CHAPTER 4: CAD/CAM SYSTEMS

4.1 CAD/CAM Overview

In the past fifteen years the interactive computer graphics and CAD/CAM technology have been impacting the drafting, design, and manufacturing tools significantly. The purpose of this chapter is to present CAD/CAM principles and tools in generic and basic terms. These principles are supplemented with engineering and design applications as well as problems. The chapter is also concerned with developing basic abilities to utilise the existing CAD/CAM systems in engineering practice.

Figure 4.1: The structure of CAD/CAM
4.1.1 CAD/CAM contents and tools

In engineering practice, CAD/CAM has been utilised in different ways by different people. Some of the applications of this technology are:

- production of drawings and design documents;
- visualisation tool for generating shaded images and animated displays;
- engineering analysis of the geometric models (finite element analysis, kinematic analysis, etc.);
- process planning and generation of NC part programmes.

The CAD process is a subset of the design process. Similarly, the CAM process is a subset of the manufacturing process. The implementation of the CAD process on current systems takes the generic flow presented in Fig. 4.2. Once a conceptual design materialises in the designer’s mind, the definition of a geometric model starts via the user interface provided by the relevant CAD system. The choice of a geometric model to CAD is analogous to the choice of a mathematical model to engineering analysis. For example, FEA might require a different model than kinematic analysis.

A valid geometrical model is created by the CAD system through its definition translator which converts the designer input into the proper database format. In order to apply engineering analysis to the geometric model, interface algorithms are provided by the system to extract the required data from the model database to perform the analysis.

In the case of FEA, these algorithms form the FEM package of the system. Design testing and evaluation may require changing the geometric model before finalising it. When the final design is achieved the drafting and detailing of the models starts, followed by documentation and production of final drawings.

The core of the CAD tools are geometric modelling and graphics applications. Aids such as colour, grids, geometric modifiers, and group facilitate structuring geometric models. Manipulations include transformation of the model in space so it can be viewed properly. Visualisation is achieved via shaded images and animation procedures which help design conceptualisation, communication, and interference detections in some cases. Tools for design modelling and simulation are well diversified and are closely related to the available analysis packages. Some FEM packages provide some form of shape and structural optimisation. Adding tolerances, performing tolerance analysis, generating a bill of materials, and investigating the effect of manufacturing on the design by utilising NC packages are also valuable tools that are available to designers.
The implementation of the CAM process on CAD/CAM systems is shown in Fig. 4.3. The geometric model developed during the CAD process forms the basis of the CAM activities. Various CAM activities may require various CAD information. Interface algorithms are usually utilised to extract such information from CAD databases. In case of process planning, features that are utilised in manufacturing (e.g., holes, slots, etc.) must be recognised to enable efficient planning of manufacturing. NC programmes, along with ordering tools and fixtures, result from process planning. Once parts are produced, CAD software can be used to inspect them. This is achieved by superposing an image of the real part with a master image stored in its model database. After passing inspection, CAM software can be utilised to instruct robot systems to assemble the parts to produce the final product.
4.2 Definition of CAD/CAM tools

Employing their constituents, CAD tools can be defined as the intersection of three sets: geometric modelling, computer graphics, and the design tools (Fig. 4.4). As can be perceived from this figure, the abstracted concepts of geometric modelling and computer graphics must be applied innovatively to serve the design process. Based on implementation in a design environment, CAD tools can be defined as the design tools (analysis codes, heuristic procedures, design practices, etc.) being augmented by computer hardware and software throughout its various phases to achieve the design goal efficiently and competitively. The level of augmentation determines the design capabilities of the various CAD/CAM systems and the effectiveness of the CAD tools they provide. Designer will always require tools that provide them with fast and reliable solutions to design situations that involve iterations and testing of more than one alternative. CAD tools can vary from geometric tools, such as manipulations of graphics entities and interference checking, on one extreme, to customised applications programmes, such as developing analysis and optimisation routines, on the other extreme. In between these two extremes, typical tools currently available include tolerance analysis, mass property calculations, and finite element modelling and analysis.
Similar to the definition of CAD tools, CAM tools can be defined as the intersection of three sets: CAD tools, networking concepts, and the manufacturing tools (Fig. 4.4). This definition enforces the link between CAD and CAM as well as database centralisation. There are two main factors that determine the success of this implementation.

- The link between CAD and CAM must be a two-way route. CAD databases must reflect manufacturing requirements such as tolerances and features. Designers must think in terms of CAM requirements when finalising their designs. On the other hand, CAD databases and their limitations must be conveyed to manufacturing engineers who plan to utilise them in process planning and other manufacturing functions. It should be pointed out that not all manufacturing processes are, or need to be, computer driven.

- The hardware and software networking of the various CAM elements to automate the manufacturing process. The factory of the future and its levels of automation are directly related to the soundness of the networking concepts. Timely synchronisation among robots, vision systems, manufacturing cells, material handling systems, and other shop-floor tasks is one of the most challenging networking problems that face the implementation of CAM.

4.3 CAD/CAM hardware

The majority of today’s CAD/CAM systems utilise open hardware architecture and standard operating systems. Open hardware architecture implies that CAD/CAM vendors no longer design and manufacture their own hardware platforms. Instead the CAD/CAM industry relies upon the giant general-purpose computer companies and smaller firms that specialise in engineering workstations. Thus users can network the CAD/CAM systems to other computer systems.
systems as well as hardwire them to various manufacturing cells and facilities. They can also run third party software to augment the analysis capabilities typically provided by CAD/CAM vendors. With the advancements in the computer technology, current CAD/CAM systems are based on the workstation concept. Such a concept provides both single-user and timesharing environments.

CAD/CAM systems based on the workstation concept represent a distinct philosophy or trend in hardware technology which is based on a distributed (stand-alone) but networked (linked) environment. Workstations can be linked together as well as to mainframes dedicated to numerical computations. Other processors may exist in the network to control other types of hardware such as file and print servers. These distributed systems are able to perform major graphics functions locally at the workstations, and operations that require more power are send to the mainframe. The communication between devices in this distributed design and manufacturing environment becomes an important part of the system configuration and design. The dynamics and rapid changes in the hardware technology have created an absorption problem at the user’s part. There are always various types and configurations of CAD/CAM systems to choose from. To choose and implement a system requires the development of a set of guidelines that must address both hardware and software requirements. A key factor in a system evaluation is the capabilities and integration of its software which influence the productivity rate directly.
- Catia, Euclid, AutoCAD, ProEngineer
  Solidworks
- MasterCAM, PowerMill
- Moldflow, C-Flow, ANSYS, I-DEAS
Overview of Manufacturing Engineering

Manufacturing engineering plays a key role in translating new product specifications from design engineering into process plans that manufacturing then uses to produce the product. Figure 8.5 shows the manufacturing engineering-related flow of information that occurs in a typical firm.

![Diagram of information flow in Manufacturing Engineering]

**Figure 8.3: Information flow in Manufacturing Engineering**
Overview of Production Control

Figure 8.6 shows the basic elements of the production control function. Demand forecasting provides an estimate of the demand for each type of product sold.

![Diagram of production control information flow]

Figure 8.4: Production control information flow
CHAPTER 5: CONCURRENT ENGINEERING

5.1 Key Definitions

Following are some selected term definitions used in this chapter.

**Assemblability** An evaluation of how easily and cheaply a product can be assembled.

**Axiomatic design** The use of well-accepted truths (axioms) and corollaries in the concurrent engineering process.

**CE (concurrent engineering)** Design of the entire life cycle of the product simultaneously using a product design team and automated engineering and production tools.

**Computer-aided DFM** Use of computer tools to apply DFM.

**Controllable factors** Those elements that can be controlled during the production process. Examples are dimensions and tolerances and material types.

**Design science** The statement that design is a teachable science and not an art. Design science is used to design products by the use of design catalogs relating function to feature.

**DFA (design for assembly)** A technique by which a product is designed for ease and economy of assembly.

**DFM (design for manufacturability)** A technique by which a product is designed for ease and economy of manufacture.

**DFM guidelines** The use of rules of thumb (heuristics) in the DFM process.

**Domain expert** An expert in a particular domain of knowledge—for example, a domain expert in the area of process planning.

**FMEA (failure-mode evaluation analysis)** Identification and prevention of various modes of product failure. The modes of failure are ranked from most to least impact on part function and then addressed one by one during a redesign process to reduce failures.

**Functionality** An evaluation of the functional performance of a product. This includes meeting the functional specifications as determined by the product development team.

**Group technology** Assignment of a code to a part which summarizes the pertinent part characteristics.

**-ities** A generic reference to the ease and economy of various stages in the life cycle of the part, e.g., producibility, maintainability, etc.

**Inspectability** An evaluation of the ease and economy of a product to be inspected for dimensional and functional conformance to a set of specifications.

**Liaison sequence** The establishment of relationships among components of an assembly in order to enumerate all possible assembly sequences for assembly analysis.

**Manufacturability** An evaluation of whether a product can be manufactured. Good products should be manufacturable.

**Orthogonal arrays** In the Taguchi method, a way of determining an experimental plan by separating the factors to allow experimental analysis of the cause-and-effect relationships of the input factors and performance.

**PDT (product development team)** The core of CE; a team of individuals with many different life-cycle domains of expertise, who work together to design a product, the production processes, and, in fact, all aspects of the life cycle of the product.

**Producibility** An evaluation of whether a product can be produced. This is also sometimes called manufacturability, but is more general and includes all facets of production, not just manufacturing.

**Product life cycle** The time from product conception to final product disposal. The life cycle includes production, inspection, and all phases of a product’s life.
SAPD (strategic approach to product design) A concurrent engineering architecture emphasizing a thorough product analysis instead of the use of design rules.

Serviceability An evaluation of the ease with which a product can be serviced in the field.

Signal-to-noise ratio A measure of a system’s resistance to being influenced by noise. The signal is the measure of performance and the noise is a measure of uncontrollable factors.

Taguchi method A technique for designing robustness into a product design which establishes design parameters, system parameters, and tolerance parameters.

ULCE (unified life-cycle engineering) A concurrent engineering architecture developed by the U.S. Air Force that emphasizes the integration of modules including design rules and metadesign knowledge about the designer’s intent.

Uncontrollable factors Those elements which are not controllable, e.g., noise, factors. Examples are the weather and the stock market.

Value engineering A technique for measuring the quality of a product design as a ratio of performance to life-cycle cost.

5.2 Concurrent Engineering

Concurrent engineering has as its purpose to detail the design while simultaneously developing production capability, field-support capability, and quality. It consists of a methodology using multi-disciplined teams to carry out this concurrency. CE tools in the form of algorithms, techniques, and software, and the expertise and judgment of people who make up the complete design and production sequence. The essence of CE is the integration of product design and process planning into one common activity. Concurrent design helps improve the quality of early design decisions and has a tremendous impact on life cycle cost of the product.

CE can be visualized as illustrated in Figure 5.1. In this figure, the designer represented by the hub of the wheel, coordinates the comments and re-design suggestions from each of the domain experts around the circumference. Communications among the experts is indicated by the circumferential arrows. In this design procedure, a conceptual design is presented radially to the group of experts, at which time each can comment on the design relative to his or her own area. Assembly experts consider assemblability problems, process planning experts consider the process sequence, and metal removal experts consider the available machine tools, new removal techniques and the requirements of the design and so on. The number of domain experts around the rim varies, but the typical domains are;

- Assembly
- Fabrication
- Inspection
- Field maintenance
- Marketing
- Domain-specific engineering functionality

These experts have the mission to conceptualize the product and optimize it until a consensus agreement is reached on the functionality, producibility, and cost constraints. The design moves from the designer out to the experts, who discuss it and suggest design changes to satisfy these three constraints. The design is then passed back to the designer, who resolves conflicts in the suggested changes, modifies the design, and sends it out again for evaluation. Hopefully, the design will need fewer and fewer changes on each iteration until it finally
arrives back at the designer with no new redesign suggestions. At this point, the design is considered to be feasible and, in all probability, somewhat optimized.

![Figure 5.1: the concept of Concurrent Engineering](image)

One can think of Concurrent Engineering (CE) as accomplishing this purpose using five interrelated elements;

1. Careful analysis and understanding of the fabrication and assembly processes. This allows the designers to predict the performance of the product and select production schemes from among alternative processes.
2. Strategic product design, conceived to support a specific strategy for making and selling the product. The product should be made to marketing specifications for market value, shelf life, and usability.
3. Rationalized manufacturing system design coordinated with product design.
4. Economic analysis of design and manufacturing alternatives to permit rational choices among design alternatives.
5. Product and system designs characterized by robustness. Robustness means resistance to unpredicted noise or errors in production and function. In other words, the product function is as resistant as possible to variations in dimensions within the tolerance.

The goals of CE within these elements are:

- Avoiding component features that are unnecessarily expensive to produce e.g., specification of surfaces smoother than necessary, wide variations in wall thickness of an injection-molded component, too-small fillet radii in a forged component, or internal apertures too close to the bend line of a sheet metal component.
• Costs or making the optimum choice of materials and processes e.g., can the component be cold-headed and finish-machined rather than machined from bar stock?
Definition of Concurrent Engineering

"Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. Typically, concurrent engineering involves the formation of cross-functional teams, which allows engineers and managers of different disciplines to work together simultaneously in developing product and process design. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, productivity, speed (time to market & response time), and user requirements (include functional and reliability)."

Align all design to support the goal: Satisfy customer expectation

• Quality,
• Cost
• Productivity,
• Speed (time to market & response time)
• User requirements (include functional and reliability)

Support the goal: Return customer and Profitability- How serious?

• Sony battery recall lost $429 million combined 94% profit shrink
• Ford 3-rd net loss $5.8 billion close 16 plants, 45000 jobs
Market analysis, R&D

Engineering Modeling

Process design GD&T

Computer Aided Design (CAD)

Computer Aided Manufacturing (CAM)

Rapid Prototyping

Cell, Quick Response Manufacturing

Production system

Quality control

Statistic Process Control (SPC)

Rapid Cell, Quick Response Manufacturing in the Product Life Cycle

Field warranty service

Manufacturing in the Product Life Cycle
Conventional product design approach

Partial processes

Idea → Product Design → Manufacturing → Assembly → Maintenance

Concurrent Product Design Approach

Product Design → Manufacturing → Assembly → Maintenance

Better collaboration between different phases

Shorter total time to market

Function overlap
• Why do companies now want to move away from serial product development process?

**Concurrent engineering of products**
Address all issues related to the complete life cycle of the product at the product design stage - from initial conceptualization, to disposal/scrap of the product.
Sequential Design ("over-the-fence" approach)

Centralised Design

Concurrent Design
Concurrent engineering

• Has to be supported by top management.
• All product development team members should be dedicated for the application of this strategy.
• Each phase in product development has to be carefully planned before actual application.
• New product’s lifecycle has to fit in in the existing product program lifecycles in a company.
Assembly in the Context of Product Development

Benefits of Concurrent Engineering

• Reduces time from design concept to market launch by 25% or more
• Reduces Capital investment by 20% or more
• Supports total quality from the start of production with earlier opportunities for continuous improvement
• Simplifies after-sales service
• Increases product life-cycle profitability throughout the supply system
How does CE reduce time?
Traditional Design and Production Process

the main problems/difficulties associated with traditional design and production process:

FOR COMPLEX PRODUCTS:
- Cycle Time Too Long
- Facility Intensive
- Cost High
- Convergence Not Assured
CE is implementable on these areas.
Virtual Assembly Analysis
Service-oriented VAA Architecture and Components