Force effort is, of course, the ICAM(integrated computer aided manufacturing) program with the ultimate goal of the automated factory for the production of aircraft.

1.5.2 Automotive Industry

The automotive industry has been particularly aggressive in applying CAD/CAM. Computer technology allows engineers to develop new designs for increasingly stringent safety requirements and to reduce weight for fuel-economy standard. In addition, product development time and costs are reduced for automobiles designed with CAD/CAM.

Computer technology enables engineers to more effectively manage the myriad of interrelated variables inherent to automobile design.

In the early stages of design, the interactive graphics capability of CAD/CAM can be used to visualize the overall shape of the automobile. In the so-called concept surfacing, the contour of the entire vehicle is developed and evaluated. Interactive graphics also is used in the detailed design and analysis of components such as the tailgate or the transaxle assembly. And in the case of moving components, kinematic capabilities may be employed to animate the mechanism on the screen. The resulting database that is compiled for the design of all these individual components then may be stored in the computer and accessed by other engineering areas to perform structural analysis, generate drawings and produce NC codes.

But mechanical components are not the only elements modeled with the computer. One innovative use of CAD/CAM technology is a manikin called "Cyberman". This computer model is used to evaluate the packaging of interior features such as seats and armrests. The computer-based manikin enables engineers to predict the positions of passengers while the vehicle is in the early stages of design, saving the expense of creating physical mockups. The model can be programmed into a number of positions and displayed on a graphics terminal as a stick figure or a complete wire-frame outline.

System simulation is an important aspect of CAD/CAM applied extensively in the automotive industry. In this approach, an analytical model of the vehicle responds to loads and driving conditions in much the same manner as the real car. The system model represents structural characteristics of components from tires and shock absorbers to the frame and sheet metal. Additional data is entered with the system model representing external loads such as tire impact with a curb the vehicle may encounter during operation.

The computer manipulates these sets of data and provides a prediction of total vehicle response in the form of an animated mode shape showing structural deformation. Actual displacements are relatively small and rapid, so these animated mode shapes show distortion in slow motion with amplitudes exaggerated for clarity.

Based on these animated mode shapes, the automobile design may be modified and resimulated until it performs satisfactorily. In this way, the design is developed and modified in the computer rather than with hardware prototypes. Consequently, CAD/CAM designs generally are closer to an optimum because numerous alternatives can be simulated and the best one refined. Another benefit of computer simulation in automobile work is reduced product development time and cost.

Finite element analysis is another CAD/CAM technique used extensively in the automobile industry to indicate areas of high stress where parts such as fenders are most likely to fail. Using this method, analysts can quickly evaluate the effect of modifying the contour or changing materials in a part. Finite element analysis is also used to evaluate the crashworthiness of automobiles. Analysts are now attempting to develop refined finite element techniques to determine the dynamic forces and displacements for an entire vehicle.

1.5.3 General Industry

The application of CAD/CAM has been rapidly spreading into many diverse areas of general industry.

Many of the same technique used in designing and manufacturing aircraft and automobiles transfer directly to other types of mobile equipment such as construction equipment and agricultural machinery. In addition, the military is also investing heavily in CAD/CAM.

CAD/CAM is also being applied to other complex mechanical systems such as machine tools and used to simulate the operation of machine tools.

Chapter 2 Computer Hardware of CAD/CAM System

Any CAD/CAM computer system is a marriage of computer hardware and software technologies, with each playing an equally important role. For example, the hardware supports the electronic representation of objects, while the software allows the objects to be created with an infinite range of geometrical shapes and sizes.

2.1 Computer System Classification of CAD/CAM

According to hardware and information processing method, CAD/CAM computer systems are divided into three groups: mainframe computers, engineering workstations or RISC systems, and microcomputers. Each group has unique characteristics that offer specific advantages and disadvantages in the implementation of CAD/CAM. Moreover, according to whether or not using the network, CAD/CAM computer systems can also be divided into stand-alone system and network system.

2.1.1 Mainframe Computer Platforms

Mainframe is an industry term for a large computer. The name comes from the way the machine is built up: all units (processing, communication etc.) were hung into a frame. Thus the main computer is built into a frame, therefore: mainframe.

This group includes all the computers larger than engineering workstations used to run CAD/CAM software.

The CAD/CAM software, usually developed by third-party vendors, runs on the mainframe with multiple users working on terminals attached to the main computer. For example, large mainframe implementations in the automotive industry have 100 or more designers and draftspersons working on a wide range of product drawings and designs.

While the computational capability at each terminal is significant in mainframe implementations, only a single image or copy of the CAD/CAM software and operating system exists on the mainframe. This feature is the most distinguishing characteristic of the mainframe and offers both advantages and disadvantages.

Advantages: Powerful design features are available at each workstation, multiple program execution is standard, a single database is shared by all operators, a good response is provided for large drawing files, support for large design and documentation projects is available, and an integrated software solution is offered for various manufacturing problems.

Disadvantages: A large initial capital investment is required, cost per terminal is high for a small number of users, complex operating systems require dedicated system managers, the complex software is not suited for entry-level operators, and a single mainframe failure