Manufacturing Methods and Material Selection

ENM 214

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MAK 208
Introduction: Design Process

Product design – the process of defining all of the product characteristics

- Product design must support product manufacturability (the ease with which a product can be made)
- Product design defines a product’s characteristics of:
  - appearance,
  - materials,
  - dimensions,
  - tolerances,
  - performance standards

Process Selection – the development of the process necessary to produce the designed product.
What is Manufacturing Process?

A sequence of operations, often done on a machine or at a given area.

Examples: welding, casting, cutting, assembling, etc.

During a manufacturing process, we add, subtract, or form materials in order to give a desired property/shape to the workpiece. Therefore, different manufacturing processes, manufacturability of a material, processing tools, environmental aspects etc., have become important issues for manufacturing processes.
Manufacturing Process

- **Literal:** Manufacture = Manus (hand) + Factus (make) → Made by hand

- **Technological:** Application of physical and chemical processes to make parts or products, including assembly of products.

- **Economical:** Transformation of materials into items of greater value by means of processing and/or assembly operations.

- **CIRP definition:** Design + production + assembly
  
  (CIRP = International Academy for Production Eng.)
Manufacturing Process

‘Manufacturing’ in a technological way

Starting material → Manufacturing process → Processed part

Machinery → Tooling → Power → Labor

Scrap and waste
Manufacturing Process

‘Manufacturing’ in a economical way

Manufacturing process

Starting material → Material in processing → Processed part

$ → Value added $$ → $$$$
Manufacturing Process

Production Quantity (Q)
Number of units of a given part or product produced annually
Three quantity ranges:

1. Low production – 1 to 100 units
2. Medium production – 100 to 10,000 units
3. High production – 10,000 to millions of units

Product Variety (P)
Number of different product or part designs or types

- ‘Hard’ product variety – products differ greatly
  Few common components
- ‘Soft’ product variety – small differences between products
  Many common components
Manufacturing Process

Manufacturing capability

• **Technological Processing capability**
  - Available processes and machines
  - Outsourcing of some operations (casting, heat treatment, etc.)

• **Physical product limitations**
  - Size, weight
  - Machine dimensions, handling

• **Production capacity** (Plant capacity)
  - Production quantity in a given time, output
Manufacturing Process

Material Modifying Processes
- Property Modifying
  - Heat treatment
  - Surface treatment
- Shape Modifying
  - Material removal
  - Material addition
  - Material retention

Joining Processes
- Permanent
- Non-permanent
- Semi-permanent
Manufacturing Process

Materials in Manufacturing

- **Metals**
  - Ferrous: Steel (iron-carbon, 0.02% - 2.11% C)
    - Cast iron (iron + 2% - 4% C + silicon)
  - Nonferrous: copper, aluminium, nickel, alloys

- **Ceramics**: clay, silica, carbides (Al, Si), nitrides (Ti)

- **Polymers**
  - Thermoplastic polymers: PE, PP, PS, PVC
  - Thermosetting polymers: phenolics, epoxies
  - Elastomers: rubber, neoprene, silicone, PU

- **Composites**: more phases, particles/fibres + matrix
glass reinforced plastic, Kevlar, WC in cobalt
Manufacturing Process

Materials in Manufacturing

Diagram showing the relationship between Metals, Ceramics, and Polymers, with intersections for Metal–ceramic composites, Metal–polymer composites, and Ceramic–polymer composites.
Manufacturing Process

Processing Operations

Shaping operations
- Solidification processes → casting of metals, moulding of plastics
- Particulate processing → powder metallurgy
- Deformation processes → forging, extrusion
- Material removal processes → machining, non-traditional, grinding

Property enhancing processes
- Heat treatments, sintering

Surface processing
- Cleaning, coating, plating, deposition
Manufacturing Process

Shaping Operations

Pouring ladle
Molten metal
Downsprue
Parting line
Mold (sand)

Sprue and runner (to be trimmed)
Solid casting
Manufacturing Process

Shaping Operations

(1) Lump of raw material

(2) Compaction under force
- Upper punch
- Lower punch
- Die
- Force

(3) Workpart during sintering
Manufacturing Process

Shaping Operations

Diagram of forging and extrusion processes:
- **Forging:** Material is shaped using a die and force to form a forging.
  - Flash (to be trimmed) is created at the edges.
- **Extrusion:** Material is forced through a die to create an extruded shape.
  - Chamber and ram are used to apply pressure.
  - Starting billet is transformed into the extruded shape.
  - Die and extruded cross section are shown.

Symbols used: $v, F$ (velocity and force).
Manufacturing Process

Shaping Operations

• **General aim**: Minimize waste and scrap!!!
  - Net shape processes $\rightarrow$ no subsequent machining

- **Turning**
  - Rotation (work)
  - Feed tool
  - Workpiece
  - Starting diameter
  - Chip
  - Diameter after turning
  - Single point cutting tool

- **Drilling**
  - Rotation
  - Feed
  - Drill bit
  - Work part
  - Hole

- **Milling**
  - Rotation
  - Material removed
  - Milling cutter
  - Feed
Manufacturing Process

Shaping Operations

General aim: Minimize waste and scrap!!!
- Net shape processes → no subsequent machining
- Near net shape processes → minimum machining
1) **Processing operations**

2) **Assembly operations**
   - Permanent joining: welding, brazing, adhesives
   - Mechanical assembly: bolts, screws, rivets, etc.

3) **Production machines and tooling**
   - Machine tools: lathe, milling machine, etc.
   - Presses, forge hammers, rolling mills
   - Welding machines and equipment
   - General and special purpose equipment
   - Tooling
The same product can be processed differently
Production System

Key Success Factors

- Low cost production efficiency
- Quality of process
- Skilled labour
- Low cost location
- Flexibility
The efficiency of a manufacturing facility depends on a number of factors, including the layout of machinery and departments.

Typical plant layout procedures determine how to arrange the various machines and departments to achieve minimization of overall production time, maximization of turnover of work-in-process, and maximization of factory output.
Production System

Types of arrangement of the facilities

1. Static or fixed position layout
2. Process based layout
3. Cell or group layout
4. Product based layout
Production System

Static or fixed position layout

Process are brought to the product -not the product to the process

Product that has constraining characteristics such as being very large, heavy or has some other constraint that prevents its location from being altered while under manufacturing

Production equipment and personnel are transported to the product and generally involves low volume products with small lot sizes.

Example: Airplane manufacturing, shipyards, railway systems
Production System

Static or fixed position layout
Production System

Process based layout

The process based layout is used in manufacturing are arranged according to the particular process type. All machines are grouped according to their function (process) such as lathes, mills, injection moulding, drilling etc.

Machines with similar functions are grouped together. This type of layout is used from job shopping or batch production companies such as different types of car production and even in service industries.
Production System

Process based layout

Material

Receiving Warehouse

Drill Presses

Punch Presses

Lathes

Grinders

Finished Goods

Inspection

Shipping Warehouse

Ship
Production System

Cell or group layout

The shop arrangement is based on product type. Such arrangement reduces the part travelling time and easy to supervise

Beneficial for volume high and the number of production type less
Product based layout

The layout conforms to the sequence of operations required to produce a product.

An example is automobile assembly, where almost all variants of the same model require the same sequence of process.
## 2) Advantages and disadvantages

<table>
<thead>
<tr>
<th></th>
<th>Fixed</th>
<th>Process</th>
<th>Cell</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td>- Very high mix and product flexibility</td>
<td>- High mix and product flexibility</td>
<td>- Good compromise between cost and flexibility</td>
<td>Low unit costs for high volume</td>
</tr>
<tr>
<td></td>
<td>- Product/customer not moved or disturbed.</td>
<td>- Relatively robust if in the case of disruptions</td>
<td>- Fast throughput.</td>
<td>- Gives Opportunities for specialization of equipment</td>
</tr>
<tr>
<td></td>
<td>- High variety of tasks for staff</td>
<td>- Easy supervision of equipment of plant</td>
<td>- Group work can result in good motivation</td>
<td>- Gives Opportunities for specialization of equipment</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>- Very high unit cost.</td>
<td>Low utilization of resources.</td>
<td>Can be costly to rearrange existing layout</td>
<td>Can have low mix and flexibility</td>
</tr>
<tr>
<td></td>
<td>- Scheduling space and activities can be difficult.</td>
<td>Can have very high WIP.</td>
<td>Can need more plan and equipment</td>
<td>Not very robust to disruption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Complex flow.</td>
<td></td>
<td>Work can be very repetitive.</td>
</tr>
</tbody>
</table>
Production System

Layout Type Selection by production volume

- Flow is intermittent
  - Low: Fixed-position layout
  - High: Process layout

- Variety
  - Low: Cell layout
  - High: Product layout

- Regular flow more important
  - Low: Flow becomes continuous
  - High: Regular Flow more feasible
Production System

Layout Type Selection by cost
Fit

When two parts are to be assembled, the relation resulting from the difference between their sizes before assembly is called a **fit**.

Three fit types

- **Clearance Fit**
  Maximum shaft dimension < Minimum hole dimension

- **Interference Fit**
  Maximum Hole size < Minimum Shaft size

- **Transition Fit**
  Maximum Hole size ≥ Minimum Shaft size
Tolerances

It is almost impossible (and sometimes uneconomical) to maintain the strict degree of accuracy as listed on a plan.

Due to the inevitable inaccuracy of manufacturing methods, a part cannot be made precisely to a given dimension, the difference between maximum and minimum limits of size is the **tolerance**.

Care needs to be taken however when determining such +/- tolerance, particularly where there are mating parts.
Tolerances

- Tolerance system
  - Dimensional Tolerance system
  - Geometrical Tolerance system
Dimensional Tolerances

Gives dimensional information of local section

Defines only allowable max. min errors
# Geometric Tolerances

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Flatness Diagram" /></td>
<td><img src="image2" alt="Circularity Diagram" /></td>
<td><img src="image3" alt="Cylindricity Diagram" /></td>
<td><img src="image4" alt="Perpendicularly Diagram" /></td>
<td><img src="image5" alt="Concentricity Diagram" /></td>
</tr>
</tbody>
</table>
Geometric Tolerances

Examples of a Flat Surface

Holes of a Flange
Tolerances: Example

Figure 6.7 - Typical Uses of Geometric Tolerancing
Surface Quality

• Importance of surface quality
  - Aesthetic reasons
  - Safety aspects
  - Influence on friction and wear
  - Influence on mechanical and physical properties
  - Important for assembly
  - Better electrical contact

• Surface technology is concerned with
  - Surface texture
  - Surface integrity
  - Relationship with manufacturing processes
Surface Quality

A microscopic view shows:

- Substrate → bulk material
- Altered layer → Layer affected by process
- Surface texture → exterior part with roughness
- In addition: Mostly an oxide film

![Diagram showing surface quality with labels for substrates, altered layers, and surface texture.](image)
Surface Quality

Surface texture
Deviations from the surface

**Roughness:** small deviations

**Waveness:** deviations with much larger spacing

**Lay:** predominant direction or pattern of the surface

**Flaws:** irregularities like cracks, inclusions, etc.
Surface Quality

Surface Roughness Value

Arithmetic average (AA) of the vertical deviations from the normal surface over a specified surface length.

\[ R_a = \frac{1}{L_m} \int_{0}^{L_m} |y| \, dx \]
Surface Quality

Surface Roughness Value (Ra)

(Figure 4: Surfaces with same Ra, but a lot of difference)
## Surface Quality

### Surface lay symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>=</td>
<td>Parallel to the plane of projection of the view in which the symbol is used</td>
</tr>
<tr>
<td>⊥</td>
<td>Perpendicular to the plane of projection of the view in which the symbol is used</td>
</tr>
<tr>
<td>X</td>
<td>Crossed in two slant direction relative to the plane of projection of the view in which the symbol is used</td>
</tr>
<tr>
<td>M</td>
<td>Multidirectional</td>
</tr>
<tr>
<td>C</td>
<td>Approximately circular relative to the centre of the surface to which the symbol is applied</td>
</tr>
<tr>
<td>R</td>
<td>Approximately radial relative to the centre of the surface to which the symbol is applied</td>
</tr>
</tbody>
</table>
Surface Quality

Surface texture obtained by any manufacturing process (e.g., turning, grinding, plating, bending)

Surface texture obtained by material removal by machining Operation (e.g., turning, drilling, Milling, slotting)

Surface texture obtained by WITHOUT removal of material (e.g., casting surfaces, welding faces, Procurement size surface)

<table>
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<tr>
<th>SYMBOL</th>
<th>INTERPRETATION</th>
<th>SYMBOL</th>
<th>INTERPRETATION</th>
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<tbody>
<tr>
<td>1.6</td>
<td>Roughness height rating is placed at the left of the long leg. The specification of only one rating shall indicate the maximum value and any lesser value shall be acceptable.</td>
<td>0.8</td>
<td>Lay designation is indicated by the lay symbol placed at the right of the long leg.</td>
</tr>
<tr>
<td>1.8</td>
<td>The specification of maximum value and minimum value roughness height ratings indicates permissible range of value rating.</td>
<td>0.8</td>
<td>Roughness-width cutoff rating is placed below the horizontal extension. When not value is shown, 0.80 is assumed.</td>
</tr>
<tr>
<td>1.6</td>
<td>Maximum waviness height rating is placed above the horizontal extension. Any lesser rating shall be acceptable.</td>
<td>0.8</td>
<td>Where required, maximum roughness width rating shall be placed at the right of the lay symbol. Any lesser rating shall be acceptable.</td>
</tr>
<tr>
<td>1.6</td>
<td>Maximum waviness width rating is placed above the horizontal extension and to the right of the waviness height rating. Any lesser rating shall be acceptable.</td>
<td>0.8</td>
<td>Material removal by machining is required to produce the surface. The basic amount of stock provided for material removal is specified at the left of the short leg of the symbol.</td>
</tr>
<tr>
<td>90%</td>
<td>Minimum requirements for contact or bearing area with a mating part or reference surface shall be indicated by a percentage value placed above the extension line as shown. Further requirements may be controlled by notes.</td>
<td>3.5</td>
<td>Removal of material is prohibited.</td>
</tr>
</tbody>
</table>
New Product Blueprinting
7 Seamless Steps

1. Market Research
   Identify most attractive opportunities

2. Discovery Interviews
   Uncover unmet customer needs

3. Preference Interviews
   Prioritize customer needs

4. Side-by-Side Testing
   Understand competitive offerings

5. Product Objectives
   Create detailed product design

6. Technical Brainstorming
   Internally brainstorm solutions

7. Business Case
   Justify costly development

Excerpted from New Product Blueprinting, by Dan Adams
Introduction: Design Process

Idea development:

all products begin with an idea whether from:

- customers,
- competitors
- suppliers

Reverse engineering:

buying a competitor’s product
Understanding of Design
- Objective / purpose
- Function
- Working Environment

Understanding of Material
- Material Properties
- Material Behavior
- Manufacturability

Understanding of Customer
- Cost
- Logistics
- Service life
- Environmental impact
Introduction

Understanding of Design

- Objective / purpose
- Expected failures /
  Critical Design location
- Working Environment

Fly in long distance

Should be mobile

Hit to ground when landing

sunny days, salt water, 15-35°C
Introduction

Understanding of Customer

- Cost
- Logistics
- Service life
- Environmental impact

Cheap

Durable
Introduction

Understanding of Material

- Material Properties
- Material Behavior

Cheap (low material/manuf. cost)

Fly in long distance (low density)

Durable (impact resistive)

Should be mobile (low density)

Hit to ground when landing (easily absorb impacts)

Sunny days, salt water, 15-35°C (non-corrosion)
Introduction

Chair
break the system down into individual components
then analyze each one

**System**: combination of sub-system or component

**Sub-system**: it is a part of system and it can be divided into sub-systems or components

**Component**: is a sub-system that cannot be split anymore
Understanding of Design : System Analysis

Personel Car

System

Sub-system

Engine

Power train

Steer System

Vehicle Frame

Engine

cooling

Electrical

system

Combustion

system

pipes

Heat Ex. Unit

Coolant Fluid

Component
Understanding of Design: System Analysis

- Frame
- Power train
- Fork
- Wheels
- Others

- Requirements (mechanical, ergonomic, aesthetic etc.)
- Function
- How many are going to be made?
- What manufacturing methods are we going to use?
Understanding of Design: System Analysis

Frame

- **Steel**
  Strong, stiff, heavy, but cheap

- **Aluminium**
  Weaker, lighter, more expensive than steel

- **Composite (CFRP)**
  Strong, stiff, very light, but expensive to buy and to fabricate
Understanding of Customer:

**Customer Needs**

- **Environment** – High/low temperature, sea, desert
- **Product Life** – Operational cost, profitability
- **Special needs** – Low weight, wear resistivity, bio compatibility
- **Safety** – Failure strategy
- **Mission** – Acceleration/deceleration, start/stop

**Governmental regulations**

**COST !!!!!**
Understanding of Customer:

**Turbine blade**

- **Environment** – High temperature up to 2000 K
- **Special needs** – Low weight
- **Product Life** – 4000 h of operations
- **Safety** – cannot be damaged (partially)
- **Mission** – special mission requirement

**COST !!!!!** (each stage contain 20-60 blades)

(each engine consists of 1 or 2 stage)
## Understanding of Material & Process

<table>
<thead>
<tr>
<th>Category</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>Strength, modulus etc.</td>
</tr>
<tr>
<td>Physical</td>
<td>Density, melting point.</td>
</tr>
<tr>
<td>Electrical</td>
<td>Conductivity, resistivity</td>
</tr>
<tr>
<td>Thermal</td>
<td>Conductivity, heat capacity</td>
</tr>
<tr>
<td>Optical</td>
<td>Absorption, transmission and scattering</td>
</tr>
<tr>
<td>Aesthetic</td>
<td>Appearance, texture, color</td>
</tr>
<tr>
<td>Processability</td>
<td>Ductility, weldability</td>
</tr>
</tbody>
</table>
What are the requirements?

- Leak free
- Comply with food standards & protect liquid from health hazards
- Withstand pressure
- Brand image & identity
- Easy to open
- Easy to store & transport
- Environmental friendly
- Cheap for high volumes

Which material?
- ceramic, glass, steel, aluminum, plastic