Pearson

Instructor's Manual and Test Bank

For

MACHINE ELEMENTS IN MECHANICAL DESIGN

Sixth Edition

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CHAPTER 1
THE NATURE OF MECHANICAL DESIGN

Problems 1-14 require the specification of functions and design requirements for design projects and have no unique solutions.

15. $D = 1.75 \text{ in} \times 25.4 \text{ mm/in} = \mathbf{44.5 \text{ mm}}$

16. $L = 46.0 \text{ m} \times 0.3048 \text{ m/ft} = \mathbf{14.0 \text{ m}}$

17. $T = 12\,500 \text{ lb·in} \times 0.1130 \text{ N·m/lb·in} = \mathbf{1418 \text{ N·m}}$

18. $A = 4.12 \text{ in}^2 \times 645.2 \text{ mm}^2/\text{in}^2 = \mathbf{2658 \text{ mm}^2}$

19. Section modulus $= S = 14.8 \text{ in}^3 \times 1.639{\times}10^4 \text{ mm}^3/\text{in}^3 = \mathbf{2.43{\times}10^5 \text{ mm}^3}$

20. Moment of inertia $= I = 88.0 \text{ in}^4 \times 4.162{\times}10^5 \text{ mm}^4/\text{in}^4 = \mathbf{3.66{\times}10^7 \text{ mm}^4}$

21. Given: $A_{min} = 750 \text{ mm}^2$: In U.S. units; $\mathbf{A_{min} = 1.162 \text{ in}^2}$

U.S. Angle – From Appendix 15-1: L2×2×3/8; $\mathbf{A = 1.36 \text{ in}^2}$ **[890 mm²]**

SI Angle – From Appendix 15-3: Angle 75×75×5; $A = 864 \text{ mm}^2$

22. Power $= P = 7.5 \text{ hp} \times 745.7 \text{ W/hp} = 5.59{\times}10^3 \text{ W} = \mathbf{5.59 \text{ kW}}$

23. Ultimate tensile strength $s_u = 127 \text{ ksi} \times 6.895 \text{ MPa/ksi} = \mathbf{876 \text{ MPa}}$

24. Given: Steel shaft; $D = 35 \text{ mm} = 0.035 \text{ m}$; $L = 675 \text{ mm} = 0.675 \text{ m}$

Find: Weight of the shaft: Weight = mass × g; $g = 9.81 \text{ m/s}^2$

Mass = density × volume; Density of steel = 7680 kg/m³ [From Appendix 3]

Volume $= V =$ area × length $= \pi D^2/4 \times L$

$V = \pi(0.035 \text{ m})^2/4 \times 0.675 \text{ m} = 6.49{\times}10^{-4} \text{ m}^3$

Mass $= 7680 \text{ kg/m}^3 \times 6.49{\times}10^{-4} \text{ m}^3 = 4.98 \text{ kg}$

Weight $= m \times g = 4.98 \text{ kg} \times 9.81 \text{ m/s}^2 = 48.9 \text{ kg·m/s}^2 = \mathbf{48.9 \text{ N}}$

25. Given: For a torsional spring, Torque = 180 lb·in for 35° of rotation.

Find the scale of the spring = Torque per unit of rotation. Express the result in both U.S. and SI units.

T = 180 lb·in × 0.1130 N·m/lb·in = 20.3 N·m

Angle = $\boldsymbol{\theta}$ = 35° × π rad/180° = 0.611 radians

Scale = $T/\boldsymbol{\theta}$ = 180 lb·in/35° = **5.14 lb·in/degree**

Scale = $T/\boldsymbol{\theta}$ = 20.3 N·m/0.611 rad = **33.3 N·m/rad**

26. Given: 12.5 hp motor operating 16 h/day, 5 days/week

Compute the energy, E, used by the motor for one year in both U.S. and SI units.

E = 12.5 hp × 16h/day × 5 days/wk × 52 wks/year × 550 ft·lb/s/hp × 3600 s/h

E = 1.03×10^{11} ft·lb/year

E = 1.03×10^{11} ft·lb/year × 1.356 J/ft·lb × 1.0 N·m/J × 1.0 W/N·m/s × 1h/3600 s

E = 38.8×10^{6} W·h/year = **38.8 MW·h/year**

27. Given: Viscosity = μ = 3.75 reyn × (1.0 lb·s/in^2)/reyn × 144 in^2/ft^2 = **540 lb·s/ft^2**

μ = 3.5 lb·s/in^2 × 4.448 N/lb × 1.0 in^2/645.2 mm^2 × 10^6 mm^2/m^2 = **25.9×10^3 N·s/m^2**

28. Given: n = 1750 rpm; 24h/day; 5.0 years. Find life in number of revolutions.

Life = 1750 rev/min × 24 h/day × 60 min/h ×365 days/year × 5 years

Life = 4.60×10^9 revolutions

CHAPTER 2
MATERIALS IN MECHANICAL DESIGN

1. Ultimate tensile strength is the apparent stress at the peak of the stress-strain curve.

2. Yield point is the value of the apparent stress from the stress-strain curve at which there is a large increase in strain with no increase in stress. It is the point where the stress-strain curve exhibits a horizontal slope.

3. Yield strength is the apparent stress from the stress-strain curve at which there is a large increase in strain with little increase in stress for materials that do not exhibit a yield point. The offset method is used by drawing a line parallel to the straight part of the stress-strain curve through a value of 0.2% on the strain axis.

4. Many low alloy steels exhibit a yield point.

5. The proportional limit is the apparent stress on the stress-strain curve at which the curve deviates from a straight line. At this value, the material is usually still elastic. The elastic limit is the apparent stress at which the material is deformed plastically and will not return to its original size and shape.

6. Hooke's law applies to that portion of the stress-strain curve that is a straight line for which stress is proportional to strain.

7. The modulus of elasticity is a measure of the stiffness of a material.

8. The percent elongation is a measure of the ductility of a material.

9. The material is not ductile. Materials having a percent elongation greater than 5% are considered to be ductile.

10. Poisson's ratio is the ratio of the lateral strain in a material to the axial strain when subjected to a tensile load.

11. **From Eq. 2-5:** $G = E/[2(1+\nu)] = (114 \text{ GPa})/[2(1+0.33)]$

    $G = 42.9 \text{ GPa}$

12. Hardness = 52.8 HRC (Approximate; Appendix 17)

13. Tensile strength = 235 ksi (Approximate; Appendix 17)

14.-17. Errors in given statements:

14. A hardness of HB 750 is extremely hard, characteristic of the hardest steels in the as-quenched or surface hardened condition. Appendix 3 shows annealed steels to have hardness values in the approximate range of HB 120 to 230.

15. Hardness on the HRB scale is normally limited to HRB 100.

16. Hardness on the HRC scale is normally no lower than HRC 20.

17. The relationship between hardness and tensile strength is only valid for steels.

18. Charpy and Izod tests measure impact strength.

19. Iron and carbon. Other elements are often present.

20. In addition to iron and carbon SAE 4340 steel contains nickel, chromium, and molybdenum. (Table 2-8)

21. Approximately 0.40% carbon in SAE 4340 steel.

22. Low-carbon: Less than 0.3%
Medium-carbon: 0.30% to 0.50%
High-carbon: 0.50% to 0.95%

23. Typically a bearing steel contains 1.0% carbon.

24. Lead is added to SAE 12L13 steel to improve machinability.

25. Shafts are often made from SAE 1040, 4140, 4340, 4640 6150, and 8650 steels. (Table 2-9)

26. Gears are often made from SAE 1040, 4140, 4340, 4640 5150, 6150, and 8650 steels (Table 2-9)

27. The blades of a post hole digger should have good wear resistance, high strength, and good ductility.
SAE 1080 steel is a reasonable choice.

28. SAE 5160 OQT 1000 is a high-carbon, chromium steel, containing approximately 0.60% carbon and 0.80% chromium. It was heat treated by heating above its upper critical temperature, quenched in oil, and then tempered at 1000 degrees Fahrenheit. It has fairly high strength (s_y = 151 ksi or 1040 MPa) and good ductility (14% elongation).

29. In general, a high hardness with good ductility are desirable for machine parts and tools subjected to impact loads as seen by a shovel. A hardness of HRC 40 corresponds to approximately HB 375 and is considered moderately hard. While this is a good level, even a higher value up to HRC 50 (HB 475) would be better, provided ductility is fairly high, say about 15% elongation. Appendix 3 shows some forms of oil-quenched **SAE 1040 and** none listed have sufficiently high hardness. Appendix 4-1 shows the same material quenched in water and tempered. **SAE 1040 WOT** has a hardness of HB 401 (HRC 43) with approximately 20% elongation and a yield point of 92 ksi.

30. Through hardening involves heating the entire part followed by quenching to achieve the hardened condition. Except for some variation in thick sections, the part is hardened throughout. But no chemical composition changes occur. In carburizing, the chemical composition of the surface is changed by the infusion of carbon. Thus, carburizing results in a hard surface while the core is softer.

31. Induction hardening is a heat treating process in which the area to be hardened is subjected to a high-frequency electric current created by a coil, inducing current flow near the surface of the part and causing local heating. After sufficient time to bring the surface to a temperature above the upper critical temperature of the material, the part is quenched to harden the surface.

32. Some carburizing grades of steels are **SAE 1015, 1020,** 1022, 1117, 1118, 4118, 4320, 4620, 4820, 8620 and 9310. The carbon content ranges from 0.10% to 0.20%. **[See Appedix A-5.]**

33. The AISI 200 and 300 series of stainless steels are nonmagnetic.

34. Chromium gives stainless steels good corrosion resistance.

35. **ASTM A992 Structural steel is used for most wide-flange beam shapes.**

36. HSLA structural steels are high-strength, low-alloy steels having yield strengths in the range of 42 - 100 ksi (290 - 700 MPa.

37. Three types of cast iron are gray iron, ductile iron, and malleable iron.

38. ASTM A48 , Grade 30 is a gray iron with a tensile strength of 30 ksi (207 MPa); no yield strength; less than 1% elongation (brittle); modulus of elasticity (stiffness) of 16.9 $\times 10^6$ psi (117 GPa).

Problem 38 (Continued)

ASTM A536, Grade 100-70-03 is a ductile iron with a tensile strength of 100 ksi (689 MPa); a yield strength of 70 ksi (483 MPa); 3% elongation (brittle); modulus of elasticity (stiffness) of $24x10^6$ psi (165 GPa).

ASTM A47, Grade 32510 is a malleable iron with a tensile strength of 50 ksi (345 MPa); a yield strength of 32.5 ksi (224 MPa); 10% elongation (ductile); modulus of elasticity (stiffnes) of $26x10^6$ (179 GPa.

strength of 85 ksi (586 MPa); a yield strength of 70 ksi (483 MPa); 3% elongation (brittle); modulus of elasticity (stiffness) of $26x10^6$ psi (179 GPa).

39. Powdered metals are preformed in a die under high pressure and sintered at a high temperature to fuse the particles. Re-pressing after sintering is sometimes used.

40. Parts made from Zamak 3 zinc casting alloy typically have good dimensional accuracy and smooth surfaces, a tensile strength of approximately 41 Ksi (283 MPa), a yield strength of 32 Ksi (221 MPa), 10% elongation, and a modulus of elasticity of $12.4x10^6$ psi (85 GPa). (Appendix 10)

41. Type D tool steels are typically used for stamping dies, punches, and gages. (Table 2-11)

42. The suffix O on aluminum 6061-O indicates the annealed condition.

43. The suffix H on aluminum 3003-H14 indicates that it was strain hardened.

44. The suffix T on aluminum 6061-T6 indicates that it was heat treated.

45. Aluminum 7178-T6 has the highest strength; tensile strength = 88 ksi (607 MPa); yield strength = 78 ksi (538 MPa).

46. Aluminum alloy 6061 is one of the most versatile.

47. Three typical uses of titanium alloys are aerospace structures, chemical processing equipment, and marine hardware.

48. Bronze is an alloy of copper with tin, aluminum, lead, phosphorus, nickel, zinc, manganese, or silicon.

49. Bronze C86200 is a manganese bronze casting alloy with a tensile strength of 95 ksi (655MPa); yield strength of 48 ksi (331 MPa); 20% elongation (ductile); modulus of elasticity of $15x10^6$ psi (103 GPa).

50. Bronze is used for gears and bearings.

51. Thermosetting plastics undergo a chemical change during forming resulting in a structure of cross-linked molecules. The process cannot be reversed or repeated. Thermoplastic materials can be formed repeatedly by reheating because the molecular structure is essentially unchanged during processing.

52. a) Gears: Nylon, polycarbonate, acetal, PET, polyurethane elastomer, phelolic. b) Helmets: ABS and polycarbonates. c) Transparent shield: Acrylic. d) Structural housing: PET ABS, polycarbonate, acrylic, PVC, phenolic, polyester/glass composite. e) Pipe: ABS, PVC. f) Wheels: Polyurethane elastomer. g) Switch parts: polyimide, phenolic, PET.

53. Designers of parts to be made from composite materials can control 1) base resin, 2) reinforcing fibers, 3) amount of fibers, 4) orientation of fibers, 5) number of layers, 6) overall thickness, 7) orientation of layers, 8) combinations of types of materials.

54. Composite materials are comprised of two or more different materials, typically a resin reinforced by fibers.

55. Resins used for composites include polyesters, epoxies, polyimides, phenolics, (all thermosets), and thermoplastics: PE, PA, PEEK, PPS, PVC.

56.

aramid, and carbon/graphite.

57. Sporting equipment is made from glass/epoxy, boron/epoxy, and graphite/epoxy composites.

58. Aerospace structures are made from glass/epoxy, boron/epoxy, graphite/epoxy, and aramid/epoxy composites.

59. Sheet molding compound is typically a glass/polyester composite.

60. SMC's are used for auto and truck body panels and large housings.

61. Reinforcing fibers are produced as continuous filaments, chopped fibers, roving, fabric, yarn, and mats.

62. Wet processing of composites involves the layup of fabric reinforcing sheets on a form, saturation of the sheets with the resin, and curing under heat and pressure.

63. Preimpregnated composite materials are produced with the resin already on the fibers in a convenient form, called a prepreg. The prepreg is layered onto the form and cured.

64. SMC's are preimpregnated fabric sheets formed in a mold and cured simultaneously under heat and pressure.

65. Pultrusion is a process of coating the fiber reinforcement as it is pulled through a heated die to produce a continuous form such as tubing, structural shapes, rod, and hat sections used to stiffen aircraft structures.

66. In the filament winding process, continuous filaments are placed around a mandrel in a controlled pattern and then cured. The process is used for pipe, pressure vessels, rocket motor cases, containers and enclosures.

67. Specific strength is the ratio of the strength of a material to its specific weight.

68. Specific stiffness is the ratio of the modulus of elasticity of a material to its specific weight.

69. Many composites have significantly higher values of specific strength and specific stiffness than metals.

Questions 70-73 refer to Figure 2-23 and Table 2-17 in the text.

General conclusions from Questions 70-73: The specific strengths of the metals listed range from $0.194\text{x}10^6$ to $1.00\text{x}10^6$, approximately a factor of 5.0. The specific stiffnesses are very nearly equal for all metals listed, approximately $1.0\text{x}10^8$ in. The specific strengths of the composites listed range from 1.87 to $4.88\text{x}10^6$ in, much higher than any of the metals. Glass/epoxy has a specific stiffness about 2/3 that of the metals. The other composites listed range from 2.2 to 8.3 times as stiff as the metals.

See Section 2-17, Table 2-16, Figures 2-23 and 2-24 for answers to Questions 74 to 100.

Supplementary Proplems – Chapter 2

1. Poisson's ratio: a) Carbon steel – 0.29; c) Lead – 0.43; e) Concrete – 0.10 to 0.25
2. See Section 2-2, subsection: Flexural Strength and Modulus, and Figure 2-5.
3. Erosive, abrasive, adhesive, fretting, surface fatigue
4. From Table 2-6: 14 alloys listed, Examples: ASTM A36, SAE 1018 HR or CD, SAE 1045 HR or CD, SAE 8620 CD.
5. From Table 2-6: SAE 304 and SAE 316
6. From Table 2-6: Six alloys listed, Examples: 2024-T4, 3003-H14, 6061-T6, 6063-T6
7. From Section 2-3: ASTM International, AISI, SAE
8. From Section 2-3: Aluminum Association
9. From Table 2-7: a) DIN 42CrMo4 or W-1.7225; b) BS 708A42; c) EN 42CrMo4; d) GB ML42CrMo4; e) JIS SCM 440H
10. From Table 2-7: a) DIN C45 or W-1.0503; b) BS 060A47; c) EN C45; d) GB 699-45; e) JIS S45C
11. From Table 2-7: a) DIN X6Cr17 or W-1.4016; b) BS 430S17; c) EN X6Cr17; d) GB ML1Cr17; e) JIS SUS430
12. From Table 2-7: a) DIN AlZnMgCu1.5 or W-3.4365; b) BS L.95, L.96; c) EN AlZn6MgCu
13. Water, brine, mineral oil, water-soluble polyalkylene glycol (PAG)
14. From Section 2-6: Fine steel or cast iron shot is projected at high velocity on critical surfaces to produce residual compressive stress that tends to improve the fatigue strength.
15. From Table 2-10: ASTM A27/A27M; A915/A915M; A128/A128M; A148/A148M
16. From Table 2-10: ASTM A757; ASTM A351; ASTM A216; ASTM A389
17. Carbidic austempered ductile iron – used for: railroad rolling stock, earthmoving equipment, agricultural machinery, crushers
18. From Section 2-10: White iron is made by rapidly chilling a casting of gray iron or ductile iron during solidification. ASTM Standard A532 describes the process. Used to improve wear resistance for ball mills, crushers, mixing equipment, and material handling devices.
19. From Section 2-11: Powders are pressed to their basic form and then heated to sinter the powder particles into a strong solid.
20. From Section 2-11: Powders are compressed by a flexible membrane in a hermetic chamber to produce a high density; may be done cold or at elevated temperatures.
21. From Section 2-11: Metal powders are fed into an injection molding machine to form a green part that is then sintered to complete the solidification and bonding processes.
22. From Section 2-11: Metal powders are first pressed and sintered, then forged in a closed-die press to achieve final form and properties.

23. From Table 2-12: Carbon steel F-0008-HT, s_u = 85 ksi (590 MPa);
Low-alloy steel FL-4405-HT, s_u = 160 ksi (1100 MPa);
Diffusion-alloyed steel FD-0205-HT, s_u = 130 ksi (900 MPa);
Sinter-hardened steel FLC-4608-HT, s_u = 100 ksi (690 MPa)

24. From Table 2-12: a) Nickel silver – CNZ-1818; s_u = 20 ksi (118 MPa)
b) Bronze – CTG-1001; (no strength listed; used for bearings)
c) Copper – C-0000; No strength listed; used for electrical applications
d) Aluminum - s_u = 32 ksi (221 MPa)

25. From Section 2-11: Projected surface area less than 50 in^2 (32 000 mm^2)

26. From Section 2-12: Aluminum casting alloys: 202, 222, 319, 360, 413, 444, 512, 535, 712, 771, 850, 852. Others available.

27. From Section 2-12: Aluminum 2014, 2024, 6061

28. From Section 2-13: Zinc *alloy No. 3* or *Zamak 3.*

29. From Section 2-13 and Appendix A10-1: Zinc ZA-8, s_u = 54 ksi (374 MPa)
ZA-12, s_u = 59 ksi (404 MPa); ZA-27, s_u = 61 ksi (421 MPa)

30. From Section 2-14: Nickel-based alloys have good corrosion resistance and retain good levels of strength at high temperatures.

31. From Section 2-15: a) Bearing bronze C93200l; b) Phosphor bronze C54400;
c) Muntz metal C37000; d) Manganese bronze C86200;
e) Copper-nickel-zinc alloy C96200; f) Manganese bronze C67500

32. From Section 2-15: H-numbers indicate the degree of hardening by strain hardening methods; a) H04 – Full hard; b) H02 – ½ hard; c) H01 – 1/8 hard; d)H08 – Spring hard

33. From Section 2-15: TD temper indicates – solution heat treated and cold worked

34. From Section 2-15 and Figure 2-18: As the percent cold reduction increases, tensile and yield strengths increase and ductility as indicated by percent elongation decreases.

35. From Section 2-18: Metals, polymers, ceramics, glasses, elastomers, hybrids

36. From Section 2-18: Foams, sandwich structures, honeycomb structures

37. From Fig. 2-31: d) Metals, b) ceramics, g) composites, c) polymers, a) wood,
h) rubbers/elastomers, f) foams

38. From Fig. 2-32: b) ceramics, d) metals, g) composites, a) wood, c) polymers, f) foams,
h) elastomers

39. From Figure 3-32: (lightest to heaviest) e) foams, a) wood, h) elastomers, g) composites,
d and b) Metals and ceramics (about equal)