Jianbin Xue

Integration of CAD/CAPP/CAM

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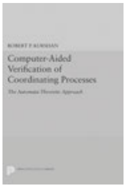

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Preface

Overview

This textbook includes the fundamental concepts of computer-aided design (CAD), computer-aided process planning (CAPP), computer-aided manufacturing (CAM), and their integration in a generic framework and also to concurrent engineering (CE). As we all know, with the development of computer science and technology, there are many commercial CAD/CAM software packages available in market today, such as Solid Works, Pro/Engineer, Pro/Creo, CATIA, Master CAM, UG-NX, AutoCAD, and so on. Although the syntax of these systems differs from one another, their semantics remains the same. So we just explain the principles of these systems in a generic and syntax-independent manner, and do not discuss their syntax, so that students can use different systems on the basis of this knowledge. The related mathematical models and concepts are discussed to help students understand the working of these systems.

This textbook has also been designed to meet the demands of both practice-oriented and theoretical courses. Students are required to master the basic knowledge of understanding three-dimensional (3D) modeling and viewing, geometric modeling, product design, process planning, manufacturing, product data management (PDM), product life-cycle management (PLM), and CE. Several widely used CAD/CAM systems are mentioned in the context. Some screenshots using these systems are illustrated in a few chapters. Students are encouraged to practice their learning by operating any of the mentioned software packages.

Audience

Students need a comprehensive and complete source of CAD/CAPP/CAM knowledge in order to become proficient in using any of the CAD/CAM systems. The professional engineers also need to have knowledge about these systems. This textbook offers concentrated knowledge and explains the subject matter in a simple, yet comprehensive and coherent, way. This textbook also helps the users get answers to specific questions they have while using CAD/CAM systems and CE.

The audience of this textbook includes the following:
- The students in mechanical engineering, industrial engineering, manufacturing engineering, and mechatronics engineering
- The instructors for CAD/CAPP/CAM courses
- The professional engineers

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Organization

This textbook consists of eight chapters. The first chapter is introduction. In this chapter, the principle concepts of CAD, CAPP, and CAM are introduced. The history of development of the systems is described. The concept of integration of CAD/CAPP/CAM is also introduced. The following three chapters describe CAD, CAPP, and CAM, respectively. In Chapter 2, the basic CAD knowledge is provided, with commonly used 3D geometric modeling CAD systems and information inside of the CAD systems. The edge-cutting technology about reverse engineering is also included in this chapter. In Chapter 3, the fundamental concepts of CAPP are presented. The variant and generative CAPP systems are introduced. Some well-known CAPP systems are discussed. In Chapter 4, the computer numerical control (CNC) and CAM are discussed. The new concept of 3D printing is also introduced. After understanding these isolated automation islands, the efforts to integrate these systems are described in Chapter 5. Data exchange methods are also listed. Several neural data formats, such as DXF, IGES, STEP, and STEP-NC are discussed. With so many files generated from the systems, PDM is required to deal with these files. In Chapter 6, the functions of PDM system are analyzed. Some well-known PDM systems are introduced. On the basis of the PDM platform, the integration of CAD/CAPP/CAM has got a new approach. The PDM concept is even extended to product life-cycle management. In Chapter 7, concurrent engineering is described, which is used to enhance the effectiveness of product development. The collaborative design and team work are emphasized in the CE design. In the last chapter, some future developments of CAD/CAPP/CAM are proposed.

This textbook has been organized in such a way that each chapter stands on its own, that is, the chapters need not be taught sequentially. Hence, the chapters can be selected depending on the course's focus, purpose, and philosophy.

Example of course syllabus

This book was initially proposed to provide a textbook for the course of integration of CAD/CAPP/CAM at postgraduate level at Nanjing University of Aeronautics and Astronautics. Here is the course syllabus that has been used for 8 years. This can offer some reference for other courses at other levels or other majors.

Course Code: FE**0530009**
Course Title in English: **Integration of CAD/CAPP/CAM**
College and department: College of Mechanical and Electrical Engineering
Semester: 2
Class hours: 40
Teaching methods: Lecture and experiments
Suitable majors: Mechanical Engineering, Mechatronics Engineering

Assessment instruments: Mini-projects and a final examination
Prerequisites: Computer aided design, numerical control programming

Course Objective and Requirements

This course is developed to systematically deliver the principle knowledge about CAD, CAPP, CAM, PDM, and CE to the students at postgraduate levels. The integration methods are studied by analyzing the exchanged information between these isolated systems. The product data model of STEP is one of the ideal solutions. The STEP model contains the information about the whole product life cycle. PDM provides a platform for 3C (which means CAD, CAPP, and CAM) systems integration. The contents of PDM are developing with the progress of 3C technology. On the basis of the integration of CAD/CAPP/CAM, the concept of CE is introduced, as well as the related theories and applications.

During this course, the students are required to master the basic principles of CAD, CAPP, CAM, and PDM, and be familiar with the commercial software packages. Students must know the integration theories and methods of CAD/CAPP/CAM. After taking this course, the logical thinking ability will be enhanced, and the ability to analyze and solve problems will also be improved. It is helpful for the students for project research in the near future.

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Last but not least, I am grateful to my family and friends who supported me with their love and encouragement.

If you have any questions or comments about this textbook, please email me at meejbxue@nuaa.edu.cn.

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Contents

1 Introduction

Questions before you read

1. Do you know anything about CAD, CAPP, and CAM?
2. What is the whole product life cycle?
3. How do you plan to carry out product design and manufacture?
4. What kinds of software packages do you need in product design and manufacture?

The goal of this chapter is to help the reader understand the basic concept of integration of CAD/CAPP/CAM, their roles in the whole product life cycle, and the brief history of the isolated systems. The concepts of product data management (PDM) and concurrent engineering (CE) are also briefly introduced in this chapter.

1.1 Product design and manufacture

Do you ever want to design and manufacture a product? During your childhood, you must have been attracted by some amazing products. You want to make it. However, your knowledge was limited at that time. You admired the carpenters who could make a number of products of wood. You also admired the blacksmiths who could make tools of steel. And now there are a large number of factories making many products of different materials every day. Do you have such an intention to find out how these products were made of? Here you will be given a general description about the product life cycle.

Product life cycle

In the field of economics, the product life cycle has been divided into four stages: introduction, growth, maturity and decline. But in this textbook, the product life cycle means the product development life cycle, which is a complex procedure, as illustrated in Figure 1.1. The product begins with a need based on customers' demands. From the voice of customers to market analysis, product design, process planning, product manufacture, sales, use and discard. The first two blocks and the last two blocks are mostly related to markets, sales and services, which can be classified into the management field. The product design, process planning and product manufacture are closely related to mechanical engineering, so these three blocks can be classified into the engineering field. The main contents of this textbook cover these three blocks: product design, process planning and product manufacture. With the development of computer science and technology, computers are used to help engineers in different stages of product development. So computer-aided design (CAD) is the automation of product design; computer-aided process planning (CAPP) is the automation of process planning; and computer-aided manufacturing (CAM) is the automation of product manufacture. This textbook introduces the integration of CAD/CAPP/CAM. The interfaces between the product design, process planning and product manufacture are described and analyzed.

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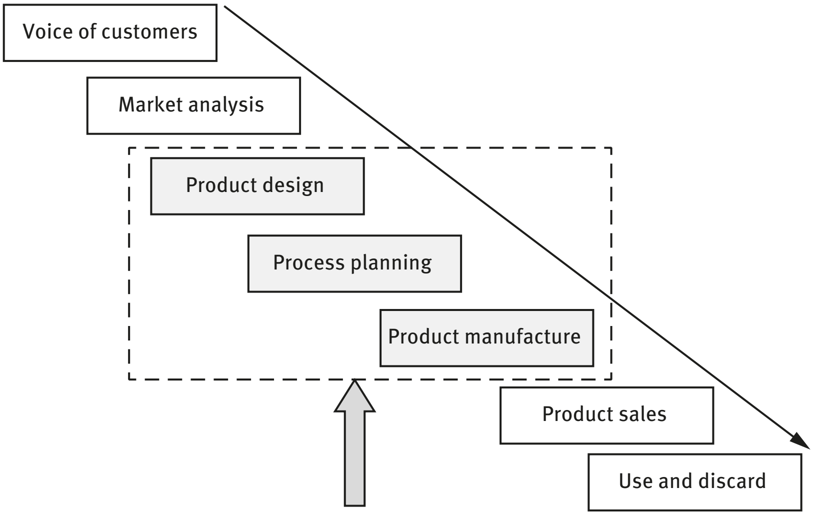

Figure 1.1: Product life cycle.

Basic concept of CAD/CAPP/CAM

Global competitions are increasing in modern manufacturing environment. Products should be delivered with increasing variety, smaller lots and higher quality. Industrial companies cannot survive worldwide competition unless they introduce new products with better quality, at lower costs, and with shorter lead-time. The availability of skilled labor is decreasing. With dramatic changes in computing power and software tools for design and production, engineers are now using CAD, CAPP, CAM, and computer-aided engineering (CAE) systems to automate their design and production processes. And industrial robots are widely used in most manufacturing companies to replace skilled human labor. These technologies are now used every day for engineering tasks. Below is a brief description that how CAD, CAPP, CAM, and CAE technologies are used during the product realization process.

The term CAD/CAPP/CAM is a shortened form of integration of CAD, CAPP and CAM. CAD and CAM are two essential tools to design and manufacture parts. CAPP is trying to bridge the two systems by seamless integration. In recent years, CAE is becoming popular. And it must be also integrated with other CAD/CAPP/CAM systems. So the integration of CAD/CAPP/CAM should be extended to be CAD/CAPP/CAM/CAE. Even more, the integration of CAD/CAPP/CAM should also consider the aspect of robots.

There are several main tasks to be finished, respectively, in each stage. Figure 1.2 shows the main tasks of the three stages.

In the stage of product design, CAD software packages are the main tools. CAD systems are used for geometric modeling, engineering analysis, simulation, scientific computing, graphics, and engineering database. Reverse engineering is a new

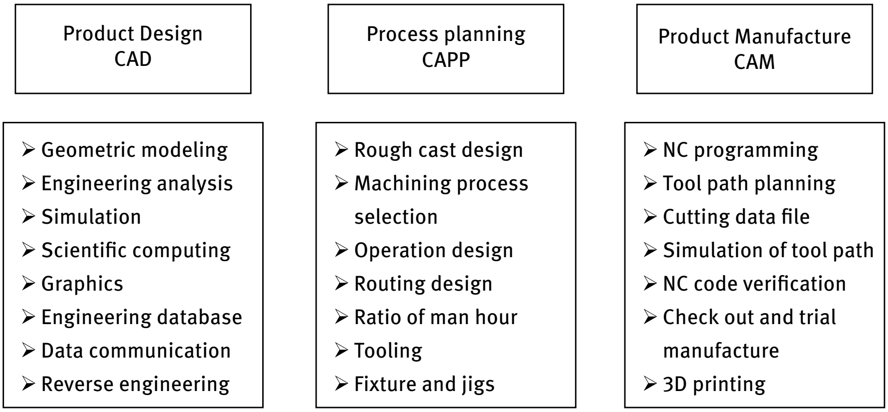

Figure 1.2: Design, process planning and manufacture.

approach for product design. With the development of network, CAD is also used to communicate among or between different engineers from different departments.

In the stage of process planning, CAPP software packages are the main tools. CAPP systems help engineers carry out rough casting design, machining process selection, operation design, routing design, ration of man-hour, tooling, and fixture and jigs.

In the product manufacture stage, CAM software packages are the main tools. CAM systems are used for numerical control (NC) programming, tool path planning, cutting data files, simulation of tool path, NC code verification, check out and trial manufacture. Three-dimensional printing is a new method for product manufacture; it is a kind of additive manufacturing.

Computer applications have been found in the entire spectrum of the product development process, ranging from conceptual design to product realization, and even recycling. CAD, CAPP, and CAM could have been independent systems. They are now seamlessly integrated as CAD/CAPP/CAM because most of the common information about products must be shared among them. So the main point is the integration, which is expressed using the forward slash (/) symbol. Here, the forward slashes among the three or four CAx systems play more important roles in the development of products. They represent the integration relationships among these systems.

1.2 Development of CAD/CAPP/CAM

1.2.1 Computer-aided design

CAD is mainly used for detailed two-dimensional engineering drawings of physical components, and for 3D modeling since the 1980s, but it is also used throughout the engineering process from conceptual design and layout of products, through strength and dynamic analysis of assemblies to definition of manufacturing methods of components.

With the advent of computers, designers have long used computers for their calculations. Initial developments were carried out in the 1960s within the aircraft and automotive industries in the area of 3D surface construction and NC programming, most of it independent of one another and often not publicly published until much later.

First commercial applications of CAD were in large companies such as the automotive and aerospace industries, as well as in electronic industries. Because computers were very expensive, only large corporations could afford the computers capable of performing the calculations.

As computers became more affordable, the application areas have gradually expanded. The personal computers dropped the prices of computers. The development of CAD software for personal computers was the right impetus for almost universal application in all areas.

CAD implementations have evolved dramatically since then. Initially, with 2D in the 1970s, it was typically limited to producing drawings similar to hand-drafted drawings. Advances in programming and computer hardware, notably solid modeling in the 1980s, have allowed more versatile applications of computers in design activities. Some key products for 1981 were the solid modeling packages – Romulus (ShapeData), Uni-Solid (Unigraphics) based on PADL-2, and the release of the surface modeler CATIA (Dassault Systèmes).

Autodesk was found in 1982, which developed a 2D system named Auto CAD. Following the idea of 2D drawing, the computer aided x alliance (CAXA) system was developed to throw off the drawing board in China. The next milestone was the release of Pro/Engineer in 1988, which used the feature-based modeling methods. Also of importance to the development of CAD was the development of the B-rep solid modeling kernels (engines for manipulating geometrically and topologically consistent 3D objects), Parasolid (Shape Data), and ACIS (Spatial Technology Inc.) at the end of the 1980s and the beginning of the 1990s. This led to the release of mid-range packages such as SolidWorks in 1995, Solid Edge (Intergraph) in 1996, and Iron CAD in 1998. Since the beginning of the 21st century, these packages have been enriched with many functional modules. Some big buyouts happened to reorganize the CAD market. In 1997, Dassault Systèmes, best known for its CATIA CAD software, acquired SolidWorks for $310 million in stock. In 2000, Unigraphics purchased structural dynamics research corporation (SDRC) I-DEAS and integrated aspects of both software packages into a single product when became Unigraphics NX. Since 2007, NX has been owned by Siemens PLM Software.

Starting the late 1980s, CAD programs could be run on personal computers. The drafting departments in many small to middle enterprises were massively downsizing. As a general rule, one CAD operator could readily replace at least four or five drafters using traditional ruler–pencil methods. Additionally, many engineers began to do their own drafting work, further eliminating the need for traditional drafting departments. This trend mirrored that of the elimination of many office jobs traditionally performed by a secretary as word processors, spreadsheets, databases, and so on became standard software packages that everyone was expected to learn.

Today, CAD is not limited to drafting and rendering, and it ventures into many more "intellectual" areas of a designer's expertise. CAD is used in many businesses and organizations around the world.

1.2.2 Computer-aided manufacturing

CAD has steadily advanced over the past seven decades to the stage at which designs for new products can be made entirely within the framework of CAD software from the development of the basic design to the bill of materials necessary to manufacture the product. But at this stage, manufacturing has not been considered carefully.

CAM takes this one step further from the conceptual design to the manufacturing of the finished product. Whereas in the past it would be necessary for design developed using 2D CAD software to be manually converted into a drafted paper-drawing detailing instructions for its manufacture, CAM software allows data from 2D CAD software to be converted directly into a set of manufacturing instructions.

Afterward, CAM software converts 3D models generated in CAD into a set of basic operating instructions written in G-code directly. G-code is a programming language that can be understood by numerically controlled machine tools. The G-code can instruct the machine tool to manufacture a large number of items with perfect precision and faith to the CAD design. G-code has a history about 70 years. Figure 1.3 shows a CNC machine tool, which can understand G-code from CAM.

Modern numerically controlled machine tools can be linked into a flexible manufacturing cell (FMC), a collection of tools that each performs a specified task in the manufacture of a product. The product is passed along the cell in the manner of a

Figure 1.3: A CNC machine tool understanding G-code from CAM.

production line, with each machine tool, that is, welding and milling machines, drills, and lathes, performing a single step of the process.

For the sake of convenience, a single computer can drive all of the tools in a single cell. G-code instructions can be fed to this controller and then left to run the cell with minimal input from human supervisors. This may be called as direct numerical control (DNC). If a center computer can drive all of the tools in several cells, the G-code instructions can be delivered to the distributed controllers, this may be called as distributed numerical control (DNC). So DNC has two meanings: one is direct numerical control and another is distributed numerical control.

Benefits of computer-aided manufacturing

The ideal state of affairs for manufacturers is an entirely automated manufacturing process. In conjunction with CAD, CAM enables manufacturers to reduce the costs of producing goods by minimizing the involvement of human operators.

In addition to lower running costs, there are several additional benefits in using CAM software. By removing the need to translate CAD models into manufacturing instructions through paper drafts, it enables manufactures to make quick alterations to the product design, feeding updated instructions to the machine tools and seeing instant results.

In addition, many CAM software packages have the ability to manage simple tasks such as the reordering of parts, further minimizing human involvement. Though all CNC machine tools have the ability to sense errors and automatically shut down, many can actually send a message to their human operators through mobile phones or e-mail, informing them of the problem and awaiting further instructions.

All in all, CAM software represents a trend to make manufacturing entirely automated. While CAD removes the need to retain a team of drafters to design new products, CAM removes the need for skilled and unskilled factory workers. All of these developments result in lower operational costs, lower-end product prices, and increased profits for manufacturers.

Problems with computer-aided manufacturing

Unfortunately, there are several limitations of CAM. Obviously, setting up the infrastructure to begin with can be extremely expensive. CAM requires not only the numerically controlled machine tools themselves but also an extensive suite of CAD/CAM software and hardware to develop the design models and convert them into manufacturing instructions – as well as trained operators to run them.

Additionally, the field of CAM is fraught with inconsistency. While all numerically controlled machine tools operate using G-code, there is no universally used standard for the code itself. Since there is such a wide variety of machine tools that use the G-code, it tends to be the case that manufacturers create their own codes to operate their own machinery.

While this lack of standardization may not be a problem in itself, it can become a problem when the time comes to convert 3D CAD designs into G-codes. CAD systems tend to store data in their own proprietary format, so it can often be a challenge to transfer data from CAD to CAM software and then into whatever form of G-code the manufacturer employs.

Well before the development of CAD, the manufacturing world adopted tools controlled by numbers and letters to fill the need for manufacturing complex shapes in an accurate and repeatable manner. During the 1950s, these numerically controlled machines used the existing technology of paper tapes with regularly spaced holes punched in them to feed numbers into controller machines that were wired to the motors positioning the work on machine tools. The electro-mechanical nature of the controllers allowed digital technologies to be easily incorporated as they were developed.

By the late 1960s, numerically controlled machining centers were commercially available, incorporating a variety of machining processes and automatic tool changing. Such tools were capable of doing work on multiple surfaces of a work-piece, moving the work-piece to positions programmed in advance and using a variety of tools – all automatically. What is more, the same work could be done over and over again with extraordinary precision and very little additional human input. NC machine tools immediately raised automation of manufacturing to a new level once feedback loops were incorporated. The tool tells the computer where it is, while the computer tells it where it should be.

What finally made NC technology enormously successful was the development of the universal NC programming language called automatically programmed tools (APT). Announced at MIT in 1962, APT allowed programmers to develop post-processors specific to each type of NC machine tool so that the output from the APT program could be shared among different parties with different manufacturing capabilities.

1.2.3 CAD/CAM software

The development of CAD had little effect on CNC initially due to the different capabilities and file formats used by drawing and machining programs. However, as CAD applications such as SolidWorks and Auto CAD incorporate CAM intelligence, and as CAM applications such as Master CAM adopt sophisticated CAD tools, both designers and manufacturers are now enjoying an increasing variety of capable CAD/CAM software. Most CAD/CAM softwares were developed for product development and the design and manufacturing of components and molds.

Today, most of new machine tools incorporate CNC technologies. These tools are used in every conceivable manufacturing sector. CNC technology is related to computer-integrated manufacturing (CIM), CAPP and other technologies such as