Tech 149: Unit 2

CAD/CAM
Chapter 23: Product Design and CAD/CAM in the Production System

Sections:

1. Product Design and CAD
2. CAM, CAD/CAM, and CIM
3. Quality Function Deployment
The Design Process

The general process of design is characterized as an iterative process consisting of six phases:

1. Recognition of need - someone recognizes the need that can be satisfied by a new design
2. Problem definition - specification of the item
3. Synthesis - creation and conceptualization
4. Analysis and optimization - the concept is analyzed and redesigned
5. Evaluation - compare design against original specification
6. Presentation - documenting the design (e.g., drawings)
The Design Process

Consists of six steps, some of which are iterative as shown at right
Step 1: Conceptualization

- Conceptualization (recognition of need & definition of the problem)
  - Form (shape, style, and character)
  - Fit (marketing fit or order winning criteria)
  - Function is determined with data from marketing

- Divided into two: Typical and atypical

- Typical design relates to repetitive design

- Atypical design is for new product
Step 2: Synthesis

- Specification of material
- Addition of geometric features
- Inclusion of greater dimensional details to conceptualized design
- Removes (filters) cost-adding features and materials
- Employs DFM and DFA to ensure good design
- About 70% of manufacturing cost is fixed in steps 1 and 2 activities
Step 3: Analysis

- Analysis means determining/describing the nature of the design by separating it into its parts to determine the fit between the proposed design and the original design goals.
- Two categories of analysis are mass properties and finite.
- Can be performed manually, but the computer increases analysis capability and reduces its time.
Step 4: Evaluation

• Checks the design against the original specifications
• Often requires construction of a prototype to test for conformance
• Often employs rapid prototyping technique
Step 5: Documentation

- Creating all necessary product and part views in the form of working drawings, detailed and assembly drawings
- Addition of dimensions, tolerances, special manufacturing notes, and standard components
- Creation of part numbers, bill of materials, and detailed part specifications
- Creation of product electronic data files used by manufacturing planning and control, production engineering, marketing and quality control
Computer-Aided Design (CAD)

Any design activity that involves the effective use of the computer to create, modify, analyze, or document an engineering design

- Commonly associated with the use of an interactive computer graphics system, referred to as a CAD system
- The term CAD/CAM is also used if the computer system supports manufacturing applications as well as design applications
(a) The design process and (b) how CAD can be used to augment the design process
Reasons for Using a CAD System

- To increase the productivity of the designer
- To expand the available geometric forms in design - wider range of mathematically defined shapes possible
- To improve the quality of the design - more engineering analysis possible, consideration of more alternatives
- To improve design documentation - better drawings than with manual drafting
How a CAD System is Used in Product Design

• Geometric modeling
  – CAD system develops a mathematical description of the geometry of an object, called a geometric model

• Engineering analysis
  – Mass properties, interference checking for assemblies, finite element modeling, kinematic analysis for mechanisms

• Design evaluation and review
  – Automatic dimensioning, error checking, animation

• Automated drafting
  – Preparation of engineering drawings quickly
Geometric Models in CAD

(a) Wire-frame model and (b) solid model
CAD System Hardware

The hardware for a typical CAD system consists of the following components:

1. One or more design workstations
2. Digital computer
3. Plotters, printers, and other output devices
4. Storage devices
CAD Workstations

• System configurations:
  – Engineering workstation
    • Stand-alone computer system dedicated to one user
    • Often networked for sharing data and plotters
  – CAD system based on a personal computer
    • PC with high-performance CPU and high resolution graphics display monitor
Workstation Configurations

(a) Engineering workstations and (b) PC-based CAD system
Types of Data Generated in Design

1. Product names
2. Parts names
3. Part views
4. Design notes
5. Product materials
6. Bill of materials (BOM)
7. Material shapes and forms
8. Product quantities
9. Material suppliers
10. Products and parts dimensions
11. Product and parts tolerances
12. Part numbers
13. Drawing numbers
14. Product cost
15. Others
Design Subsystem

- CAD
- Suppliers
- Part Nos.
- Dimensions
- Material
- Cost
- Parts
- BOM
- Design Subsystem
Types of CIM Subsystems

- CAD
- CAE
- CAPP
- CAM

Data Base
Product As Origin Of Data

Product

CUS

Lay

Des

Sup

M/H

M/H

Insp

Anal

Cost

Com

Sch

Life

Unit

Wor

Proc

Mate

MAR

Product As Origin Of Data
Design

1. Conceptual design (parts and assembly)
2. Synthesis (materials, geometry, DFM etc.)
3. Analysis (meeting original design goals)
4. Evaluation (using prototypes)
5. Documentation (views, BOM, part numbers, dimensions etc.)
6. Bill of materials (BOM) creation
7. Product structure diagram
Computer Integrated Manufacturing Network Demands

- A common database for enterprise information flow

- Easy, accurate and instantaneous movement of part geometry files and product data between departments

- An enterprise network is a communications system that supports communications and the exchange of information and data among various devices connected to the network over distances from several feet to thousands of miles
Data is Defined as:

- Information
- Statistics
- Facts
- Figures
- Number
- Records
- Report
- Account
- Minutes
- Proceedings
How Data is Acquired and Used in a CIM Environment

- By Simple Data Acquisition, such as:
  - Given Data
  - Measurement Data
- By Data Generation (from CAD)
- By Data Importation (from CAD)
- By Data Analysis (from CAD)
- By Data Computing (from CAD)
- By Data Conversion (from CAD)
- By Data Formatting (from CAD)
- By Data Processing (from CAD)
- By Data Translation
Manufacturing

1. MRP & daily production scheduling tasks
2. Capacity & production activity control tasks
3. Part manufacture (material processing)
4. Product assembly
5. Quality and inspection tasks
6. Material handling tasks
7. Storage & retrieval tasks
System-To-System Communication
Worker-To-System Communication
System-To-Worker Communication

CNC Machine  Operator
Worker-To-Worker Communication

CAD (Designer) ↔ CAE (Man Engineer)
Sample CIM Sub-Systems

Design

Sales & Mark

Prod Eng

Man
Sample
CIM Network
Computer-Aided Manufacturing

The effective use of computer technology in manufacturing planning and control

• Most closely associated with functions in manufacturing engineering, such as process planning and NC part programming

• CAM applications can be divided into two broad categories:
  1. Manufacturing planning
  2. Manufacturing control
Computer-aided Manufacturing

Includes the use of CAD files to:
1. Define the machine tool that will process the part
2. Define the stock or material
3. Define the features to machine
4. Generate operations
5. Select the origin
6. Generate tool paths
7. Simulate tool paths
8. Generate NC code
9. Download NC programs
10. Operate the CNC machine that will cut the part
Data Communication Processes in CAD/CAM

In CAD/CAM:
- Data is created
- Data is generated
- Data is simulated
- Data is transformed
- Data is translated
- Data is cleaned

- Data is stored
- Data is communicated
- Data is manipulated
- Data is managed
- Data is analyzed
- Data is retrieved
- Data is interpreted
CAM Applications in Manufacturing Planning

- Computer-aided process planning (CAPP)
- Computer-assisted NC part programming
- CAD/CAM assisted NC part programming
- Computerized machinability data systems
- Computerized work standards
- Cost estimating
- Production and inventory planning
- Computer-aided assembly line balancing
CAM Applications in Manufacturing Control

- Process monitoring and control
- Quality control
- Shop floor control
- Inventory control
- Just-in-time production systems
**CAD/CAM**

- Concerned with the engineering functions in both design and manufacturing
- Denotes an integration of design and manufacturing activities by means of computer systems
  - Goal is to not only automate certain phases of design and certain phases of manufacturing, but to also automate the transition from design to manufacturing
  - In the ideal CAD/CAM system, the product design specification residing in the CAD data base would be automatically converted into the process plan for making the product
Computer Integrated Manufacturing

- Includes all of the engineering functions of CAD/CAM
- Also includes the firm's business functions that are related to manufacturing
- Ideal CIM system applies computer and communications technology to all of the operational functions and information processing functions in manufacturing
  - From order receipt,
  - Through design and production,
  - To product shipment
The Scope of CAD/CAM and CIM

- **Scope of CAD/CAM**
  - Computerized: order entry, customer billing, accounts receivable, etc.
  - CAD: Geometric modeling, engineering analysis, design evaluation, automated drafting
  - CAM: NC part programming, production scheduling, manufacturing resource planning

- **Scope of CIM**
  - Business functions
  - Product design
  - Manufacturing planning
  - Manufacturing control
  - Factory operations

- CAM: Process control, quality control, shop floor control, inventory control
Chapter 7: Computer Numerical Control

Sections:
1. Fundamentals of NC Technology
2. Computers and Numerical Control
3. Applications of NC
4. Analysis of Positioning Systems
5. NC Part Programming
Numerical Control (NC) Defined

Form of programmable automation in which the mechanical actions of a machine tool or other equipment are controlled by a program containing coded alphanumeric data

- The alphanumeric data represent relative positions between a workhead (e.g., cutting tool) and a work part
- When the current job is completed, a new program can be entered for the next job
Basic Components of an NC System

1. Program of instructions
   – Called a *part program* in machining

2. Machine control unit
   – Controls the process

3. Processing equipment
   – Performs the process
Basic Components of an NC System

- Program
- Machine control unit
- Processing equipment
NC Coordinate Systems

(a) For flat and block-like parts and (b) for rotational parts
Motion Control Systems

Point-to-Point systems
• Also called *positioning systems*
• System moves to a location and performs an operation at that location (e.g., drilling)
• Also applicable in robotics

Continuous path systems
• Also called *contouring systems* in machining
• System performs an operation during movement (e.g., milling and turning)
Point-To-Point Control

NC drilling of three holes in flat plate
Continuous Path Control

NC profile milling of part outline
Interpolation Methods

1. Linear interpolation
   – Straight line between two points in space

2. Circular interpolation
   – Circular arc defined by starting point, end point, center or radius, and direction

3. Helical interpolation
   – Circular plus linear motion

4. Parabolic and cubic interpolation
   – Free form curves using higher order equations
Circular Interpolation

Approximation of a curved path in NC by a series of straight line segments, where tolerance is defined on (a) inside, (b) outside, and (c) both inside and outside of the actual curve.
Absolute and Incremental Positioning

Absolute positioning
• Locations defined relative to origin of axis system

Incremental positioning
• Locations defined relative to previous position
• Example: drilling
Absolute vs. Incremental Positioning

The work head is presently at point (20, 20) and is to be moved to point (40, 50)

- In absolute positioning, the move is specified by $x = 40$, $y = 50$
- In incremental positioning, the move is specified by $x = 20$, $y = 30$
Computer Numerical Control (CNC) – Additional Features

• Storage of more than one part program
• Program editing at the machine tool
• Fixed cycles and programming subroutines
• Adaptive control
• Interpolation
• Positioning features for setup – to help operator align work part on machine tool table
• Acceleration and deceleration computations
• Communications interface
• Diagnostics
Configuration of CNC Machine Control Unit

- **Memory**
  - ROM - Operating system
  - RAM - Part programs

- **Central processing unit (CPU)**

- **Input/output interface**
  - Operator panel
  - Tape reader

- **System bus**

- **Machine tool controls**
  - Position control
  - Spindle speed control

- **Sequence controls**
  - Coolant
  - Fixture clamping
  - Tool changer
DNC
Direct numerical control (DNC) – control of multiple machine tools by a single (mainframe) computer through direct connection and in real time

• 1960s technology
• Two way communication

Distributed numerical control (DNC) – network consisting of central computer connected to machine tool MCUs, which are CNC

• Present technology
• Two way communication
General Configuration of a Direct Numerical Control System

Connection to MCU is behind the tape reader (BTR). In distributed NC, entire programs are downloaded to each MCU, which is CNC rather than conventional NC.
Applications of NC

• Machine tool applications:
  – Milling, drilling, turning, boring, grinding
  – Machining centers, turning centers, mill-turn centers
  – Other metalworking processes:
    • Punch presses for hole punching and sheet metal bending
    • Tube bending
    • Thermal cutting machines
    • Wire EDM
    • Welding
Common NC Machining Operations

(a) Turning
(b) drilling
(c) milling
(d) grinding
CNC Four-Axis Horizontal Milling Machine

(a) With safety panels installed and (b) safety panels removed to show typical axes configuration
NC Application
Characteristics (Machining)

Where NC is most appropriate:
1. Batch production
2. Repeat orders
3. Complex part geometries
4. Much metal needs to be removed from the starting work part
5. Many separate machining operations on the part
6. Part is expensive
Other Applications of NC

• Rapid prototyping and additive manufacturing
• Water jet cutting and abrasive water jet cutting
• Component placement machines in electronics assembly
• Coordinate measuring machines
• Wood routers and granite cutters
• Tape laying machines for polymer composites
• Filament winding machines for polymer composites
Advantages of NC

- Nonproductive time is reduced
- Greater accuracy and repeatability
- Lower scrap rates
- Inspection requirements are reduced
- More complex part geometries are possible
- Engineering changes are easier to make
- Simpler fixtures
- Shorter lead times
- Reduce parts inventory and less floor space
- Operator skill-level requirements are reduced
Disadvantages of NC

• Higher investment cost
  – CNC machines are more expensive

• Higher maintenance effort
  – CNC machines are more technologically sophisticated

• Part programming issues
  – Need for skilled programmers
  – Time investment for each new part
  – Repeat orders are easy because part program is already available
NC Positioning System

- Typical motor and leadscrew arrangement in an NC positioning system for one linear axis
- For x-y capability, the apparatus would be piggybacked on top of a second perpendicular axis
NC Part Programming

1. Manual part programming
2. Computer-assisted part programming
3. CAD/CAM part programming
4. Manual data input
Types of Words

N - sequence number prefix
G - preparatory words
  - Example: G00 = PTP rapid traverse move
X, Y, Z - prefixes for x, y, and z-axes
F - feed rate prefix
S - spindle speed
T - tool selection
M - miscellaneous command
  - Example: M07 = turn cutting fluid on
Example: Word Address Format

N001 G00 X07000 Y03000 M03
N002 Y06000
Issues in Manual Part Programming

• Adequate for simple jobs, e.g., PTP drilling
• Linear interpolation
  
  G01 G94 X050.0 Y086.5 Z100.0 F40
  S800
• Circular interpolation
  
  G02 G17 X088.0 Y040.0 R028.0 F30
• Cutter offset
  
  G42 G01 X100.0 Y040.0 D05
Computer-Assisted Part Programming

• Manual part programming is time-consuming, tedious, and subject to human errors for complex jobs
• Machining instructions are written in English-like statements that are translated by the computer into the low-level machine code of the MCU
• APT (Automatically Programmed Tool)
• The various tasks in computer-assisted part programming are divided between
  – The human part programmer
  – The computer
Computer-Assisted Part Programming

- Sequence of activities in computer-assisted part programming
Part Programmer's Job

- Two main tasks of the programmer:
  1. Define the part geometry
  2. Specify the tool path
Defining Part Geometry

• Underlying assumption: no matter how complex the part geometry, it is composed of basic geometric elements and mathematically defined surfaces
• Geometry elements are sometimes defined only for use in specifying tool path
• Examples of part geometry definitions:
  
P4 = POINT/35,90,0
L1 = LINE/P1,P2
C1 = CIRCLE/CENTER,P8,RADIUS,30
Specifying Tool Path and Operation Sequence

- Tool path consists of a sequence of points or connected line and arc segments, using previously defined geometry elements

- Point-to-Point command:
  
  \[ \text{GOTO/P0} \]

- Continuous path command
  
  \[ \text{GOLFT/L2,TANTO,C1} \]
Other Functions in Computer-Assisted Part Programming

- Specifying cutting speeds and feed rates
- Designating cutter size (for tool offset calculations)
- Specifying tolerances in circular interpolation
- Naming the program
- Identifying the machine tool
Cutter Offset

Cutter path must be offset from actual part outline by a distance equal to the cutter radius.
Computer Tasks in Computer-Assisted Part Programming

1. **Input translation** – converts the coded instructions in the part program into computer-usable form

2. **Arithmetic and cutter offset computations** – performs the mathematical computations to define the part surface and generate the tool path, including cutter offset compensation (CLFILE)

3. **Editing** – provides readable data on cutter locations and machine tool operating commands (CLDATA)

4. **Postprocessing** – converts CLDATA into low-level code that can be interpreted by the MCU
CAD/CAM Part Programming

- Geometry definition
  - If CAD/CAM system was used to define the original part geometry, no need to recreate that geometry as in APT
  - Automatic labeling of geometry elements

created geometry
Tool Path Generation Using AD/CAM

• Basic approach: enter the commands one by one (similar to APT)
  – CAD/CAM system provides immediate graphical verification of the command

• Automatic software modules for common machining cycles
  – Profile milling
  – Pocket milling
  – Drilling bolt circles
Examples of Machining Cycles in Automated NC Programming Modules

(a) Pocket milling, (b) contour turning, (c) facing, and (d) threading
Manual Data Input

• Machine operator does part programming at machine
  – Operator enters program by responding to prompts and questions by system
  – Monitor with graphics verifies tool path
  – Usually for relatively simple parts

• Ideal for small shop that cannot afford a part programming staff

• To minimize changeover time, system should allow programming of next job while current job is running
Chapter 13: Introduction to Manufacturing Systems

Sections:

1. Components of a Manufacturing System
2. Types of Manufacturing Systems
Manufacturing System Defined

A collection of integrated equipment and human resources, whose function is to perform one or more processing and/or assembly operations on a starting raw material, part, or set of parts

• Equipment includes
  – Production machines and tools
  – Material handling and work positioning devices
  – Computer systems

• Human resources are required either full-time or periodically to keep the system running
Components of a Manufacturing System

1. Production machines
2. Material handling system
3. Computer system to coordinate and/or control the preceding components
4. Human workers to operate and manage the system
Production Machines

• In virtually all modern manufacturing systems, most of the actual processing or assembly work is accomplished by machines or with the aid of tools.

• Classification of production machines:
  1. Manually operated machines are controlled or supervised by a human worker.
  2. Semi-automated machines perform a portion of the work cycle under some form of program control, and a worker tends the machine the rest of the cycle.
  3. Fully automated machines operate for extended periods of time with no human attention.
Material Handling System

- In most manufacturing systems that process or assemble discrete parts and products, the following material handling functions must be provided:
  1. Loading work units at each station
  2. Positioning work units at each station
  3. Unloading work units at each station
  4. Transporting work units between stations in multi-station systems
  5. Temporary storage of work units
Work Transport Between Stations

- Two general categories of work transport in multi-station manufacturing systems:
  1. Fixed routing
     - Work units always flow through the same sequence of workstations
     - Most production lines exemplify this category
  2. Variable routing
     - Work units are moved through a variety of different station sequences
     - Most job shops exemplify this category
(a) Fixed and (b) Variable Routing

(a) Diagram:
- Starting work units
- Arrows indicate work flow
- Workstations
- Completed work units

(b) Diagram:
- Starting work units
- Arrows indicate work flow
- Workstations
- Completed work units
Computer Control System

• Typical computer functions in a manufacturing system:
  – Communicate instructions to workers
  – Download part programs to computer-controlled machines
  – Control material handling system
  – Schedule production
  – Failure diagnosis when malfunctions occur
  – Safety monitoring
  – Quality control
  – Operations management
Human Resources

• Manually operated manufacturing systems
  – Direct labor workers perform the value-added physical work on the part or product

• Automated manufacturing systems
  – Direct labor performs functions such as loading and unloading parts, changing and sharpening tools
  – Also needed are:
    • Computer programmers and operators
    • NC part programmers
    • Maintenance and repair personnel
Types of Manufacturing Systems

- Factors that define and distinguish manufacturing systems:
  1. Types of operations
  2. Number of workstations and system layout
  3. Level of automation (manning level)
  4. System flexibility
Types of Operations Performed

• Processing versus assembly operations
• Type(s) of materials processed
• Size and weight of work units
• Part geometry
  – For machined parts, rotational vs. non-rotational
• Part or product complexity
  – For assembled products, number of components per product
  – For individual parts, number of distinct operations to complete processing
Number of Workstations

• Convenient measure of the size of the system
  – Let $n =$ number of workstations
  – Individual workstations can be identified by subscript $i$, where $i = 1, 2, ..., n$

• Affects performance factors such as workload capacity, production rate, and reliability
  – As $n$ increases, this usually means greater workload capacity and higher production rate
  – There must be a synergistic effect that derives from $n$ multiple stations working together vs. $n$ single stations
System Layout

- Applies mainly to multi-station systems
- Fixed routing vs. variable routing
  - In systems with fixed routing, workstations are usually arranged linearly
  - In systems with variable routing, a variety of layouts are possible
- System layout is an important factor in determining the most appropriate type of material handling system
Level of Automation

- Level of workstation automation
  - Manually operated
  - Semi-automated
  - Fully automated

- Manning level $M_i = \text{proportion of time worker is in attendance at station } i$
  - $M_i = 1$ means that one worker must be at the station continuously
  - $M_i \geq 1$ indicates manual operations
  - $M_i < 1$ usually denotes some form of automation
System Flexibility

The degree to which the system is capable of dealing with variations in the parts or products it produces

• Examples of differences and variations among parts and products:
  – Starting material
  – Size and weight of work unit
  – Part geometry
  – Part or product complexity
  – Optional features in an assembled product
Enablers of Flexibility

• Identification of the different work units
  – The system must be able to identify the differences between work units in order to perform the correct processing sequence

• Quick changeover of operating instructions
  – The required work cycle programs must be readily available to the control unit

• Quick changeover of the physical setup
  – System must be able to change over the fixtures and tools required for the next work unit in minimum time
Classification of Manufacturing Systems

• Single-station cells
  – $n = 1$

• Multi-station systems with fixed routing
  – $n > 1$

• Multi-station systems with variable routing
  – $n > 1$
Classification of Manufacturing Systems

- Manufacturing systems
  - Single-station cell
    - Manned machine
    - Automated machine
  - Multistation fixed routing
    - Manual production line
    - Automated production line
  - Multistation variable routing
    - Cellular manufacturing
    - Flexible manufacturing system
Single-Station Cells

- $n = 1$

Two categories:

1. Manned workstations - manually operated or semi-automated production machine ($M = 1$)
2. Fully automated machine ($M < 1$)

Most widely used manufacturing system - reasons:

- Easiest and least expensive to implement
- Most adaptable, adjustable, and flexible system
- Can be converted to automated station if demand for part or product justifies
Multi-Station Systems with Fixed Routing

• $n > 1$

• Common example: a production line
  – A series of workstations laid out so that the part or product moves through each station, and a portion of the total work content is performed at each station

• Stations can be manually operated or automated or a combination of manual and automated

• Used for processing operations or assembly operations

• Generally associated with mass production
Multi-Station Systems with Variable Routing

- $n > 1$
- A group of workstations organized to produce a limited range of part or product styles in medium quantities:
  - Production of a family of parts requiring similar (but not identical) processing operations
  - Assembly of a family of products requiring similar (but not identical) assembly operations
  - Production of a complete set of components used to assemble one unit of a final product
- Typical case in cellular manufacturing