FE Mechanical

Free practice problems and worked solutions

This sample contains 14 original problems, one from each knowledge area, already available free on EngineerProof. The original Form A problem numbers are retained. This is a sample, not a complete 110-question exam or a predictor of your NCEES result.

Work the questions before consulting the solutions. Each solution includes the calculation and an explanation of the other choices. The full forms, contents, and purchase conditions are at:

https://engineerproof.inshihub.com/fe-mechanical

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Practice questions

Mathematics

3. A right circular conical hopper stands apex down, 8 ft deep with an 8 ft top diameter. Granular material is fed in at a steady 12 ft^3/min. When the material depth is 6 ft, the rate at which the surface level rises is most nearly:

(A) 0.106 ft/min

(B) 0.141 ft/min

(C) 0.424 ft/min

(D) 1.273 ft/min

Probability and Statistics

8. A bearing assembly line draws 65 percent of its bearings from supplier A and 35 percent from supplier B. Supplier A ships 2.0 percent defective units; supplier B ships 5.0 percent defective units. A bearing drawn at random from the line is found to be defective. The probability that it came from supplier B is most nearly:

(A) 0.350

(B) 0.426

(C) 0.574

(D) 0.714

Ethics and Professional Practice

14. A licensed professional engineer is asked to apply a seal to a structural connection design package prepared by an unlicensed designer employed at a different firm. The engineer did not direct or control the preparation of the design but has since reviewed the calculations and found them technically acceptable. Under the NCEES Model Rules, applying the seal is:

(A) Permissible, because the calculations were reviewed and found acceptable

(B) Permissible, provided the originating designer is credited on the drawings

(C) Permissible, provided the engineer accepts liability for the design in writing

(D) Not permissible, because the work was not performed under responsible charge

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Engineering Economics

17. A municipal pumping station rated at $0.85 \mathrm{m}^3/\mathrm{s}$ has a first cost of USD 480{,}000, annual maintenance of USD 18{,}000, and a major overhaul costing USD 60{,}000 at the end of every eighth year of service. The station is to be maintained in service indefinitely. At an interest rate of 6% per year, the capitalized cost is most nearly:

(A) USD 780,000

(B) USD 881,000

(C) USD 905,000

(D) USD 941,000

Electricity and Magnetism

23. A 48 V ideal DC source feeds node A through a 6 Ω series resistor, and a 12 Ω resistor connects node A to the source return. A variable resistive load is then connected between node A and the return. The maximum power the load can absorb is most nearly:

(A) 64 W

(B) 144 W

(C) 256 W

(D) 576 W

Statics

28. A vertical mast is fixed at the origin with its top at point A, 12 m above the base. Two guy cables run from A to ground anchors: cable AB to anchor B, located 9 m from the base along the positive x axis, and cable AC to anchor C, located 5 m from the base along the negative y axis. The tension is 3.0 kN in AB and 2.6 kN in AC. The magnitude of the resultant of the two cable forces acting at A is most nearly:

(A) 2.06 kN

(B) 3.97 kN

(C) 4.80 kN

(D) 5.22 kN

Dynamics, Kinematics, and Vibrations

38. Gravel leaves the end of a horizontal conveyor at 24 ft/s. The discharge point is 18 ft above the surface of the stockpile, and air resistance is negligible. The horizontal distance from the discharge point to the point of impact is most nearly:

(A) 17.9 ft

(B) 25.4 ft

(C) 26.8 ft

(D) 46.0 ft

Mechanics of Materials

48. A stepped tie rod of high-strength alloy steel with a 690 MPa yield strength hangs from a rigid ceiling and carries a 40 kN axial tensile load at its lower end. The upper segment is 900 mm long with a 20 mm diameter; the lower segment is 600 mm long with a 14 mm diameter. The modulus of elasticity is 200 GPa. The total elongation of the rod is most nearly:

(A) 0.21 mm

(B) 0.95 mm

(C) 1.35 mm

(D) 1.95 mm

Material Properties and Processing

58. The engineering stress-strain response of a hot-rolled structural steel is idealized by two straight segments: a linear elastic rise from the origin to yield at 350 MPa and 0.0018 strain, followed by a straight line to fracture at 520 MPa and 0.160 strain. The modulus of toughness is most nearly:

(A) $0.32\ \mathrm{MJ/m^3}$

(B) $41.4\ \mathrm{MJ/m^3}$

(C) $69.1\ \mathrm{MJ/m^3}$

(D) $83.2\ \mathrm{MJ/m^3}$

Fluid Mechanics

69. A horizontal venturi meter in a chilled-water line has an inlet diameter of 150 mm and a throat diameter of 75 mm. The measured pressure drop from inlet to throat is 28 kPa, the meter coefficient is 0.98, and the water density is $1,000$ kg/m^3. The volumetric flow rate is most nearly:

(A) 32.4 L/s

(B) 33.5 L/s

(C) 34.1 L/s

(D) 37.4 L/s

Thermodynamics

76. A rigid vessel of volume 0.30 m^3 contains 2.0 kg of water at 1.0 MPa. At 1.0 MPa the saturation properties are $v_f = 0.001127$ m^3/kg, $v_g = 0.19444$ m^3/kg, $u_f = 761.7$ kJ/kg, and $u_{fg} = 1,822.0$ kJ/kg. The total internal energy of the contents is most nearly:

(A) 1,520 kJ

(B) 2,810 kJ

(C) 4,330 kJ

(D) 5,170 kJ

Heat Transfer

86. A composite panel consists of a 12 mm thick stainless steel plate ($k = 15$ W/(m·K)) bonded to an 8 mm thick aluminum plate ($k = 180$ W/(m·K)). The bond has a thermal contact resistance of 2.5×10^{-4} m$^2 \cdot$ K/W. Under steady one-dimensional conduction the exposed steel face is held at 210 °C and the exposed aluminum face at 90 °C. The heat flux through the panel is most nearly:

(A) 76 kW/m^2

(B) 110 kW/m^2

(C) 142 kW/m^2

(D) 150 kW/m^2

Measurements, Instrumentation, and Controls

94. A single active foil gauge of gauge factor 2.10 is bonded along the axis of a steel tie rod ($E = 200$ GPa) and wired as one arm of a quarter-bridge excited at 10.0 V DC. The bridge is balanced at no load; under load the bridge output is 1.05 mV. The axial stress in the rod is most nearly:

(A) 20 MPa

(B) 40 MPa

(C) 84 MPa

(D) 176 MPa

Mechanical Design and Analysis

101. A ductile steel bracket has a yield strength of 46 ksi. At the critical point the plane stress state is $\sigma_x = 18$ ksi, $\sigma_y = -6$ ksi, and $\tau_{xy} = 8$ ksi. Using the maximum distortion energy theory, the factor of safety against yielding is most nearly:

(A) 1.79

(B) 1.99

(C) 2.18

(D) 2.56

Worked solutions

Mathematics

Problem 3

Answer: (C)

A right circular conical hopper stands apex down, 8 ft deep with an 8 ft top diameter. Granular material is fed in at a steady 12 ft^3/min. When the material depth is 6 ft, the rate at which the surface level rises is most nearly:

Because the free surface at 6 ft depth spans only 28.3 ft^2, a 12 ft^3/min feed lifts the level about 0.42 ft/min.

Similar triangles fix the surface radius at half the depth, which collapses the cone volume to a function of depth alone.

$$r = \frac{h}{2}$$

$$V = \frac{\pi}{3} r^2 h = \frac{\pi h^3}{12}$$

Differentiating in time links the two rates, and the instantaneous depth of 6 ft closes the problem.

$$\frac{dV}{dt} = \frac{\pi h^2}{4} \cdot \frac{dh}{dt}$$

$$\frac{dh}{dt} = \frac{4(12)}{\pi(6)^2} = 0.424 \text{ ft/min}$$

FE REFERENCE HANDBOOK — MATHEMATICS: DERIVATIVES AND INDEFINITE INTEGRALS; MENSURATION OF AREAS AND VOLUMES, RIGHT CIRCULAR CONE

WHY THE OTHER CHOICES APPEAR

(A) Taking $r = h$ instead of $h/2$ gives $dh/dt = 12/[\pi(6)^2] = 0.106$ ft/min.

(B) Dropping the 1/3 from the cone volume gives $V = \pi h^3/4$ and $dh/dt = 48/[3\pi(6)^2] = 0.141$ ft/min.

(D) Carrying the 1/3 into the rate equation as $dV/dt = (\pi/3)r^2\, dh/dt$ with $r = 3$ ft gives $12/9.425 = 1.273$ ft/min.

Probability and Statistics

Problem 8

Answer: (C)

A bearing assembly line draws 65 percent of its bearings from supplier A and 35 percent from supplier B. Supplier A ships 2.0 percent defective units; supplier B ships 5.0 percent defective units. A bearing drawn at random from the line is found to be defective. The probability that it came from supplier B is most nearly:

Supplier B ships the smaller volume but the higher defect rate, and weighting each rate by its production share assigns about 57 percent of the defective bearings to supplier B.

Defective units arise from two mutually exclusive supplier streams, so the overall defect rate is the share-weighted sum of the two individual rates.

$$P(D) = P(A)P(D \mid A) + P(B)P(D \mid B) = 0.65(0.020) + 0.35(0.050) = 0.0305$$

Reversing the direction of conditioning divides supplier B's joint contribution by that overall rate.

$$P(B \mid D) = \frac{P(B)P(D \mid B)}{P(D)} = \frac{0.0175}{0.0305} = 0.574$$

FE REFERENCE HANDBOOK — ENGINEERING PROBABILITY AND STATISTICS: BAYES' THEOREM

WHY THE OTHER CHOICES APPEAR

(A) Reports the prior production share P(B) = 0.350 without updating on the observed defect.

(B) Computes the complementary posterior P(A|D) = 0.0130/0.0305 = 0.426, the wrong supplier.

(D) Forms the ratio of defect rates alone, 0.050/(0.020 + 0.050) = 0.714, omitting the production shares.

Ethics and Professional Practice

Problem 14

Answer: (D)

A licensed professional engineer is asked to apply a seal to a structural connection design package prepared by an unlicensed designer employed at a different firm. The engineer did not direct or control the preparation of the design but has since reviewed the calculations and found them technically acceptable. Under the NCEES Model Rules, applying the seal is:

The seal certifies work prepared by the licensee or under the licensee's responsible charge, and after-the-fact review establishes no such direct control.

Sealing is a certification that the documents were prepared by the licensee personally or under the licensee's responsible charge, which requires direct control and personal supervision while the work is being performed.

Review conducted after completion supplies no control over the assumptions, load paths, and detailing decisions already made, so the responsible-charge test fails even though the reviewer is competent in the subject matter.

Attribution on the title block and a written assumption of liability are contractual devices that never create the supervisory relationship the seal represents, leaving the package unsealable by this engineer.

FE REFERENCE HANDBOOK — ETHICS AND PROFESSIONAL PRACTICE: NCEES MODEL RULES, RULES OF PROFESSIONAL CONDUCT (RESPONSIBLE CHARGE AND SEALING OF DOCUMENTS)

WHY THE OTHER CHOICES APPEAR

(A) Substitutes technical review for responsible charge, treating a competence check as equivalent to supervision of the work.

(B) Assumes credit to the originating designer cures the defect, but disclosure of authorship does not transfer supervisory control to the sealing licensee.

(C) Assumes liability may be purchased by contract, whereas the seal attests to how the work was produced, not to who pays for its failure.

Engineering Economics

Problem 17

Answer: (B)

A municipal pumping station rated at $0.85 \mathrm{m}^3/\mathrm{s}$ has a first cost of USD 480{,}000, annual maintenance of USD 18{,}000, and a major overhaul costing USD 60{,}000 at the end of every eighth year of service. The station is to be maintained in service indefinitely. At an interest rate of 6% per year, the capitalized cost is most nearly:

Converting the eight-year overhaul to an annual equivalent of USD 6{,}062 lifts the perpetual annual charge to USD 24{,}062, which capitalized at 6% and added to the first cost gives roughly USD 881{,}000.

Capitalized cost is the present worth of a perpetual annual disbursement, so every recurring outlay must first be expressed as an equivalent uniform annual amount.

$$CC = P + \frac{A}{i}$$

The overhaul repeats on an eight-year cycle, so a sinking fund accumulated over each cycle carries it, not a capital recovery charge.

$$(A/F, 6\%, 8) = \frac{0.06}{(1.06)^8 - 1} = 0.10104$$

$$A_{OH} = 60,000 \times 0.10104 = 6,062 \text{ USD/yr}$$

Total perpetual annual cost divided by the interest rate is the fund that must stand behind the station beyond its first cost.

$$A = 18,000 + 6,062 = 24,062 \text{ USD/yr}$$

$$CC = 480,000 + \frac{24,062}{0.06} = 881,000 \text{ USD}$$

FE REFERENCE HANDBOOK — ENGINEERING ECONOMICS: CAPITALIZED COSTS; SINKING FUND FACTOR (A/F)

WHY THE OTHER CHOICES APPEAR

(A) Omits the overhaul entirely and capitalizes only maintenance: 480,000 + 18,000/0.06 = 780,000.

(C) Prorates the overhaul arithmetically as 60,000/8 = 7,500 per year instead of using the sinking-fund factor: 480,000 + 25,500/0.06 = 905,000.

(D) Uses (A/P, 6%, 8) = 0.16104 in place of (A/F, 6%, 8), giving 9,662 per year and 480,000 + 27,662/0.06 = 941,000.

Electricity and Magnetism

Problem 23

Answer: (A)

A 48 V ideal DC source feeds node A through a 6 Ω series resistor, and a 12 Ω resistor connects node A to the source return. A variable resistive load is then connected between node A and the return. The maximum power the load can absorb is most nearly:

Matching the load to the 4 Ω Thevenin resistance caps the transfer at 64 W, one quarter of V_{th}^2/R_{th}.

Maximum transfer requires the load to equal the Thevenin resistance at the terminals, which is the 6 Ω source branch in parallel with the 12 Ω element.

$$R_{th} = \frac{(6)(12)}{6+12} = 4\ \Omega$$

$$V_{th} = 48 \times \frac{12}{6+12} = 32\ \text{V}$$

Half the Thevenin voltage lands on a matched load, which is why the ceiling depends on the equivalent source alone and not on any particular load value.

$$P_{max} = \frac{V_{th}^2}{4R_{th}} = \frac{(32)^2}{4(4)} = 64\ \text{W}$$

FE REFERENCE HANDBOOK — ELECTRICITY AND MAGNETISM: THEVENIN EQUIVALENT CIRCUIT AND MAXIMUM POWER TRANSFER

WHY THE OTHER CHOICES APPEAR

(B) Using the 48 V source voltage in place of the 32 V Thevenin voltage gives $48^2/[4(4)] = 144$ W.

(C) Omitting the matched-load factor of 4 gives $32^2/4 = 256$ W.

(D) Committing both errors together gives $48^2/4 = 576$ W.

Statics

Problem 28

Answer: (D)

A vertical mast is fixed at the origin with its top at point A, 12 m above the base. Two guy cables run from A to ground anchors: cable AB to anchor B, located 9 m from the base along the positive x axis, and cable AC to anchor C, located 5 m from the base along the negative y axis. The tension is 3.0 kN in AB and 2.6 kN in AC. The magnitude of the resultant of the two cable forces acting at A is most nearly:

The two tensions combine to a resultant of 5.22 kN at A, of which 4.8 kN acts vertically downward along the mast.

Each cable force is its tension scaled by the unit vector along its own leg, so the anchor geometry alone fixes the direction cosines.

$$\vec{F}_{AB} = 3.0\,\frac{(9,\,0,\,-12)}{15} = (1.8,\,0,\,-2.4)\ \text{kN}$$

$$\vec{F}_{AC} = 2.6\,\frac{(0,\,-5,\,-12)}{13} = (0,\,-1.0,\,-2.4)\ \text{kN}$$

Concurrent forces must be added component by component before any magnitude is extracted.

$$\vec{R} = (1.8,\,-1.0,\,-4.8)\ \text{kN}$$

$$R = \sqrt{1.8^2 + 1.0^2 + 4.8^2} = 5.22\ \text{kN}$$

FE REFERENCE HANDBOOK — STATICS: FORCE (VECTOR COMPONENTS AND RESULTANT)

WHY THE OTHER CHOICES APPEAR

(A) Magnitude of the horizontal components only, $\sqrt{1.8^2 + 1.0^2} = 2.06$ kN, discarding the vertical resultant.

(B) Root-sum-square of the two tension magnitudes, $\sqrt{3.0^2 + 2.6^2} = 3.97$ kN, as if the cables were mutually perpendicular.

(C) Sum of the vertical components alone, $2.4 + 2.4 = 4.80$ kN.

Dynamics, Kinematics, and Vibrations

Problem 38

Answer: (B)

Gravel leaves the end of a horizontal conveyor at 24 ft/s. The discharge point is 18 ft above the surface of the stockpile, and air resistance is negligible. The horizontal distance from the discharge point to the point of impact is most nearly:

The 18 ft drop takes 1.06 s, and the constant 24 ft/s horizontal velocity carries the gravel about 25.4 ft in that time.

Horizontal and vertical motion are uncoupled, so the drop height alone fixes the time of flight.

$$18 = \frac{1}{2}(32.2)t^2$$

$$t = 1.057 \text{ s}$$

Zero horizontal acceleration holds the discharge speed constant over that interval.

$$x = (24)(1.057) = 25.4 \text{ ft}$$

FE REFERENCE HANDBOOK — DYNAMICS: PARTICLE KINEMATICS, PROJECTILE MOTION

WHY THE OTHER CHOICES APPEAR

(A) Uses h rather than 2h in the fall-time expression, giving t = sqrt(18/32.2) = 0.748 s and x = 17.9 ft.

(C) Omits the square root on the fall time, taking t = 2h/g = 1.118 s so that x = 26.8 ft.

(D) Applies the SI gravitational constant 9.81 to USCS data, giving t = sqrt(36/9.81) = 1.916 s and x = 46.0 ft.

Mechanics of Materials

Problem 48

Answer: (C)

A stepped tie rod of high-strength alloy steel with a 690 MPa yield strength hangs from a rigid ceiling and carries a 40 kN axial tensile load at its lower end. The upper segment is 900 mm long with a 20 mm diameter; the lower segment is 600 mm long with a 14 mm diameter. The modulus of elasticity is 200 GPa. The total elongation of the rod is most nearly:

Axial flexibility varies inversely with area, so the 14 mm segment supplies more than half of the 1.35 mm total elongation.

Both segments transmit the full 40 kN, so their elongations add and each cross-sectional area must be evaluated separately.

$$A_1 = \frac{\pi(20)^2}{4} = 314.2\text{mm}^2$$

$$A_2 = \frac{\pi(14)^2}{4} = 153.9\text{mm}^2$$

The higher of the two axial stresses occurs in the slender segment and stays well below the 690 MPa yield strength, so the linear elastic relation governs throughout.

$$\sigma_2 = \frac{40,000}{153.9} = 259.8 \text{ MPa} < 690 \text{ MPa}$$

Deformation scales inversely with area, so the slender lower segment stretches more even though it is shorter, and the two contributions sum to the downward movement of the loaded end relative to the ceiling.

$$\delta_1 = \frac{(40,000)(900)}{(314.2)(200,000)} = 0.573 \text{ mm}$$

$$\delta_2 = \frac{(40,000)(600)}{(153.9)(200,000)} = 0.780 \text{ mm}$$

$$\delta = 0.573 + 0.780 = 1.35 \text{ mm}$$

FE REFERENCE HANDBOOK — MECHANICS OF MATERIALS: UNIAXIAL LOADING AND DEFORMATION, Δ = PL/(AE)

WHY THE OTHER CHOICES APPEAR

(A) Subtracting the segment elongations instead of adding them, 0.780 - 0.573 = 0.21 mm.

(B) Carrying the 20 mm diameter over the full 1500 mm length, giving 0.95 mm.

(D) Carrying the 14 mm diameter over the full 1500 mm length, giving 1.95 mm.

Material Properties and Processing

Problem 58

Answer: (C)

The engineering stress-strain response of a hot-rolled structural steel is idealized by two straight segments: a linear elastic rise from the origin to yield at 350 MPa and 0.0018 strain, followed by a straight line to fracture at 520 MPa and 0.160 strain. The modulus of toughness is most nearly:

Nearly all of the area under the curve lies in the plastic trapezoid, so the modulus of toughness is about 69 MJ/m^3.

Modulus of toughness is the total energy per unit volume absorbed to fracture, which is the area under the engineering stress-strain curve; the idealized curve splits into an elastic triangle and a plastic trapezoid.

$$U_T = U_1 + U_2$$

Yield strain is small, so the elastic triangle contributes a negligible share of the total.

$$U_1 = \frac{1}{2}(350 \text{ MPa})(0.0018) = 0.315 \text{ MJ/m}^3$$

Stress rises linearly from yield to fracture, so the plastic region is a trapezoid whose height is the mean of the two stress levels.

$$U_2 = \frac{350 + 520}{2}(0.160 - 0.0018) = 68.8 \text{ MJ/m}^3$$

$$U_T = 0.315 + 68.8 = 69.1 \text{ MJ/m}^3$$

FE REFERENCE HANDBOOK — MATERIALS SCIENCE AND ENGINEERING: ENGINEERING STRESS-STRAIN CURVE, MODULUS OF TOUGHNESS

WHY THE OTHER CHOICES APPEAR

(A) Counts only the elastic triangle, $\frac{1}{2}(350)(0.0018) = 0.315 \text{ MJ/m}^3$, which is the modulus of resilience rather than the toughness.

(B) Treats the plastic region as a triangle of height equal to the ultimate strength, $\frac{1}{2}(520)(0.1582) + 0.315 = 41.4 \text{ MJ/m}^3$.

(D) Takes the area as a full rectangle of ultimate strength times fracture strain, $520 \times 0.160 = 83.2 \text{ MJ/m}^3$.

Fluid Mechanics

Problem 69

Answer: (B)

A horizontal venturi meter in a chilled-water line has an inlet diameter of 150 mm and a throat diameter of 75 mm. The measured pressure drop from inlet to throat is 28 kPa, the meter coefficient is 0.98, and the water density is $1,000$ kg/m^3. The volumetric flow rate is most nearly:

With a diameter ratio of 0.5 *the velocity-of-approach factor is* 0.9375*, yielding a throat velocity of* 7.57 *m/s and about* 33.5 *L/s.*

Continuity locks the inlet speed to the throat speed through the area ratio, and the horizontal energy balance converts the measured pressure drop into a single throat velocity.

$$\beta = \frac{75}{150} = 0.5$$

$$V_2 = C_v \sqrt{\frac{2\Delta p}{\rho(1 - \beta^4)}}$$

Retaining the $1 - \beta^4$ term keeps the upstream kinetic energy in the balance, which at $\beta = 0.5$ raises the velocity by about 3 percent.

$$V_2 = 0.98\sqrt{\frac{2(28,000)}{(1000)(0.9375)}} = 7.57 \text{ m/s}$$

Throat area converts that velocity into discharge.

$$Q = V_2 A_2 = (7.57)\frac{\pi(0.075)^2}{4} = 0.0335\ \mathrm{m^3/s}$$

FE REFERENCE HANDBOOK — FLUID MECHANICS: FLOW MEASUREMENT, VENTURI METERS (WITH THE CONTINUITY EQUATION)

WHY THE OTHER CHOICES APPEAR

(A) Drops the velocity-of-approach factor and uses $V_2 = C_v\sqrt{2\Delta p/\rho} = 7.33$ m/s, giving 32.4 L/s.

(C) Omits the meter coefficient 0.98, using the ideal throat velocity 7.73 m/s to obtain 34.1 L/s.

(D) Writes the correction as $1 - \beta^2 = 0.75$ instead of $1 - \beta^4$, raising the velocity to 8.47 m/s and the flow to 37.4 L/s.

Thermodynamics

Problem 76

Answer: (C)

A rigid vessel of volume 0.30 $\mathrm{m^3}$ contains 2.0 kg of water at 1.0 MPa. At 1.0 MPa the saturation properties are $v_f = 0.001127\ \mathrm{m^3/kg}$, $v_g = 0.19444\ \mathrm{m^3/kg}$, $u_f = 761.7$ kJ/kg, and $u_{fg} = 1,822.0$ kJ/kg. The total internal energy of the contents is most nearly:

The specific volume of $0.150\ m^3$/kg places the water at 77% quality, which carries about 4,330 kJ of internal energy.

Dividing the vessel volume by the charge mass fixes the specific volume, and its position between v_f and v_g confirms a two-phase state.

$$v = \frac{0.30}{2.0} = 0.150\mathrm{m^3/kg}$$

Quality measures how far that specific volume has advanced across the saturation span.

$$x = \frac{0.150 - 0.001127}{0.19444 - 0.001127} = 0.770$$

Internal energy follows the same lever rule between the liquid and vapor values, and the vessel holds 2.0 kg.

$$u = 761.7 + 0.770(1822.0) = 2165\ \mathrm{kJ/kg}$$

$$U = 2.0(2165) = 4330\ \mathrm{kJ}$$

FE REFERENCE HANDBOOK — THERMODYNAMICS: PROPERTIES FOR TWO-PHASE (SATURATED) SYSTEMS, QUALITY

WHY THE OTHER CHOICES APPEAR

(A) Treats the contents as saturated liquid, $U = 2.0(761.7) = 1523$ kJ.

(B) Drops u_f and keeps only the evaporation term, $U = 2.0(0.770)(1822.0) = 2806$ kJ.

(D) Treats the contents as saturated vapor, $U = 2.0(761.7 + 1822.0) = 5167$ kJ.

Heat Transfer

Problem 86

Answer: (B)

A composite panel consists of a 12 mm thick stainless steel plate ($k = 15$ W/(m·K)) bonded to an 8 mm thick aluminum plate ($k = 180$ W/(m·K)). The bond has a thermal contact resistance of $2.5 \times 10^{-4}\ \mathrm{m^2 \cdot K/W}$. Under steady one-dimensional conduction the exposed steel face is held at 210 °C and the exposed aluminum face at 90 °C. The heat flux through the panel is most nearly:

The bonded joint contributes nearly one quarter of the series resistance, holding the flux to about 110 kW/m².

Series resistances per unit area govern the panel, and the bonded joint enters the chain exactly as a solid layer does.

$$R''_{tot} = \frac{L_1}{k_1} + R''_{t,c} + \frac{L_2}{k_2}$$

$$R''_{tot} = \frac{0.012}{15} + 2.5 \times 10^{-4} + \frac{0.008}{180} = 1.094 \times 10^{-3}\ \mathrm{m^2 \cdot K/W}$$

One-dimensional steady flow drives the entire 120 K face-to-face difference through that single chain.

$$q'' = \frac{\Delta T}{R''_{tot}} = \frac{120}{1.094 \times 10^{-3}} = 1.10 \times 10^5\ \mathrm{W/m^2}$$

The joint absorbs 27 K of the drop against only 4.9 K for the aluminum, so discarding contact resistance would overstate the flux by about 30 percent.

$$\Delta T_c = q'' R''_{t,c} = 1.096 \times 10^5 (2.5 \times 10^{-4}) = 27.4\ \mathrm{K}$$

FE REFERENCE HANDBOOK — HEAT TRANSFER: CONDUCTION THROUGH A PLANE WALL AND THERMAL RESISTANCES IN SERIES

WHY THE OTHER CHOICES APPEAR

(A) Uses the steel conductivity for the aluminum layer as well, raising the total to 1.583e-3 m²·K/W and giving 75.8 kW/m².

(C) Omits the contact resistance, leaving 8.44e-4 m²·K/W and 142 kW/m².

(D) Counts only the steel layer, 120 divided by 8.0e-4, giving 150 kW/m².

Measurements, Instrumentation, and Controls

Problem 94

Answer: (B)

A single active foil gauge of gauge factor 2.10 is bonded along the axis of a steel tie rod ($E = 200$ GPa) and wired as one arm of a quarter-bridge excited at 10.0 V DC. The bridge is balanced at no load; under load the bridge output is 1.05 mV. The axial stress in the rod is most nearly:

The bridge output corresponds to 200 microstrain in the active arm, or 40 MPa of axial stress in the steel rod.

A single active arm unbalances the bridge by one quarter of the fractional resistance change, so the output-to-excitation ratio carries a factor of four.

$$\frac{V_o}{V_{ex}} = \frac{GF \cdot \epsilon}{4}$$

$$\epsilon = \frac{4(1.05 \times 10^{-3})}{2.10(10.0)} = 2.00 \times 10^{-4}$$

Hooke's law in uniaxial tension converts the surface strain to stress, since the rod remains elastic.

$$\sigma = E\epsilon = (200 \times 10^9)(2.00 \times 10^{-4}) = 40 \times 10^6 \text{ Pa}$$

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WHY THE OTHER CHOICES APPEAR

(A) Uses the half-bridge factor of 2 instead of 4, giving 100 microstrain and 20 MPa.

(C) Omits the gauge factor entirely, giving $4(1.05 \text{ mV})/(10.0 \text{ V}) = 420$ microstrain and 84 MPa.

(D) Multiplies by the gauge factor instead of dividing, giving 882 microstrain and 176 MPa.

Mechanical Design and Analysis

Problem 101

Answer: (A)

A ductile steel bracket has a yield strength of 46 ksi. At the critical point the plane stress state is $\sigma_x = 18$ ksi, $\sigma_y = -6$ ksi, and $\tau_{xy} = 8$ ksi. Using the maximum distortion energy theory, the factor of safety against yielding is most nearly:

A von Mises stress of 25.7 ksi against the 46 ksi yield strength gives a factor of safety of roughly 1.79.

Distortion energy collapses the biaxial state into one equivalent uniaxial stress, and for plane stress all three in-plane components enter directly.

$$\sigma' = \sqrt{\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2}$$

$$\sigma' = \sqrt{324 + 108 + 36 + 192} = \sqrt{660} = 25.7 \text{ ksi}$$

Yielding becomes a single scalar comparison; the compressive σ_y increases σ' rather than relieving it, which holds the margin below two.

$$n = \frac{S_y}{\sigma'} = \frac{46}{25.7} = 1.79$$

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WHY THE OTHER CHOICES APPEAR

(B) Factor of 3 omitted from the shear term: $\sqrt{324 + 108 + 36 + 64} = 23.1$ ksi gives $46/23.1 = 1.99$.

(C) Sign of σ_y taken as positive: $\sqrt{324 - 108 + 36 + 192} = 21.1$ ksi gives $46/21.1 = 2.18$.

(D) Shear and transverse components ignored, checking σ_x alone: $46/18 = 2.56$.