31 MECHANICAL ASSEMBLY

Review Questions

31.1 How does mechanical assembly differ from the other methods of assembly discussed in previous chapters (e.g., welding, brazing, etc.)?

Answer. Mechanical assembly uses a mechanical fastening method for joining two (or more) parts, whereas welding, brazing, soldering, and adhesive bonding use heat and/or pressure, sometimes combined with a filler material to permanently join parts. Also, many of the mechanical fastening methods allow for disassembly - not possible with welding and brazing.

31.2 What are some of the reasons why assemblies must be sometimes disassembled?

Answer. For maintenance and repair service, to replace worn-out components, and to make adjustments.

31.3 What is the technical difference between a screw and a bolt?

Answer. Both are externally threaded fasteners. A screw is generally assembled into a blind threaded hole, whereas a bolt is assembled using a nut.

31.4 What are *screw thread inserts*?

Answer. Screw thread inserts are internally threaded plugs or wire coils made to be inserted into an unthreaded hole and to accept an externally threaded fastener. They are assembled into weaker materials to provide strong threads.

31.5 What is a *stud* (in the context of threaded fasteners)?

Answer. A stud is an externally threaded fastener that does not have the usual head possessed by a bolt.

31.6 What is *torque-turn tightening*?

Answer. Torque-turn tightening involves the tightening of the threaded fastener to a certain low torque level, and then advancing the fastener by a specified additional amount of turn (e.g., a quarter turn).

31.7 Define *proof strength* as the term applies in threaded fasteners.

Answer. Proof strength can be defined as the maximum tensile stress that an externally threaded fastener can sustain without permanent deformation. Basically, it is the yield strength.

31.8 What are the three ways in which a threaded fastener can fail during tightening?

Answer. (1) Stripping of the bolt or screw threads, (2) stripping of the internal fastener threads, and (3) excessive tensile load on the cross-sectional area of the bolt or screw.

31.9 What is a *rivet*?

Answer. A rivet is an unthreaded headed pin used to join two parts by inserting the pin through holes in the parts and deforming the unheaded portion over the opposite side.

31.10 What is the difference between a shrink fit and expansion fit in assembly?

Answer. In a shrink fit, the outside part is expanded by heating to fit over the mating component. Then cooling causes an interference fit with the component. In an expansion fit, the internal part is cooled so that it can be readily inserted into the mating component. Then, upon warming to room temperature, it expands to cause an interference fit with its mating part.

31.11 What are the advantages of snap fitting?

Answer. Advantages of snap fitting include (1) the method is fast, (2) no tooling is required, and (3) the parts can be designed with self-aligning features for ease of mating.

31.12 What is a *retaining ring*?

Answer. A retaining ring is a fastener that snaps into a circumferential groove on a shaft or tube to form a shoulder. The assembly can be used to locate or restrict the movement of parts mounted on the shaft.

31.13 What is the difference between industrial stitching and stapling?

Answer. In stitching the U-shaped fasteners are formed during the assembly process. In stapling, the fasteners are preformed.

31.14 What are *integral fasteners*?

Answer. Integral fasteners make use of a forming operation on one of the parts to be joined to interlock the components and create a mechanically fastened joint.

31.15 Identify some of the general principles and guidelines that apply specifically to automated assembly.

Answer. Some of the principles and guidelines that apply specifically to automated assembly include the following: (1) Use modularity in product design. Each module to be produced on a single assembly system should have a maximum of 12 or 13 parts and should be designed around a base part to which other components are added. (2) Reduce the need for multiple components to be handled at once. (3) Limit the required directions of access. The ideal is for all components to be added vertically from above. (4) Use only high quality components. Poor quality components cause jams in feeding and assembly mechanisms. (5) Use snap fit assembly to eliminate the need for threaded fasteners.

Problems

Answers to problems labeled **(A)** are listed in an Appendix at the back of the book.

Threaded Fasteners

31.1 **(A)** (SI units) A metric 5 × 0.8 bolt is tightened to produce a preload = 200 N. The torque coefficient = 0.20. Determine the (a) torque that is applied and (b) resulting stress on the bolt.

Solution: (a) $T = C_t DF$ = 0.20(5.0)(200) = **200 N-mm = 0.20 N-m**

(b) $A_s = 0.25\pi(D - 0.9382p)^2 = 0.25\,\pi(5.0 - 0.9382(0.8))^2 = 14.18\text{ mm}^2$
$\sigma = F/A_s = 200/14.18 = 14.1\text{ N/mm}^2$ = **14.1 MPa**

31.2 (SI units) A metric 12 × 1.75 bolt is subjected to a torque of 20 N-m during tightening. If the torque coefficient is 0.24, determine the tensile stress on the bolt.

Solution: T = 20 N-m = 20,000 N-mm
$F = T/ C_tD$ = 20,000/(0.24 × 12) = 8333 N
$A_s = 0.25\pi(12 - 0.9382 \times 1.75)^2 = 84.27$ mm^2
σ = 8333/84.27 = **98.9 N/mm^2 = 98.9 MPa**

31.3 (USCS units) A 3/8-16 UNC nut and bolt are used to assemble steel plates. The clearance holes in the plates are 7/16 in. The plates are clamped together by the nut and bolt with a force of 500 lb. If the torque coefficient is 0.22, determine the (a) torque that is applied and (b) resulting stress on the bolt.

Solution (a) $T = C_tDF$ = 0.22(3/8)(500) = **41.25 in-lb**

(b) $A_s = 0.25\pi(D - 0.9743/n)^2 = 0.25\pi(3/8 - 0.9743/16)^2 = 0.0775$ in^2
$\sigma = F/A_s$ = 500/0.0775 = **6,452 lb/in^2**

31.4 (SI units) An alloy steel metric 10 × 1.25 screw is used in a threaded hole and tightened to 30% of its proof strength (see Table 31.2). Determine the maximum torque that should be used if the torque coefficient = 0.18.

Solution: $A_s = 0.25\pi(10 - 0.9382 \times 1.25)^2 = 61.2$ mm^2
From Table 31.2, proof strength = 830 MPa
σ = 0.3 of 830 MPa = 249 MPa = 249 N/mm^2
$F = \sigma A_s$ = 249(61.2) = 15,239 N
$T = C_tDF$ = 0.18(10)(15,239) = **27,430 N-mm = 27.4 N-m**

31.5 **(A)** (USCS units) A 1/2-20 UNF screw is preloaded to a tension force = 750 lb. The torque coefficient = 0.22. Determine the (a) torque that should be applied and (b) resulting stress on the bolt.

Solution: (a) $T = C_tDF$ = 0.22(0.50)(750) = **82.5 in-lb**

(b) $A_s = 0.25\pi(D - 0.9743/n)^2 = 0.25\pi(1/2 - 0.9743/20)^2 = 0.160$ in^2
$\sigma = F/A_s$ = 750/0.16 = **4,689 lb/in^2**

31.6 (SI units) Threaded metric fasteners are available in several systems, two of which are given in Table 31.1: coarse and fine. Fine threads are not cut as deep and, as a result, have a larger tensile stress area for the same nominal diameter. Using a proof strength of 228 MPa and a 12 mm bolt, determine the (a) maximum preload that can be used for coarse pitch and fine pitch threads and (b) percent increase in preload of fine threads compared to course threads.

Solution: (a) For the coarse thread,
$A_s = 0.25\pi(D - 0.9382p)^2 = 0.25\pi(12 - 0.9382 \times 1.75)^2 = 84.3$ mm^2
$F = A_s\sigma$ = 84.3(228) = **19,220 N**
For the fine thread,
$A_s = 0.25\pi(D - 0.9382p)^2 = 0.25\pi(12 - 0.9382 \times 1.25)^2 = 92.1$ mm^2
$F = A_s\sigma$ = 92.1(228) = **20,999 N**

(b) Percent increase = (20,999 – 19,220)/19,220 = 0.0925 = **9.25 % increase**

31.7 (USCS units) A pneumatic torque wrench is used to tighten 3/4-10 UNC bolts in an automobile final assembly plant. A torque of 50 ft-lb is generated by the wrench. If the torque coefficient = 0.20, determine the tensile stress in the bolt.

Solution: T = 50 ft-lb = 600 in-lb
$F = T/C_tD$ = 600/(0.20 × 0.75) = 4000 lb
$A_s = 0.25\pi(0.75 - 0.9743/10)^2 = 0.334$ in^2
σ = 4000/0.334 = **11,976 lb/in^2**

31.8 **(A)** (USCS units) The designer has specified that a 3/8-16 UNC low-carbon steel bolt in a certain application should be stressed to 50% of its proof stress (see Table 31.2). Determine the maximum torque that should be used if the torque coefficient = 0.25.

Solution: $A_s = 0.25\pi(0.375 - 0.9743/16)^2 = 0.0775$ in^2
From Table 31.2, proof stress for low-carbon steel bolt = 33,000 lb/in^2
$F = \sigma A_s$ = 0.50(33,000)(0.0775) = 1279 lb
$T = C_tDF$ = 0.25(0.375)(1279) = **120 in-lb**

Interference Fits

31.9 **(A)** (SI units) A gear made of an aluminum alloy (modulus of elasticity = 69 GPa) is press-fitted onto an aluminum shaft. The gear has an outside diameter (at the top of its teeth) = 50 mm and a root diameter (at the base of its teeth) = 45 mm. The nominal internal diameter of the gear = 30 mm, and the interference = 0.03 mm. Compute the (a) radial pressure between the shaft and the gear and (b) maximum effective stress in the gear at its inside diameter.

Solution: The root diamter (at the base of the teeth) should be used for D_c.
(a) $p_f = Ei(D_c^2 - D_p^2)/D_pD_c^2 = 69{,}000(0.03)(45^2 - 30^2)/(30 \times 45^2)$ = **38.33 MPa**

(b) Max $\sigma_e = 2p_fD_c^2/(D_c^2 - D_p^2) = 2(38.33)(45^2)/(45^2 - 30^2)$ = **138 MPa**

31.10 (SI units) A dowel pin made of steel (elastic modulus = 209 GPa) is to be press-fitted into a steel collar. The pin has a nominal diameter of 15.0 mm, and the collar has an outside diameter of 20.0 mm. (a) Compute the radial pressure and the maximum effective stress if the interference between the shaft OD and the collar ID is 0.02 mm. (b) Determine the effect of increasing the outside diameter of the collar to 30.0 mm on the radial pressure and the maximum effective stress.

Solution: (a) $p_f = Ei(D_c^2 - D_p^2)/D_pD_c^2 = 209{,}000(0.02)(20^2 - 15^2)/(15 \times 20^2)$ = **122 MPa**
Max $\sigma_e = 2p_fD_c^2/(D_c^2 - D_p^2) = 2(122)(20^2)/(20^2 - 15^2)$ = **557 MPa**

(b) When D_c = 30 mm, $p_f = 209{,}000(0.02)(30^2 - 15^2)/(15 \times 30^2)$ = **209 MPa**
Max $\sigma_e = 2(209)(30^2)/(30^2 - 15^2)$ = **557 MPa**

31.11 (USCS units) A pin made of alloy steel is press-fitted into a hole machined in the base of a large machine. The hole has a diameter of 1.498 in. The pin has a diameter of 1.500 in. The base of the machine is 4 ft by 8 ft and is the same steel as the pin: modulus of elasticity = 30×10^6 lb/in^2, yield strength = 85,000 lb/in^2, and a tensile strength = 120,000 lb/in^2. Determine the (a) radial pressure between the pin and the base and (b) maximum effective stress in the interface.

Solution: (a) $i = 2.500 - 2.498 = 0.002$ in
$p_f = Ei/D_p = 30\times10^6 (0.002)/1.5 =$ **40,000 lb/in²**

(b) Max $\sigma_e = 2p_f = 2(40,000) =$ **80,000 lb/in²**

31.12 (USCS units) A steel collar is press fitted onto a steel shaft. The modulus of elasticity of steel = 30×10^6 lb/in². The collar has an internal diameter = 2.4985 in, and the shaft has an outside diameter = 2.500 in. The outside diameter of the collar = 4.000 in. Determine the (a) radial (interference) pressure on the assembly and (b) maximum effective stress in the collar at its inside diameter.

Solution: (a) $i = 2.500 - 2.4985 = 0.0015$ in, $p_f = Ei(D_c^2 - D_p^2)/D_pD_c^2$
p_f **=** $30 \times 10^6(0.0015)(4.000^2 - 2.500^2)/(2.500 \times 4.000^2) =$ **10,969 lb/in²**

(b) Max $\sigma_e = 2p_fD_c^2/(D_c^2 - D_p^2) = 2(10,969)(4.000^2)/(4.000^2 - 2.500^2) =$ **36,000 lb/in²**

31.13 (USCS units) A steel collar is to be heated from room temperature (70°F) to 500°F. Its inside diameter = 1.000 in, and its outside diameter = 1.625 in. The coefficient of thermal expansion for steel is given in Table 4.1. Determine the increase in the inside diameter of the collar.

Solution: From Table 4.1, coefficient of thermal expansion for steel $\alpha = 6.7(10^{-6})$ °F^{-1}
$(D_2 - D_1) = \alpha D_1(T_2 - T_1) = 6.7 \times 10^{-6}(1.0)(500 - 70) = 2881 \times 10^{-6} =$ **0.0029 in**

31.14 (SI units) A shaft made of aluminum is 25.0 mm in diameter at room temperature (21°C). The coefficient of thermal expansion for aluminum is given in Table 4.1. If it must be reduced in size by 0.10 mm in order to be expansion-fitted into a hole, determine the temperature to which the shaft must be cooled.

Solution: From Table 4.1, coefficient of thermal expansion for aluminum $\alpha = 24(10^{-6})$ °C^{-1}
$(D_2 - D_1) = \alpha D_1(T_2 - T_1) = -0.10 = 24 \times 10^{-6}(25)(T_2 - 21)$
$T_2 - 21 = -0.10/(24 \times 10^{-6} \times 25) = -167$
$T_2 = -167 + 21 =$ **–146°C**

31.15 **(A)** (SI units) A steel ring has an inside diameter = 30 mm and an outside diameter = 50 mm at room temperature (21°C). The coefficient of thermal expansion for steel is given in Table 4.1. Determine the inside diameter of the ring when heated to 400°C.

Solution: From Table 4.1, the coefficient of thermal expansion for steel $\alpha = 12(10^{-6})$ °C^{-1}
$(D_2 - D_1) = \alpha D_1(T_2 - T_1) = D_2 - 30 = 12 \times 10^{-6}(30)(400 - 21) = 0.136$ mm
$D_2 = 30 + 0.136 =$ **30.136 mm**

31.16 **(A)** (USCS units) A steel bearing for the output shaft of a 200 hp motor is to be heated so it expands enough to press on a steel shaft. At 70°F, the bearing has an inside diameter of 4.000 in and an outside diameter of 7.000 in. The shaft has an outside diameter of 4.004 in. The modulus of elasticity and coefficient of thermal expansion for steel are given in Tables 3.1 and 4.1, respectively. (a) At what temperature will the bearing have 0.005 of clearance to fit over the shaft? (b) After it is assembled and cooled, what is the radial pressure between the bearing and shaft? (c) Determine the maximum effective stress in the bearing.

Solution: (a) Interference $i = 0.004$ in, additional required clearance = 0.005 in
Total expansion = 0.004 + 0.005 = 0.009 in = $(D_2 - D_1)$

From Table 3.1, $E = 30 \times 10^6$ lb/in^2; and from Table 4.1, $\alpha = 6.7\times10^{-6}$ °F^{-1}
$T_2 = (D_2 - D_1)/\alpha D_1 + T_1 = 0.009/(6.7\times10^{-6} \times 4.000) + 70 = 336 + 70 =$ **406°F**

(b) $p_f = Ei\,(D_c^2 - D_p^2)/D_pD_c^2 = 30\times10^6(0.004)(7^2 - 4^2)/(4 \times 7^2) =$ **20,204 lb/in^2**

(c) Max $\sigma_e = 2p_fD_c^2/(D_c^2 - D_p^2) = 2(20{,}204)(7^2)/(7^2 - 4^2) =$ **60,000 lb/in^2**

31.17 (SI units) A pin is to be inserted into a collar of the same metal using an expansion fit. The coefficient of thermal expansion of the metal = 12.3×10^{-6} m/m/°C, its yield strength = 400 MPa, and its modulus of elasticity = 209 GPa. At room temperature (20°C), the outer and inner diameters of the collar = 95.00 mm and 60.00 mm, respectively, and the pin has a diameter = 60.03 mm. The pin is to be reduced in size for assembly into the collar by cooling to a sufficiently low temperature that there is a clearance of 0.06 mm. Determine the (a) temperature to which the pin must be cooled for assembly and (b) radial pressure at room temperature after assembly. (c) What is the safety factor in the resulting assembly?

Solution: (a) $D_2 - D_1 = \alpha D_1(T_2 - T_1)$
$T_2 = (D_2 - D_1)/(\alpha D_1) + T_1 = ((60.00-0.06) - 60.03)/(12.3\times10^{-6}\times60.03) + 20 =$ **–101.9°C**

(b) $p_f = Ei(D_c^2 - D_p^2)/D_pD_c^2$
$p_f = 209\times10^9(0.03)(95^2 - 60^2)/(60(95^2) = 0.0628(10^9)$ N/m^2 = **62.8 MPa**

(c) Max $\sigma_e = 2p_fD_c^2/(D_c^2 - D_p^2) = 2(62.8)(95^2)/(95^2 - 60^2) = 209$ MPa
If $Y = 400$ MPa and Max $\sigma_e = Y/SF$, then $SF = Y/(\text{ Max } \sigma_e) = 400/209 =$ **1.91**