Objectives
• Describe many types of fastening systems and their uses.
• Understand principles of stress area, pitch diameters, and thread types and forms.
• Understand different types of tensioning systems and how preloaded joints are created and the analysis of appropriate tightening loads.
• Describe principles of elastic analysis and how the preload affects the ability of joints to resist future loading and/or pressures.
• Recognize types of fastening systems, their basic principles, and where they may be applicable.

Introduction
• Principal purpose of fasteners are
  – Disassembly for inspection and repair
  – Modular design, where a product consists of a number of subassemblies.

Fastener types
• Removable: This type permits the parts to be readily disconnected without damaging the fastener, e.g. nut and bolt.
• Semi-permanent: For this type, the parts can be disconnected, but some damage usually occurs to the fastener, e.g. cotter pin
• Permanent: When this type of fastener is used, the parts will never be disassembled. e.g. rivets and welding

Fastener application
• Primary function
• Appearance
• Number of fasteners
• Operating conditions
• Frequency of disassembly
• Adjustability
• Types of materials
• Consequences of failure

Screw thread terminology (Fig. 6.1)
• Major diameter: The major diameter is the largest diameter of the thread. It determines the nominal size.
• Minor diameter: It is the smallest diameter of the thread. In external thread, it is also called as root diameter.
• Pitch: is the axial distance between any point of one thread and the corresponding point of an adjacent thread.
• Lead: The distance a bolt advances into a nut in one revolution is called lead.
Cross-section of a Unified thread

- Using a torque wrench with a specified torque limit
- Turning through a specified angle after full engagement
- Hydraulic tensioning – use a hydraulic cylinder to stretch a bolt for imparting an initial tension
Example Problem 6-1: Torquing Methods

- A ¾-UNC-grade 5 bolt is to be preloaded to 85 percent of its proof strength.
- The length of engagement is 5 inches.
- The bolt is new and non-lubricated but likely has traces of cutting oil present.
- Determine the required torque:

\[ T = C D F_i \]

\[ T = 0.2 (\text{¾ in}) 24,130 \text{ lb} = 3620 \text{ in-lb or 302 ft-lb} \]

\[ F_i = 0.85 S_p A_s \]

\[ F_i = 0.85 (85,000 \text{ lb/in}^2) (0.334 \text{ in}^2) = 24,130 \text{ lb} \]

Turn-of-the-Nut method

- Find the elongation needed to produce the appropriate preload

\[ \delta = \frac{F L}{AE} \]

\[ \text{Required torque angle} = \frac{\delta 360}{\text{pitch}} \]

Heating Method

- Use the linear expansion of the material under heat

\[ \Delta T = \frac{\delta}{\alpha L} \]

Example Problem 6-2: Turn-of-the-Nut Method

- From prior problem, determine the angle of rotation needed, using the turn-of-nut method.

\[ \delta = \frac{F L}{AE} \]

\[ \delta = \frac{24,130 \text{ lb}}{0.334 \text{ in}^2} = 72,309 \text{ in}^{-1} \]

\[ \text{torque angle} = \frac{72,309 \text{ in}^{-1} 360}{0.1 \text{ in}} = 2653 \text{ in-lb or 221 ft-lb} \]

Example Problem 6-3: Heating Methods

- In Example Problem 6-1, to obtain the same preload, determine the temperature we would need to heat this bolt above the service temperature.

\[ \Delta T = \frac{\delta}{\alpha L} \]

\[ \Delta T = \frac{72,309 \text{ in}^{-1}}{6.5 \times 10^{-6} \text{ in/°F}} \approx 1100 \text{ °F} \]
Elastic Analysis of Bolted Connections

- Bolted connection – residual tension in the bolt, residual compression in the clamped part
- Applied load to the part gets compensated by this to some extent.

\[ \delta = \frac{F \cdot L}{A \cdot E} \]

Elastic Analysis of Bolted Connections

- If \( k \) is the stiffness of the joint
- The stiffness of the bolt is \( k_b = \frac{A_b \cdot E}{L_b} \)
- The stiffness of the joint is \( k_j = \frac{A \cdot E}{L} \)

\[ F_k = \frac{b}{b \cdot L} \]

Elastic Analysis of Bolted Connections

- Recommended preload, \( F_i \) is given by

\[ F_i = Q \cdot F_i \left( \frac{k_i}{k_b + k_i} \right) \quad \text{Eq 6.7} \]

- \( Q \) – margin factor (similar to safety factor)
- \( F_i \) – Applied load
- New load on bolt is \( F_t = F_i + \Delta F_b \)

\[ \Delta F_b = F_i \left( \frac{k_b}{k_b + k_i} \right) \]

Elastic Analysis of Bolted Connections

- Total force on the bolt

\[ F_i = F_i + \frac{k_b}{k_b + k_i} \quad \text{Eq 6.8} \]

- Total force on the flange

\[ F_i = F_i - \frac{k_i}{k_b + k_i} \quad \text{Eq 6.9} \]

Bolt in shear

\[ \tau = \frac{P}{A} \]

\( \tau \) = Shear stress in the bolt
\( P \) = Applied shear force
\( A \) = Cross-sectional area of the bolt
Multiple fasteners

\[ \tau = \frac{P}{N_{A}} \]

Concentric of bolts

FIGURE 11.38 Fastener with multiple bolts loaded in shear (zero eccentricity design)

Eccentric loading

FIGURE 11.39 Eccentrically loaded fastened component loaded in shear

Dual loading

\[ T = P_{e} \]

Dual loads on bolts as a result of eccentricity

Shear force on multiple fasteners

(a) Direct shear (P) (P)

(b) Secondary shear (\(F_{1}, F_{2}, F_{3}\) and \(F_{4}\))

FIGURE 11.41 Vector addition of direct and secondary shear forces
Secondary shear forces

- Direction is perpendicular to the line running from the center of the bolt to the centroid
- Direction opposes the applied torque, T
- Magnitude is proportional to the distance from the center of the bolt to the centroid

\[ F_1 l_1 + F_2 l_2 + F_3 l_3 + F_4 l_4 - P e = 0 \]

Bolted connector

Graphical addition

"Mr. Osbourne, may I be excused? My brain is full."

Figure 11.43 Direct and secondary shear forces (a) Direct shear forces (b) Secondary shear forces at 45°
Conclusions

• A variety of mechanical fasteners are discussed.
• Screw thread is the most important part of a fastener.
• Force acting on various fasteners have been analyzed.