MECHANICAL ASSEMBLY

1. Threaded Fasteners
2. Rivets and Eyelets
3. Interference fit
4. Other methods
5. Molding Inserts and Integral Fastener
6. Design for assembly

Introduction

- The use of various fastening methods to mechanically attach two parts together, usually using fasteners.
- Two Major classes
  - Those that allow for disassembly (e.g.: bolt)
  - Those that create permanent joint (e.g.: rivet)
- Ease of assembly and disassembly
  - Done by unskilled labor with simple tools and inspected readily
- Threaded fastener, rivets, interference fit, other mechanical fastening methods and molded-in inserts and integral fastener.

1. Threaded Fasteners

- Screw, bolts and nuts
- Various screws and bolts
- Assembly of collar on shaft
- Other threaded fasteners
- Washer ensures tightness of the joints.
- Stresses in bolts $\sigma = \frac{F}{A}$
- A right amount of torque $T = C_D F$

Bolt and Screw

- A variety of sizes, threads, and shapes
- Standardization to promotes interchangeability
- U.S. is converting to metric.
- Different screw head styles and sizes require different screwdriver designs
  - Machine screws
    - generic type, generally designed for assembly into tapped holes
  - Capscrews
    - same geometry as machine screws but made of higher strength metals and to closer tolerances

Setscrew & Self-Tapping Screws

- Setscrew
  - Screw, bolts, and nuts
- Various screws and bolts
- Assembly of collar on shaft
- Other threaded fasteners
- Washer ensures tightness of the joints.
- Stresses in bolts $\sigma = \frac{F}{A}$
- A right amount of torque $T = C_D F$

2. Rivets and Eyelets

- Rivets
  - Solid,
  - Tubular,
  - Semitubular,
  - Bifurcated
  - Compression
- Eyelets
  - Setting
3. Interference fit

- Press fitting
  Radial Pressure \( P_r = \frac{E(D_f^2 - D_e^2)}{D_f D_e} \)
- Shrink and Expansion fit
- Snap fits and Retaining rings

\[ \sigma_T = \frac{2p(D_f^2 - D_e^2)}{D_f D_e} \leq \frac{Y}{S_f} \]

4. Other Mechanical Fastening Methods

- Stitching, Stapling and Sewing
  - Wire stitches
  - Cotter pin

5. Molding Inserts & Integral Fasteners

- A Permanent joint between parts by shaping one of the components through casting, molding or sheet-metal forming
  - Molding or Casting Inserts
  - Integral Fasteners - Components are deformed so they interlock as a mechanically fastened joint
  - Lanced tabs, embossed protrusions, seaming, beading, dimpling

6. Design for assembly

- Design with the assembly cost in mind
- General Principles
  - Use few parts
  - Reduce the number of threaded fasteners
  - Standardize fasteners
  - Reduce part orientation difficulties
  - Avoid parts that tangle
- Design for Automated Assembly
  - Use modularity in product design
  - Reduce the need for multiple components to be handled at once
  - Reduce the number of parts
  - Reduce the number of assembly direction
  - Use High Quality components
  - Use snap-fit assembly

RAPID PROTOTYPING

Fundamentals of Rapid Prototyping
Rapid Prototyping Technologies
Applications & Benefits of Rapid Prototyping
Fundamentals

A family of fabrication processes to make prototypes directly from a CAD model:
- Traditionally, machining requiring significant lead-times – several weeks, depending on part complexity and difficulty in ordering materials.
- RP allows a part to be made in hours or days rather than weeks with a computer model.

Prefer a physical model of a new part:
- Creating a prototype is an integral step in design.
- A virtual prototype may not be sufficient.
- Visually and physically examined to assess its merits and shortcomings.

Other Names used:
- Layer manufacturing
- Direct CAD manufacturing
- Solid freeform fabrication
- Rapid prototyping & manufacturing (RPM) – increasingly to make production parts and production tooling, not just prototypes.

Two Basic Categories

1. **Material removal RP** - machining, (milling & drilling) using a dedicated CNC machine:
   - Often use wax due to machinability and recyclability.
   - The small CNC machines called *desktop machining*.

2. **Material addition RP** - adds materials layer by layer to build the solid part from bottom to top:
   - Liquid monomers cured layer by layer into solid polymers.
   - Powders aggregated & bonded layer by layer.
   - Solid sheets laminated to create the solid part.

RP Steps

1. **Geometric modeling** - modeling the component on a CAD system to define its enclosed volume.
2. **Tessellation of the geometric model** - the CAD model is converted into a computerized format that approximates its surfaces by facets (triangles or polygons).
3. **Slicing of the model into layers** - the model in computerized format is sliced into closely-spaced parallel horizontal layers.

Liquid-Based RP Systems

- Starting material is a liquid.
- About a dozen RP technologies are in this category.
- The following are described here:
  - Stereolithography
  - Solid ground curing
  - Droplet deposition manufacturing.

Stereolithography (STL)

A plastic part from a photosensitive liquid monomer using a directed laser beam to cure the polymer:
- Each layer is scanned (at typically 500 to 2500 mm/s) onto the previous layer to build the 3-D geometry.
- Most widely used RP and the first RP (1988) by 3D Systems Inc. based on the work by Charles Hull.
- Resolution & intricate shape controlled by the thickness of each layer 0.076 mm to 0.50 mm thick.
- Thinner the layer, longer the processing time.
- Polymerization by UV light from helium- cadmium or argon ion lasers.
Part Build Time in STL

Time to complete a single layer: \( T_i = \frac{A_i}{vD} + T_d \)

where \( T_i \) = time to complete layer \( i \);
\( A_i \) = area of layer \( i \);
\( v \) = average scanning speed of the laser beam at the surface;
\( D \) = diameter of the “spot size,” assumed circular; and
\( T_d \) = delay time between layers to reposition the worktable.

The total build cycle time is:

\[ T_c = \sum_{i=1}^{n} T_i \]

where \( T_c \) = STL build cycle time; and
\( n \) = number of layers used to approximate the part.

* Typically from one hour for small parts of simple geometry up to several dozen hours for complex parts.

Solid Ground Curing (SGC)

Curing a photosensitive polymer layer by layer. However, an entire layer is exposed to UV using a mask.

- Hardening takes 2 to 3s for each layer.
- SGC steps for each layer:
  1. mask preparation,
  2. applying liquid photopolymer layer,
  3. mask positioning and exposure of layer,
  4. uncured polymer removed
  5. wax filling,
  6. milling for flatness and thickness.

Facts about SGC

- The sequence for each layer takes about 90 seconds.
- Time to produce a part by SGC is claimed to be about eight times faster than other RP systems.
- The solid cubic form created in SGC consists of solid polymer and wax.
- The wax provides support for fragile and overhanging features of the part during fabrication, but can be melted away later to leave the free-standing part.

Droplet Deposition Manufacturing (DDM)

The starting material is melted and small droplets are shot by a nozzle onto a previously formed layer.

- Droplets cold weld to surface to form a new layer.
- Deposition for each layer controlled by a moving x-y spray nozzle whose path is based on a cross-section of a CAD geometric model that is sliced into layers.
- After each layer is applied, the platform supporting the part is lowered a distance equal to the layer thickness.
- Work materials used in BPM include wax and thermoplastics.

Solid-Based RP Systems

- Starting material is a solid.
- Two types:
  - Laminated object manufacturing
  - Fused deposition modeling.

Laminated Object Manufacturing (LOM)

A solid physical model is made by stacking layers of sheet stock, each an outline of the cross-sectional shape of a CAD model that is sliced into layers.

- Starting sheet stock, such as paper, plastic, cellulose, metals, or fiber-reinforced materials.
- The sheet material with adhesive backing as rolls that are spooled between two reels.
- After cutting, excess material to support the part during building.
Fused Deposition Modeling (FDM)
A long filament of wax or polymer is extruded onto the existing part surface from a workhead to complete each new layer
• The workhead is controlled in the x-y plane during each layer and then moves up by a distance equal to one layer in the z-direction
• The extrudate is solidified and cold welded to the cooler part surface in about 0.1 s
• Part is fabricated from the base up, using a layer-by-layer procedure

Selective Laser Sintering (SLS)
A moving laser beam sinters heat-fusible powders in areas corresponding to the CAD geometry model one layer at a time to build the solid part
• After each layer is completed, a new layer of loose powders is spread across the surface
• Layer by layer, the powders are gradually bonded into a solid mass that forms the 3-D part geometry
• In areas not sintered by the laser beam, the powders are loose and can be poured out of completed part

Powder-Based Rapid Prototyping Systems
• Two RP systems are described here:
  – Selective laser sintering
  – Three dimensional printing

3 Dimensional Printing (3DP)
The part built in layer-by-layer fashion using an ink-jet printer to eject the binder onto successive layers of powders
• The binder is deposited in the cross-sections of the solid part, as determined by slicing the CAD model.
• The binder holds the powders together to form the solid part, while the unbonded powders remain loose to be removed later
• A final sintering step to consolidate the individual powders

RP Applications
1. Design
   • To confirm the design, to reduced lead times to produce prototype components, to improve visualization and to reduce design errors and to compute mass properties
2. Engineering analysis and planning
   – Compare different shapes and style for aesthetic appeal
   – Wind tunnel testing of different streamline shapes
   – Stress analysis of a physical model
   – For process planning and tool design
3. Tooling and manufacturing
   – Rapid tool making (RTM) to fabricate production tooling
     Two approaches
     – Indirect RTM Method - The pattern created by RP is used to fabricate the tool
       – Patterns for sand casting and investment casting
       – Electrodes for EDM
     – Direct RTM Method - RP to make the tool itself
       – 3DP to create a die of metal powders followed by sintering and infiltration to complete the die

Other Aspects
RP Applications: Manufacturing
• Small batches of plastic parts not economical for injection molding due to the high mold cost
• Parts with intricate internal geometries not with conventional technologies without assembly
• One-of-a-kind, customized parts such as bone replacements

Problems with RP
• Part accuracy:
  – Staircase appearance for a sloping part surface due to layering
  – Shrinkage and distortion of RP parts
• Limited variety of materials in RP
  – Mechanical performance is limited by the materials used in the RP process