CAD/CAM

PRINCIPLES AND APPLICATIONS

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Preface

CAD/CAM has originated from traditional designing and manufacturing concepts. Like material standards, there are design standards proposed by every country, such as ASME standards, British standards, for design of pressure vessels, piping, welded joints, etc. Introduction of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) in industries resulted in several benefits such as reduction of production times and manufacturing wastage and higher output. Early design procedures of a product which were proposed by design pioneers like late Dr Shigley have now been modified with soft computational approaches. Although the basic steps starting from product need to its final evaluation have remained the same, the use of computers and software standards have made the design procedure so simple that design and manufacturing are integrated and are no longer considered to be in sequence.

Today, a designer need not send hardcopy of drawings to the manufacturing section; he can simply upload the CAD database in the form of computer drawings and models.

Computer aided engineering and manufacturing is one of the rapidly developing branches in modern manufacturing practices. The state-of-the-art technologies of CAD and CAM have seen revolutionary advancements in the previous decade. A product during its life cycle undergoes several activities and passes through various departments like CAD, CAM, managerial, and marketing divisions. To understand and develop the product cycle thoroughly, CAD/CAM engineers must learn and understand all concepts under this umbrella.

CAD and CAM have equal importance in the overall production procedure. Each of these sections has four modules. For example, in CAD the four modules are geometric modelling, design analysis and optimization, review and evaluation, and computer-aided drafting. In dealing with the concepts, one should understand the connectivity of each module with the other. There are many commercial CAD modellers available today. These are developed with user interactive graphical interfaces based on graphics and exchange standards proposed by International Standard Organization. Interoperability of CAD models from one system to another is now a quite simple task due to the exchange formats including IGES, STEP, etc. Just like CAD technology, there are several developments happening in CAM such as look-ahead interpolator for accurate tool contours, optimal layouts for cellular manufacturing. Societies of computer aided design and machine tools and manufacturing have been encouraging new inventions in these areas to simplify and economize the existing concepts.

About the Book

CAD/CAM: Principles and Applications is primarily designed to serve as a textbook for undergraduate students of mechanical and allied engineering disciplines. However, the scope of this book has been expanded to go beyond the needs of an undergraduate engineering student. It will also serve as a reference book for students preparing for competitive exams, technologists with interest in CAD/CAM, and practitioners of various branches of engineering who are involved in using CAD/CAM.

The book thoroughly explains all relevant and important topics in a student friendly manner. The language and approach towards understanding the principal concepts of CAD/CAM and the underlying mathematical challenges is clear. It lays emphasis on explaining the principles as well as the applications of a given topic using examples and self-explanatory figures, diagrams, and tables.

Key Features

- Includes dedicated chapters on mathematical modelling coupled with CAD standards
- Presents finite element method (FEM) and Computer-aided Quality Control as separate chapters, and CAM and part programming are discussed together
- Provides an exclusive chapter on design evaluation tools dealing with CAD applications in virtual engineering, virtual prototyping, and rapid prototyping
- Contains solved examples, multiple choice questions with answers, and numerical exercises at the end of every chapter
- Explains CAD software tools and CAM interpolation working elaborately
- Includes elaborate appendices on Solidworks, CNC Simulators, Parametric Interpolation in CNC, Reverse Engineering, GUI in MATLAB

Organization of the Book

The book focuses on the classical concepts and developments in the area of CAD/CAM. It has 15 chapters along with a few appendices addressing the requirements of both academicians and industrial practitioners.

Brief introduction to the subject of CAD/CAM has been elicited in *Chapter 1*. *Chapter 2* deals with hardware and software configurations of CAD systems. Here, the necessary introduction of computer graphics has been also provided. Computer graphics is an important in geometric modelling and design animations and simulations. *Chapter 3* highlights the concepts of computer aided drafting and geometric modelling. Necessary requirements of these software are also explored.

Chapter 4 discusses concepts of curves necessary in wireframe modelling. *Chapter 5* presents surface modelling and gives overview of various surface patches. Readers have a prior knowledge of the parametric representations can skip these two chapters. *Chapter 6* gives concepts of solid-modelling and visual realizations of solids. Though all these are very classical concepts, on studying these the reader will be able to appreciate their implementation in modern CAD tools. *Chapter 7* describes the concepts of finite element modelling and optimization methods.

Chapter 8 summarizes the important standards to be followed in development of CAD tools from hardware and exchange perspectives. Two important design evaluation tools commonly used by CAD community are dealt with in detail in *Chapter 9*. *Chapter 10* presents an overview of CAM and describes standard practices in NC/CNC machine programming. *Chapter 11* describes the group technology and cellular manufacturing issues. *Chapter 12* presents production management and material requirements planning concepts.

Chapter 13 explores various computer aided manufacturing procedures including flexible manufacturing systems, lean manufacturing, JIT, and intelligent manufacturing systems. *Chapter 14* deals with computer-aided quality control with contact and non-contact techniques with integrated CAD/CAM systems. *Chapter 15* presents the concepts of computer integrated manufacturing systems with special emphasis on classical definitions such as standards and total quality management techniques.

The book has five appendices providing an introduction to Geometric Modelling using Solidworks®.

Appendix A discusses the brief history and details of Solidworks, its basic features, assembly modelling, and drawing module with the help of some solved examples to illustrate concepts.

Appendix B explains about CNC simulators and its types along with their usage. This appendix contains various computer simulation programs which is used to draw complex figures in CAD/CAM.

Parametric interpolations in CNC systems forms *Appendix C*. This appendix explains to the users how mathematical interpolation of parametric curves can be performed in CNC systems. The AKIMA spline curve is also discussed in details.

Reverse Engineering—Reverse Geometric Modelling and Inverse Analysis are important concepts to be learnt by design engineers to be able to approach critical product problems from the perspective of design thinking. This is described in *Appendix D*.

Appendix E is on GUI in MATLAB. This appendix basically enables reader to effectively use MATLAB using the GUI. The appendix gives an overview of basic MATLAB commands and sample programs which can be used to create effective GUI. It also consists of various programs for practice and implementation on computer systems.

Online Resources

To aid the faculty and students using this book, additional resources are available at http://india.oup.com/orcs/9780199464746.

For Faculty
- PowerPoint Slides
- Solutions manual

For Students
- Case studies
- Additional problems

Acknowledgements

I am grateful for the advice of reviewers and team at Oxford University Press involved in this project. I hope the book meets the requirements of several pre-final and final year students at various universities.

My special thanks to all other people involved in this work, especially to my family for their encouragement in sharing lot of time in discussing modern concepts of CAD/CAM.

Knowledge being a continuum, we have to keep updating ourselves with new concepts and practices from time to time.

Any suggestions for improvement of the book are welcome and would be duly acknowledged.

J. Srinivas

Features of

Comprehensive Coverage

Includes dedicated chapters on *Numerical Control Manufacturing, Computer Aided Manufacturing and Computer-aided Quality Control*. The book also discusses rapid prototyping (including 3D printing) in adequate detail which would raise students' curiosity for further studies and research.

14 CHAPTER

Computer-aided Quality Control

9.4 THREE-DIMENSIONAL PRINTING

Three-dimensional printing, popularly called 3-D printing, is the most advanced form of RP available. 3-D printing is based on topography and photosculpture. It was originally developed in 1986 by Charles W. Hull to build objects layer by layer based on digital drawings. Three-dimensional printing (3DP) is very similar to inkjet printing process. 3DP technologies adopt a process chain, which consists of five steps—3-D modelling, data conversion and transmission, checking and preparing, building, and post-processing. Figure 9.16 shows the process of 3DP.

Figures and Tables

The book has more than 230 interactive figures and tables aiding users to visualize the concepts and principles of CAD/CAM.

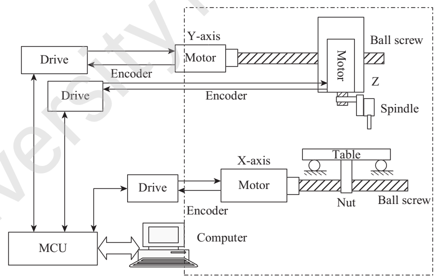

Fig. 10.2 Schematic of a three-axis CNC system

Table 10.1 Components that give motion in a five-axis machining centre

Axis	Movement	Provided by
x axis	Linear	Saddle
y axis	Linear	Column
z axis	Linear	Table
a axis	Contouring and tilting	Spindle
b axis	Rotary	Rotary table

Example 10.3 Write an NC program to machine the aluminium part shown in Fig. 10.18. Here, a 50 mm diameter blank, 65 mm long pin is to be used. Use the following steps:
(a) Face-off to final length
(b) Rough cut 40 mm diameter in two passes
(c) Rough turn taper in two passes
(d) Finish machine to final dimensions
(e) Absolute programming is to be used
(f) Spindle speed of 750 rpm and feed rate of 225 mm/min.
Specify the rapid feed rate by F0.

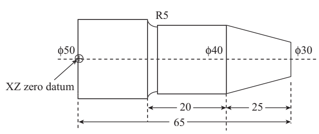

Fig. 10.18 Turning example (all dimensions are in mm)

Solved Examples

Numerous solved examples interspersed throughout the chapters give readers the opportunity to understand the application of concepts in practical engineering problems.

the Book

Appendices

The book has five introductory appendices on geometric modelling using Solidworks®, CNC Simulators, and Parametric Interpolations in CNC systems, Reverse Engineering and GUI in MATLAB.

APPENDIX A

Geometric Modelling Using SolidWorks(R)

Solid modelling is a more realistic representation of object geometry. Previously, CAD systems are based on wireframe or surface modelling approaches, where user creates the 2D objects by specifying coordinates of each corner and completes the diagrams. There were no parametric- or feature-based programs at that time. Nowadays, several solid modelling-based commercial software tools are employed for various applications. Here, a brief introduction of using SolidWorks(R) software will be provided. More or less, in all solid modelling tools, principally, there are four modules: sketching, part modelling, assembly modelling, and drawing or drafting. Apart from these, surface modelling, mould design, kinematic analysis, finite element modelling, and so on are to be treated as secondary issues. Tools in commercial finite element analysis, such as NASTRAN, ABAQUS, and ANSYS, also have their own built-in solid modelling environments for creating complex geometries. However, the additional and flexible features of CAD tools have been attracting several users for geometric modelling applications.

Exhaustive Chapter-end Self Assessments Section

The self-assessment section provides multiple choice questions with answers, mixed bag of critical-thinking questions, and concept-based questions and numerical problems for practice at the end of each chapter.

SELF-ASSESSMENT

Multiple Choice Questions

9.1 When dynamism is introduced for digital mock-up technology, it becomes
(a) Virtual engineering (c) Animation
(b) Virtual prototyping (d) Motion study

9.2 For getting perfect kinematic analysis of a virtual product, Gruebler's count should be
(a) Greater than zero (c) Imaginary
(b) Less than or equal to zero (d) None of the above

9.3 Extended finite element method (XFEM) supports
(a) Structural analysis (c) Modal analysis
(b) Fracture studies (d) None of the above

Short Questions

9.1 What are the main roles and functions of prototypes?
9.2 Briefly explain how virtual prototyping simulates product performance and reliability.

Problems for Practice

9.1 Construct a four-bar linkage with two hinges (as shown in Fig. 9.17) as base link and a crank, coupler, and output link using assembly module in Pro/E or SolidWorks.

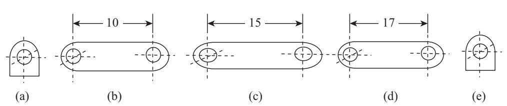

Fig. 9.17 Part diagrams of individual components (a) Base (b) Crank (c) Coupler (d) Output (e) Base (All holes are of 2 mm diameter)

Brief Contents

Detailed Contents

1 CHAPTER

Introduction to CAD/CAM

Learning Objectives

After reading this chapter, the reader will be able to understand the following concepts:

- Basic concepts of CAD and CAM
- Product life cycle
- CAD/CAM integration
- Benefits of CAD/CAM

INTRODUCTION

Computer-aided design/Computer-aided manufacturing (CAD/CAM) is a technology used to perform certain functions in design and manufacturing with the aid of computers. The process of using computers for the creation, modification, analysis, or optimization of designs is referred to as computer-aided design (CAD). CAD is used to design and develop products. CAD is also used in designing tools and machinery employed in manufacturing.

CAD systems make use of computers along with various graphics terminals and interactive input devices. On the other hand, computer-aided manufacturing (CAM) refers to the use of computers for various activities relating to the manufacture of a product. These activities include process planning, manufacturing, scheduling of parts/products, etc. The role of computers in CAD/CAM may be broadly categorized as follows:

1. Supporting functions facilitating efficient manufacturing of a product
2. Monitoring and control functions related to the manufacture of a product
3. Supporting functions that enable computers deliver quality products to the customers

The first two groups fall under CAD/CAM, whereas the last group deals with business activities. The process employing the three stages is often called computer-integrated manufacturing (CIM).

During the early 1960s, design and manufacturing operations were carried out independently. Manufacturing departments used to adopt a drawing document generated from the design section for fabrication of a product. The process was time-consuming and required enormous resources to generate the final product. CAD/CAM played a major role in reducing the time taken by the product to reach the market. With the concept of automation in production systems that began in industries during the 1980s, the need for computers in design and manufacturing was recognized. Conventional design procedure begins with the need for a product. Following the identification of a need, the design problem is defined.

CAD/CAM technology has been utilized across different disciplines including aerospace, automobile, construction, electronics, petroleum, etc. Some basic applications of CAD/CAM are: generation of engineering drawings and documents, creation of solid models as visual images for animation and kinematic/dynamic simulations. CAD/CAM has widespread usage even in some advanced applications such as finite analysis of geometric models, creation of process plans and computer numerical control programs for machine tools etc. This chapter gives a brief overview of CAD/CAM tools and its historical developments as well as its benefits in modern industries. In order to understand the scope of CAD/CAM in industries, we need to begin with the concept of product life cycle.

1.1 PRODUCT LIFE CYCLE

The product design and development stage begins with a market need and ends with the actual product in the market. With changing market demand, it is important that a product reaches the market within the shortest possible time. The traditional product life cycle consists of two stages as follows:

1. Design stage
2. Manufacturing

Figure 1.1 shows the typical product life cycle of a component.

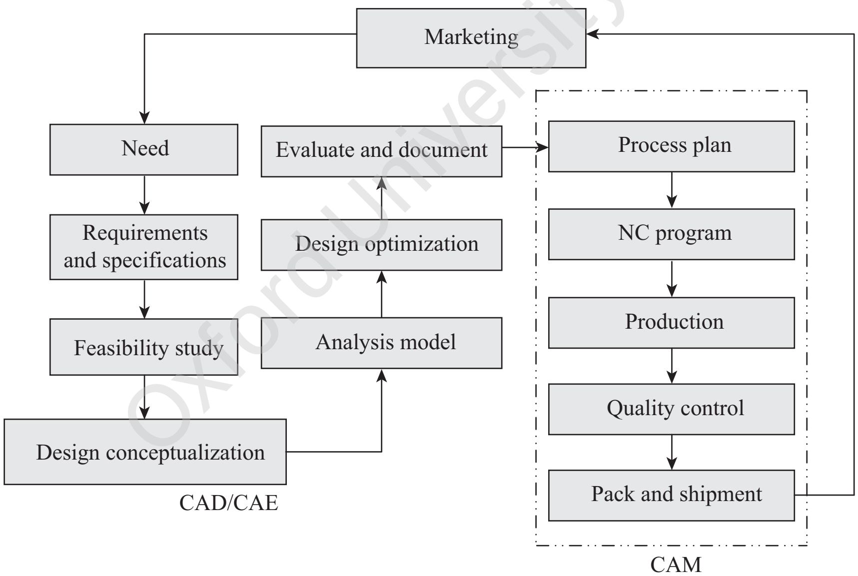

Fig. 1.1 Important phases in a product life cycle

The process of conceiving the design starts with a need which is identified on the basis of customer/market demands and ends with a complete description of the product, usually in the form of a drawing. In fact, the design process consists of synthesis and analysis phases. During the synthesis phase, functionality and uniqueness of product are identified and are shown with the help of various elaborate sketches and drawings. Synthesis is crucial in design and the information generated in this stage is qualitative and is difficult to capture in a computer.

In synthesis phase, the modeller's intuition based on previous designs is very important. The geometrical modelling procedure in the CAD system is equivalent to the synthesis phase of a traditional design. Based on physical constraints, the dimensions of geometry are specified. The designer creates a graphical image of the object on graphics terminals and stores the image in data files. The mathematical description of the image of an object allows display and manipulation functions on graphics terminal through signals from the central processing unit (CPU) of the CAD system.

Analysis of the sub-process involves evaluation of product performance with the help of modelling and simulations. The design is improved through analysis procedure and the process is repeated until the design has been optimized within the constraints imposed on the designer. General purpose computer programs may be used to perform engineering analysis. Some examples of typical analyses undergone by a design comprise the following:

1. Analysis of mass properties (a feature of most CAD systems) of solid objects
2. Stress analysis to verify the strength of the design
3. Interference checking in assemblies to detect collision between the components while they move in the assembly
4. Kinematic analysis to check whether the model used provides the required motions

Once the initial design is completed, optimization procedures are employed to obtain certain objectives such as achieving a desired stress criteria or thermal/fluid characteristics so as to alter the original geometric dimensions/topology to form a new design. After verifying the optimized model using the analysis module, the evaluation phase begins with these nominal dimensions. For evaluation purposes, prototypes are often built at the laboratory level. These are not the final function prototypes and are, therefore, called rapid prototypes. Examples include, products prepared from 3-D printing technology and fused deposition modelling. Rapid prototyping enables the construction of a prototype by depositing layers/slices from the bottom to the top and thus constructs the prototype directly from the design. Sometimes, virtual prototyping is directly used in a computer using mechanism-generation tools in order to assess their functionality in various respects. If the design evaluation is satisfactory, the design documents will be prepared; otherwise, a new design process is initiated. Design documentation includes preparation of drawings, reports, bills of materials, etc. Conventionally, blue prints are made from drawings and passed on to manufacturing. More often, computer prototypes are utilized because they are less expensive and faster to generate.

The manufacturing process starts from the design specifications and ends with shipping of actual products. Process planning establishes process parameters and selects the machines. The process plan helps in creating the product more effectively. It results in production planning, material ordering, and machine programming operations. Other requirements such as design of jigs and fixtures are also handled at this stage. Process planning is similar to synthesis in the design phase. Computer-aided process planning (CAPP) software aids in most of these activities. In the next step, the products are inspected with quality control techniques and the selected components are assembled and packaged for shipment.

Computers play a prominent role in a product life cycle. The product–life concept is generated from the conceptual design of a product. Sales, marketing, and feedback reports are created from the CAM system. These two are considered the first and last activities in the cycle. The intermediate activities namely, CAD and CAM, are described in the following section.

1.2 SCOPE AND APPLICATIONS OF CAD/CAM

The scope of CAD/CAM can be defined on the basis of the product life cycle. Modern manufacturing industries focus on high-quality components with short lead times and low production costs. In this regard, computers are used in several tasks during product development, starting from modelling to the final stage of fabrication. CAD refers to the process of using computers for design conceptualization, creation, modification, and analysis of components. Such a design process is interactive in nature and involves six important steps as follows:

1. Recognition of the need
2. Definition of the problem
3. Synthesis
4. Analysis and optimization
5. Evaluation
6. Documentation

The recognition of a need involves the realization that a problem exists for which a corrective action is needed. This may include identification of some defect in the current machine by an engineer. The definition of the problem involves a thorough specification of the item (such as physical and functional characteristics, cost, quality, and so on) to be designed. Synthesis refers to the generation of a basic model including its complete drawing. A certain component is conceptualized by the designer, subjected to analysis, and improved further by optimization. The components and subsystems are synthesized into the final overall system in a similar iterative manner. Evaluation deals with measuring the design against the specifications established in the problem definition phase. It involves, often, fabrication of prototype and its testing to assess the operating performance, quality, reliability, and other criteria. The final phase of the design process is presentation, which includes documentation of design by means of drawings, material specifications, assembly lists, etc. Thus, finally, a design database is created. The main disadvantage of a traditional design process is its time-consuming stages during the iterative procedure.

Computers may be applied for design-related tasks in an effective manner. CAD has a number of components that will help in the various stages of the design process. Some of the basic elements of a CAD system include the following:

1. Graphic package for visualization
2. Geometry manager for maintaining data structures containing geometric information
3. A library of numerical methods to perform various numerical operations
4. An interface to connect the user and the system
5. A data manager to store and maintain large amounts of CAD data

CAD data have some unique characteristics that make their management difficult. The database of a CAD object involves a complex structure with large volume of data. In many CAD systems, the designed object has many aspects of data to be stored which may be updated later. It may also be used in the design of more complex objects and may, in turn, consist of lower-level components. When the lower-level component is changed, the higher-level component should either change automatically or become invalid. All these different aspects of data need to be stored and properly dealt with in an integrated environment that can be accessed by different CAD utilities so that the cost of storing, maintaining, and accessing these objects becomes minimal. The database provides general purpose programs that can be used to access and manipulate large amount of stored data. Database systems must be efficiently used to store CAD data for easy retrieval and better product management of stored information. Currently, several types of database systems are available. The basic role of CAD is to define the geometry of a mechanical part, architectural structure, electronic circuit, building layout etc. Computer-aided drafting and geometric modelling are typically used for these purposes.

The final functional product of design modelling is obtained from manufacturing operations. CAM requires the use of geometric description of an object and motion control programs to generate the necessary commands for control. A typical CAM software includes computer-aided process planning (CAPP) systems, numerical control (NC) software for numerically controlled machine tools, quality inspection software, software for programming robots, and automated guided vehicles used for material handling. The main area of focus in CAM is NC technology, an approach of using programmed instructions to control a machine tool. NC instructions are generated based on geometric data obtained from a CAD database along with additional data (more details of NC technology will be explained in Chapter 10)

Computer-aided engineering (CAE) is concerned with the use of computer systems to analyse CAD geometry and allows the designer to simulate and study the behaviour of a product so as to refine and optimize the design. CAE tools are available for a wide range of analyses, such as kinematics and dynamic analysis. Kinematic simulations, for example, help designers to virtually simulate the motion sequence of various links (parts) in an assembly model or to identify the interference states of the parts during the motion.

Dynamic analysis programs are used to find displacements in complex component assemblies such as in automobile bodies. Stress analysis, thermal analysis, harmonic and transient analysis, and fluid dynamics studies are some of the applications in dynamic studies of CAE. CAD, CAM, and CAE technologies are used in synergy to automate the specific functions during the design and manufacture of a part. As they were developed separately, the importance of integrating the design and manufacturing activities is not yet fully realized in some industries. To solve this problem, a new technology called *computer-integrated manufacturing* (CIM) has been introduced. CIM is concerned with using computer database to do various activities. It is a process of integration of CAD, CAM, and the business aspects of a company. Therefore, CIM includes management information system (MIS), sales, marketing, finance, database management, design, and manufacturing concepts. Figure 1.2 shows the basic activities in a traditional design and manufacturing environment. The concepts of CIM will be discussed in Chapter 15.

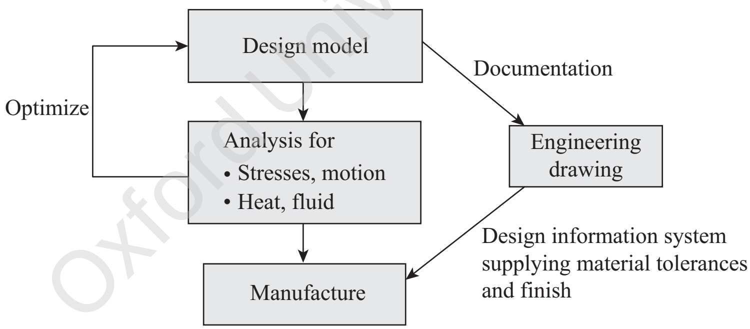

Fig. 1.2 Conventional layout of design and manufacture

CAD/CAM technology is utilized in different applications. Some of these are explained as follows:

For production of drawings and documents An engineer's interest is to visualize his creation as a realistic model with varying shapes and sizes. An architect's task is to use the CAD software to mould all the relevant components together to produce drawings and specifications. All such activities are possible with the use of CAD and CAM. Electrical and electronic designs use CAD and CAM systems to design printed circuit boards, wire diagrams, and design management systems.

Generation of images and animated displays as a visual tool Computer graphics are required in various fields in the modern scenario. Solids are displayed in shades and various colours. Also, solid models are employed in animated images that are necessary for effective visualization both in engineering simulations (e.g., in order to show the stress contours or vibration modes) and dynamic image displaying. Realistic solids with shades can be used as advertisement tools.

Analysis work on geometric models CAD can be effectively used for executing analysis work on geometric models. Most industrial problems are generated as CAD models and are analysed in multibody system dynamics simulation tools such as ADAMS for obtaining the realistic behaviour of the components. Further, various analysis stages are required for geometry, depending upon the type of loading and other boundary conditions.

Generation of process plans CAM can be conveniently used for the generation of process plans and NC part programs during manufacturing. CAD can be employed to generate a virtual plant (factory) and simulate the conditions to optimize the plant layout.

Generation of part programs Computer numerical part programs are generated by modern CAM software such as Mastercam and SolidCAM, using the process plan and CAD model. These are very helpful in saving time in programming. Various part programming languages are supported by most CAM software.

Inspection and assembly Often inspection software utilizes coordinate measuring machines which compares the coordinates of actual part with respect to a master database. Similarly, assembly process is achieved by robots which are trained with various offline programming and image processing techniques. All these come under CAM.

1.3 COMPUTERS FOR DESIGN AND MANUFACTURE

CAD systems perform various design-related tasks. These tasks can be broadly grouped into the following:

1. Geometric modelling
2. Engineering analysis
3. Design review and evaluation
4. Automated drafting

These are the final four phases of Shigley's general design process, dealt in Section 1.2. The first two phases of conventional design, namely, recognition of need and problem definition are creative in nature and are brought down manually.

Figure 1.3 shows these phases in CAD.

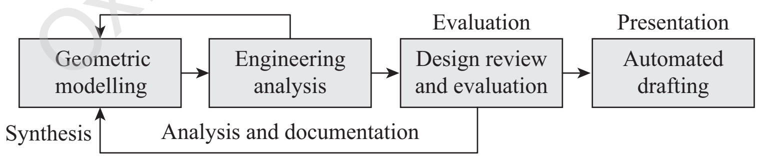

Fig. 1.3 Principal activities in a CAD process

Geometrical modelling corresponds to the synthesis phase of a general design procedure, where a physical object is visualized as computer graphics model. It is used to create production drawings and helps in the documentation of the design. Engineering analysis represents the analysis and optimization stage in conventional design. It includes volume/mass property calculation, computational fluid dynamics, kinematic and dynamic analysis, and assembly and tolerance analysis. Once some changes are required, the geometrical model needs to be redrawn. Design review and evaluation in CAD correspond to the fifth step in the general design procedure. These deal with checking the accuracy of a design by preparing virtual (computer-based) models or rapid prototypes (non-functional products). Finally, the design image data is converted into hardcopy document in the last phase. This is known as automated drafting in CAD. The details of geometric modelling and automated drafting will be dealt in Chapter 3, whereas engineering analysis phase will be described in Chapter 7. Design review and evaluation strategies will be explained in Chapter 9.

Similar to CAD, CAM has four principal phases as follows:

1. Tool and fixture design
2. NC programming
3. Computer-aided process planning (CAPP)
4. Production planning and scheduling

Figure 1.4 shows these basic modules in CAM. The basic input information required for CAM is the geometrical modelling data.

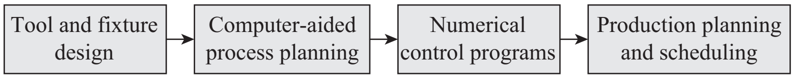

Fig. 1.4 Essential modules in CAM

The design of tools and fixtures is essential in this field as in conventional manufacturing. Work holding jigs and guiding fixtures along with multiple cutting tool turrets have to be carefully designed at the initial level. Using geometric model, the fixtures, mould cavities, cores, and other tools can be developed. Solid modelling tools such as Pro/E and SolidWorks facilitate several manufacturing features (like mould design) in this regard. NC programs carrying alphanumeric instructions can be generated, based on the process plans and these may be virtually executed to understand the simulation of machining operations on a computer screen. Computer numerical control (CNC) simulators from MTab is an example of that. The final operations are functional prototype generation on machining centres. This requires passing the NC codes on high-end machine tools.

Compared with conventional manufacturing strategies such as job shop (very small lots), batch (medium lots), and mass production (high volume), CAM facilitates product generation in the shortest lead times, with minimum maintenance and improved reliability. There is greater operating flexibility for standalone CNC machines. As for CAM processes, the basic geometric information is supplied as a CAD model, the interface algorithm extracts the geometric information from the CAD model, and feeds it to process planning, part programming, as well as inspection and packaging operations. The function of computers in this context is to control and monitor the NC machines and robots. In NC machines, for example, the control actions are provided to the machine tool as alpha-numeric instructions with a certain programming syntax so as to move the machine tool at a desired speed and feed-rate. There is a machine control unit that helps in understanding the instructions. Once the product is ready, some of the important activities that follow include its inspection, handling, and packaging. These production planning and scheduling activities are also a part of the CAM system.

The details of the necessary NC technology will be provided in Chapter 10. CAPP will be described in Chapter 11, whereas computer-aided scheduling procedure will be described in Chapter 12, and computer-aided inspection operations will be presented in Chapter 14. Therefore, the concept of CAM basically uses a CAD model (tool) for the generation of the end product.

1.4 DEVELOPMENTS IN CAD/CAM TECHNOLOGY

This section briefly highlights the various developments in CAD/CAM. A brief introduction of its history is explained here.

CAD/CAM technology has a long history. Isometric projections and sectional views were first introduced by Leonardo da Vinci. In the 18th century, orthographic projections were invented by Gaspard Monge, a French mathematician. Later, with the invention of computers and graphics technology, CAD/CAM has taken a new dimension. During 1950–60, development in interactive computer graphics led to the concept of numerical control technology and machine tool programming concepts. A decade later, the invention of graphic terminals like storage tubes based on cathode ray tube (CRT) technology were invented. During 1970–80, several standards for software configuration such as initial graphics exchange specification (IGES) and graphical kernel system (GKS) were invented and most CAD systems were employed for drafting applications. From 1980 onwards, research towards CAD/CAM integration concepts started. The invention of various curves and surfaces, concept of virtual factories, reverse engineering and networking, etc., began during this period.

Computer graphics and software technology have led to enormous developments in CAD/CAM. CAD tools such as geometric modellers and analysis software are common in the study of computer graphics as well as in geometric modelling and design.

As shown in Fig. 1.5, CAD tools work as a common feature in computer graphics, geometric modelling, and several other design analysis and heuristic codes. CAD tools may also be used for the manipulation of graphics elements, interference checking in assemblies, tolerance analysis, mass property calculations and finite element modelling, in the development of analysis and optimization routines, and so on. Fig. 1.6 shows the CAM tools, where the geometric model from CAD is utilized to initiate the CAM process.

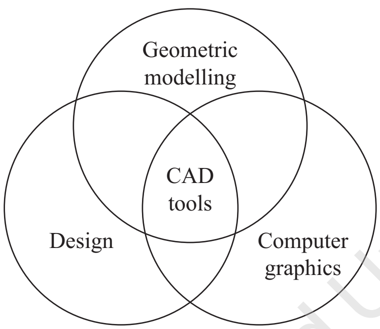

Fig. 1.5 CAD tools

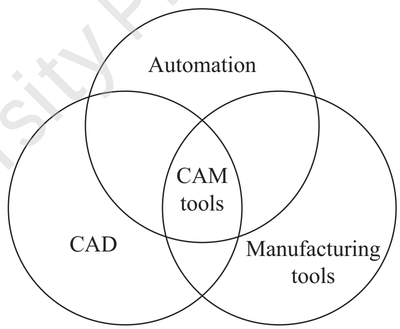

Fig. 1.6 CAM tools

Advanced software programs can analyse and test the designs before a prototype is made. For example, finite element analysis allows predicts stress points on a part and the effects of loading. Once a part is designed, the graphics systems can be used to program the tool path for machining operations. When integrated with an NC postprocessor, the NC programs can be produced.

In the early 1960s, there were only CAD systems and engineers used them to draw pictures of parts. Till the mid-1980s, CAD and CAM remained two independent technologies with offline data transfer. After the development of database management systems, the concept of integrated technologies began. Today, many commercial vendors of CAD and CAM systems have begun to employ integrated software tools to increase the productivity and improve the marketability and usability of products.

In an integrated CAD/CAM system, a direct link is established between product design and manufacturing. The ultimate goal of CAD/CAM is to automate the transition from design to manufacture. Integrated CAD/CAM systems provide design/drafting, planning, scheduling, and fabrication capabilities in a far more effective manner. The primary effort for integration lies in the development of process planning systems. Process planning is a function in the manufacturing process that aims to establish the required processes and parameters along with the selection of machines used for these processes. The output of process planning is a process plan which describes the sequence of the selected manufacturing processes or assembly operations. A process plan is sometimes called a route-sheet. Operation sequence and the selection of jig and fixtures and tools are shown in the process plan. Many factors such as part geometry, accuracy and surface finish, quantity of items, and materials would influence the process plan. These are often prepared manually. A skilled machinist examines the part drawing and develops the necessary instructions. The plan may contain simple operational descriptions or may be elaborate as in an automated transfer line. The complexity of the plan entirely depends on the process-planner's knowledge of manufacturing capabilities, tools, materials, etc., which is done in a routine manner. This process can be done automatically by integrating a CAD data file with process-planning software called CAPP.

Many systems import CAD drawings so as to generate CAM programs for automating manufacturing operations. For example, let an engineer draw a machine part in CAD. The CAD drawing is then brought into a CAE program for analysis. When the design is finalized, the drawing is brought into a CAD/CAM system which uses numerical data from the CAD drawing for actual manufacturing.

CAD/CAM integration is the process of generating production files from design files with the aid of a computer and software. This seems logical, but it is not self-evident. The design data is stored in a different way than the manufacturing data. Nevertheless, this is a very important step because maintaining quality implies that a design change is carried out in the manufacturing process as well. In some cases, the CAD software can take the possibilities and limitations of the manufacturing machine into account, and the designer can be notified during the design process itself. The concept of CIM attempts to describe complete automation with all processes functioning under computer control. The integrated manufacturing concept helps in managing and control the overall factory environment. There have been big workstation-based integrated CAD/CAM systems in use for several years. Integration plays a very important role in the future of CAD/CAM products.

In practice, there are three different types of integration as follows:

Data integration It is the ability to share part models (common data files or a common database). This is the most important type of integration for CAD/CAM. A better means to data integration is available in file format such as a Parasolid file. Such formats tightly define the data transferred from one Parasolid-based software program to another in a flawless manner. Manufacturing database is an integrated CAD/CAM database. It includes product data generated during design such as bill of materials, part list, material specifications, etc., along with manufacturing data.

Interface integration It is a common look and feel for different software modules. This reduces the learning curve for a common user of the different modules.

Application integration It is the way in which different software modules work together for a single user. This can be achieved by having the different functions physically in the same computer program.

Figure 1.7 shows the concept of an integrated CAD/CAM system using a proper database structure. A CAD/CAM database contains part libraries, geometric relationships, material information, analysis algorithms, etc. The database includes application database and manufacturing database.

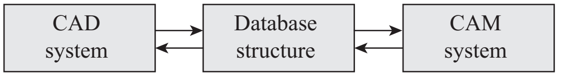

Figure 1.7 Concept of an integrated CAD/CAM system

Database must be complete in all respect and help in supporting all applications from modelling to manufacturing. It must be easy to employ and should allow timely modifications for iterative designs. Multiple users should able to access the database to deliver effective output. Modern CAD/CAM systems are well-developed and have several integration modules among themselves.

By using interactive CAD systems, design, drafting, and documentation errors are drastically minimized. Without manual handling of information in highly repetitive environments, the errors are further reduced. The accuracy in an interactive CAD system in a 3-D curved space design is higher than the one provided by manual means. Interactive CAD generates and updates 2-D and 3-D drawing, and are very effective in understanding and interpreting the components. The original drawings and reports are often stored in the database of a CAD system, which makes them more accessible. CAD/CAM database is used for manufacture planning and control as well as in design.

1.5 ADVANTAGES OF CAD AND CAM

There are several benefits of using CAD/CAM technology in production firms. Integrated CAD/CAM systems facilitate the following advantages:

1. Increased productivity
2. Shorter lead times
3. Reduced human resources
4. Improved accuracy of design
5. Easier recognition of component interactions during analysis
6. Better functional analysis to reduce prototype testing
7. Assistance in preparing documents/drawings
8. More standardization in designs
9. Improved productivity in tool design
10. Fewer errors in NC part programs
11. Saving material and machining time
12. Makes management personnel more effective
13. Assists in inspection of complicated parts
14. Provides good communication interface and greater understanding

The applications of CAD/CAM spread over a wide area in engineering practice. Some of the applications of CAD/CAM may be pointed as follows:

Industrial and architectural designs Here, CAD/CAM software provide graphics-based result that is used to create concept sketches for assessment and approval. The architect's task is to use CAD for moulding all relevant components together to produce drawings and specifications.

Mechanical designs Here, models can be used to produce and analyse the products in various ways such as finite element analysis, interference checking, kinematics, dynamics, and so on. Data from the 3-D model can be directly transferred to CNC machines or rapid prototyping machines for manufacturing the product. Computer-aided drafting (technical drafts) uses the computer rather than traditional drawing boards.

Electrical and electronics design The application of CAD for electronics includes printed-circuit board design, wire diagrams, and design management systems.

Plant layouts CAD technology is used for virtual plant (factory) generation and optimization of the the plant layout. Layout tools are used in this process with the CAD system.

Marketing designs CAD generates picture realism including colouring, shading, and light source positioning. Such pictures have wide acceptability in the market through advertisements.

SUMMARY

Computers play a vital role from product conceptualization to product distribution in the market. Product life cycle is the basis to define CAD/CAM concept. A production cycle includes product need (design conceptualization), design modelling (through CAD), manufacturing stages (through CAM), and finally management and marketing (production management).

CAD refers to the use of computers to design, analyse, and evaluate a product and encompasses the following four steps: geometric modelling, engineering analysis and optimization, evaluation/review, and computer-aided drafting.

CAM is the use of computers to manufacture the final functional prototypes using high-end machine tools. CAM has four important modules as follows—tool and fixture designs, computer-aided process planning, NC part programming, and computer-aided production planning and control.

Computer-integrated manufacturing (CIM) is a combined CAD/CAM system that includes management information system (MIS), sales, marketing, finance, database management, design, manufacturing, etc.

Earlier, CAD/CAM systems were independent technologies and modern factories consider the concept of integration through well-developed database structure.

There are several advantages of using CAD and CAM for design and manufacturing operations in industries. Various engineering disciplines are benefitted due to the use of CAD/CAM tools.

SELF-ASSESSMENT

Multiple Choice Questions

1.1 The technology concerned with the use of computer to analyse the geometry for simulation is called
(a) CAD
(b) CAM
(c) CAE
(d) CIM

1.2 Which of the following are the benefits of CAD?
(a) Increased productivity
(b) Reduced lead time
(c) Fewer errors
(d) All the above

1.3 Which of the following is not a functional area of CAD and CAE systems?
(a) Geometric modelling
(b) Process planning
(c) Engineering analysis
(d) Evaluation

1.4 Which the following phase of phases in CAD is virtual prototyping process of digital mock-up studies related to?
(a) Optimization
(b) Documentation
(c) Geometric modelling
(d) Evaluation

1.5 CAM has two applications—computer monitoring and control and manufacturing support applications. Which of the following belongs to the first category?
(a) CAPP
(b) Material handling
(c) NC part programming
(d) Scheduling

1.6 The process of integration of CAD, CAM, and factory business is known as
(a) CADD
(b) CIM
(c) CAE
(d) CAPP

1.7 Automation technology capable of manufacturing a variety of parts is known as
(a) Fixed automation
(b) Programmable automation
(c) Flexible automation
(d) None of the above

1.8 Technology that brings together all the modules of a product at one place is known as
(a) Reverse engineering
(b) Concurrent engineering
(c) Traditional engineering
(d) None of the above

1.9 Which of the following is true in computer-aided drafting?
(a) It is done before analysis
(b) It is often a 3-D modelling
(c) It is drawn with a reference
(d) It can be used further for analysis

1.10 Computer-aided engineering uses the geometric model for
(a) Manufacturing
(b) Evaluating desired functions
(c) Drawing the final print
(d) None of the above

Short Questions

1.1 Define CAD and CAM processes used in a typical CAD/CAM system.
1.2 Explain (a) product life cycle (b) computer graphics and geometric modelling.
1.3 What is (a) NC and CNC, (b) CAE, (c) CAPP, and (d) CIM ?
1.4 Explain the advantages of CAD/CAM.
1.5 What are various applications of CAD/CAM?
1.6 Write short notes on the history of CAD/CAM developments.
1.7 Differentiate between the computer-aided drafting and computer-aided design and drafting.
1.8 Explain the four important modules of computer-aided manufacturing.
1.9 What are the CAD tools and CAM tools in practice?
1.10 Explain the concept of CAE and distinguish it from a geometric model.

Answers to Multiple Choice Questions

1. (c)	2. (d)	3. (b)	4. (d)	5. (b)	6. (b)
7. (c)	8. (b)	9. (c)	10. (b)		