SOLUTIONS MANUAL FOR
MECHANICAL DESIGN
OF MACHINE COMPONENTS
SECOND EDITION: SI VERSION

by
ANSEL C. UGURAL
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NOTES TO THE INSTRUCTOR

The Solutions Manual to accompany the text MECHANICAL DESIGN of Machine Components supplements the study of machine design developed in the book. The main objective of the manual is to provide efficient solutions for problems in design and analysis of variously loaded mechanical components. In addition, this manual can serve to guide the instructor in the assignment of problems, in grading these problems, and in preparing lecture materials as well as examination questions. Every effort has been made to have a solutions manual that cuts through the clutter and is self-explanatory as possible thus reducing the work on the instructor. It is written and class tested by the author.

As indicated in its preface, the text is designed for the junior-senior courses in machine or mechanical design. However, because of the number of optional sections which have been included, MECHANICAL DESIGN of Machine Components may also be used to teach an upper level course. In order to accommodate courses of varying emphases, considerably more material has been presented in the book than can be covered effectively in a single three-credit-hour course. Machine/mechanical design is one of the student’s first courses in professional engineering, as distinct from basic science and mathematics. There is never enough time to discuss all of the required material in details.

To assist the instructor in making up a schedule that will best fit his classes, major topics that will probably be covered in every machine design course and secondary topics which may be selected to complement this core to form courses of various emphases are indicated in the following Sample Assignment Schedule. The major topics should be covered in some depth. The secondary topics, because of time limitations and/or treatment on other courses, are suggested for brief coverage. We note that the topics which may be used with more advanced students are marked with asterisks in the textbook.

The problems in the sample schedule have been listed according to the portions of material they illustrate. Instructor will easily find additional problems in the text to amplify a particular subject in discussing a problem assigned for homework. Answers to selected problems are given at the end of the text. Space limitations preclude our including solutions to open-ended web problems. Since the integrated approach used in this text differs from that used in other texts, the instructor is advised to read its preface, where the author has outlined his general philosophy. A brief description of the topics covered in each chapter throughout the text is given in the following. It is hoped that this material will help the instructor in organizing his course to best fit the needs of, his students.

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Chapter 1 attempts to present the basic concepts and an overview of the subject. Sections 1.1 through 1.8 discuss the scope of treatment, machine and mechanical design, problem formulation, factor of safety, and units. The load analysis is normally the critical step in designing any machine or structural member (Secs. 1.8 through 1.9). The determination of loads is encountered repeatedly in subsequent chapters. Case studies provide a number of machine or component projects throughout the book. These show that the members must function in combination to produce a useful device. Section 1.10 review the work, energy, and power. The foregoing basic considerations need to be understood in order to appreciate the loading applied to a member. The last two sections emphasize the fact that stress and strain are concepts of great importance to a comprehension of design analysis.

Chapter 2 reviews the general properties of materials and some processes to improve the strength of metals. Sections 2.3 through 2.14 introduce stress-strain relationships, material behavior under various loads, modulus of resilience and toughness, and hardness, selecting materials. Since students have previously taken materials courses, little time can be justified in covering this chapter. Much of the material included in Chapters 3 through 5 is also a review for students. Of particular significance are the Mohr’s circle representation of state of stress, a clear understanding of the three-dimensional aspects of stress, influence of impact force on stress and deformation within a component, applications of Castigliano’s theorem, energy of distortion, and Euler’s formula. Stress concentration is introduced in here, but little applications made of it until studying fatigue (Chap.7).

The first section of Chapter 6 attempts to provide an overview of the broad subject of “failure”, against which all machine/mechanical elements must be designed. The discipline of fracture mechanics is introduced in Secs. 6.2 through 6.4. Yield and fracture criteria for static failure are discussed in Secs. 6.4 through 6.12. The last 3 sections deal with the method of reliability prediction in design. Chapter 7 is devoted to the fatigue and behavior of materials under repeated loadings. The emphasis is on the Goodman failure criterion. Surface failure is discussed in Chapter 8. Sections 8.1 through 8.3 briefly review the corrosion and friction. Following these the surface wear is discussed. Sections 8.6 through 8.10 deal with the surfaces contact stresses and the surface fatigue failure and its prevention. The background provided here is directly applied to representative common machine elements in later chapters.

Sections 9.1 through 9.4 of Chapter 9 treat the stresses and design of shafts under static loads. Emphasis is on design of shafts for fluctuating loading (Secs. 9.6 and 9.7). The last 5 sections introduce common parts associated with shafting. Chapter 10 introduces the lubrication as well as both journal and roller bearings. As pointed out in Sec. 8.9, rolling element bearings provide interesting applications of contact stress and fatigue. Much of the material covered in Secs. 11.1 through 11.7 of Chapter 11 introduce nomenclature, tooth systems, and fundamentals of general gearing. Gear trains and spur gear force analysis are taken up in Secs. 11.6 and 11.7. The remaining sections concern with gear design, material, and manufacture. Non-spur gearing is considered in Chapter 12. Spur gears are merely a special case of helical gears (Secs. 12.2 through 12.5) having zero helix angle. Sections 12.6 through 12.8 deal with bevel gears. Worm gears are fundamentally different from other gears, but have much in common with power screws to be taken up in Chap. 15.
Chapter 13 is devoted to the design of belts, chains, clutches, and brakes. Only a few different analyses are needed, with surface forms effecting the equations more than the functions of these devices. Belts, clutches, and brakes are machine elements depending upon friction for their function. Design of various springs is considered in Chapter 14. The emphasis is on helical coil springs (Secs. 14.3 through 14.9) that provide good illustrations of the static load analysis and torsional fatigue loading. Leaf springs (Sec. 14.11) illustrate primarily bending fatigue loading. Chapter 15 attempts to present screws and connections. Of particular importance is the load analysis of power screws and a clear understanding of the fatigue stresses in threaded fasteners. There are alternatives to threaded fasteners and riveted or welded joints. Modern adhesives (Secs. 15.17 and 15.18) can change traditional preferred choices.

It is important to assign at least portions of the analysis and design of miscellaneous mechanical members treated in Chapter 16. Sections 16.3 through 16.7 concern with thick-walled cylinders, press or shrink fits, and disk flywheels. The remaining sections concerns with the bending of curved frames, plate and shells-like machine and structural components, and pressure vessels. Buckling of thin-walled cylinders and spheres is also briefly discussed. Chapter 17 represents an addition to the material traditionally covered in “Machine/Mechanical Design” textbooks. It attempts to provide an introduction to the finite element analysis in design. Some practical case studies illustrate solutions of problems involving structural assemblies, deflection of beams, and stress concentration factors in plates. Finally, case studies in preliminary design of the entire crane with winch and a high-speed cutting machine are introduced in Chapter 18.
SAMPLE ASSIGNMENT SCHEDULE

MACHINE/MECHANICAL DESIGN (3 credits.)


Prerequisites: Courses on Mechanics of Materials and Engineering Materials.

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* Secondary topics. The remaining, major topics constitute the “main stream” of the machine design course.
Section 1  BASICS

CHAPTER 1  INTRODUCTION

SOLUTION (1.1)

Free Body: Angle Bracket (Fig. S1.1)

(a) \[ \sum M_B = 0; \quad F(0.5) - 68(0.25) - 28.8(0.5) = 0, \quad F = 62.8 \text{ kN} \]

(b) \[ \sum F_x = 0: \quad R_{Bx} + 28.8 - F = 0, \quad R_{Bx} = 34 \text{ kN} \]
\[ \sum F_y = 0: \quad R_{By} - 68 - 21.6 = 0, \quad R_{By} = 89.6 \text{ kN} \]

Thus \[ R_B = \sqrt{(34)^2 + (89.6)^2} = 95.8 \text{ kN} \]

and \[ \alpha = \tan^{-1} \frac{34}{89.6} = 20.8^\circ \]

Figure S1.1

SOLUTION (1.2)

Free Body: Beam ADE (Fig. S1.2)
\[ \sum M_A = 0: \quad -W(3.75a) + F_{BD}(2a) = 0, \quad F_{BD} = 1.875W \]
\[ \sum F_x = 0: \quad R_{Ax} = 0 \]
\[ \sum F_y = 0: \quad -R_{Ay} + F_{BD} - W = 0, \quad R_{Ay} = 0.875W \]

Free-Body: Entire structure (Fig. S1.2)
\[ \sum M_A = 0: \quad R_c(3a) - W(3.75a) = 0, \quad R_c = 1.25W \]

Free Body: Part AO (Fig. S1.2)
\[ V = 0.875W \]
\[ F = 0 \]
\[ M = 0.875aW \]

Figure S1.2
SOLUTION (1.3)

Segment CD

\[ M_D = \frac{1}{2} (29)(0.6^2) = 5.22 \text{ kN} \cdot \text{m} \]

\[ V_D = 17.4 \text{ kN} \]

Segment CE

\[ M_E = 34.8 (1.8) - 45.82 (1.2) = 7.656 \text{ kN} \cdot \text{m} \]

\[ V_E = 11.02 \text{ kN} \]

SOLUTION (1.4)

(a)

\[ \sum M_B = 0: \quad 0.8 R_C (6) - 0.6 R_C (2) - 24(4) = 0 \]

\[ : R_C = 26.667 \text{ kN} \]

\[ R_{Cz} = 16 \text{ kN}, \quad R_{Cy} = 21.334 \text{ kN} \]

Then

\[ \sum F_x = 0: \quad R_{Bx} = 16 \text{ kN} \]

\[ \sum F_y = 0: \quad R_{By} = 12.66 \text{ kN} \]

(b) Segment CD

\[ M_D = 21.334 (3) - 12 (1.5) - 6 (2) = 34 \text{ kN} \cdot \text{m} \]

\[ F_D = 16 \text{ kN} \]

\[ V_D = 21.334 - 18 = 3.334 \text{ kN} \]
SOLUTION (1.5)

\[ \sum M_A = 0: \quad R_{Cz} = \frac{1}{2} R_{Cy} \]

\[ \sum M_B = 0: \quad 40(5) - 4R_{Cy} = 0 \quad R_{Cy} = 50 \text{ kN} \]

Then

\[ R_{Cy} = 75 \text{ kN} \]

\[ R_{By} = 10 \text{ kN} \], \[ R_{Bz} = 75 \text{ kN} \]

(b)

\[ F_D = 75 \left( \frac{1}{2} \right) + 50 \left( \frac{1}{2} \right) = 85 \text{ kN} \]

\[ V_D = 75 \left( \frac{1}{2} \right) - 50 \left( \frac{1}{3} \right) = 30 \text{ kN} \]

\[ M_D = 75(1) - 50(0.75) = 37.5 \text{ kN \cdot m} \]

SOLUTION (1.6)

(a)

Free body entire connection

\[ \sum M_C = 0: \quad R_A (0.7) - T = 0 \]

\[ T = 0.7 R_A \]

Segment AB

\[ AB = \sqrt{(0.5)^2 + (0.15)^2} = 0.522 \text{ m} \]

\[ \sum M_B = 0: \quad 18 \left( 0.15 \right) - R_A (0.5) = 0 \]

\[ R_A = 5.4 \text{ kN} \]

and

\[ T = 3.78 \text{ kN \cdot m} \]

(b)

\[ \sum F_z = 0: \quad 18 - \frac{0.5}{0.522} F_{AB} = 0 \]

\[ F_{AB} = 18.729 \text{ kN} \]

SOLUTION (1.7)

Free Body: Entire Crankshaft (Fig. S1.7a)

(a) From symmetry: \( R_A = R_B \)

\[ \sum F_z = 0: \quad R_A = R_B = 2 \text{ kN} \]

\[ \sum M_y = 0: \quad -4(0.05) + T = 0 \]

\[ T = 0.2 \text{ kN \cdot m} = 200 \text{ N \cdot m} \]

(CONT.)
1.7 (CONT.)

Figure S 1.7

(b) Cross Section at D (Fig. S1.7b)

\[ V_z = 2 \text{ kN} \]
\[ T = 200 \text{ N \cdot m} \]
\[ M_y = 2(0.07) = 0.14 \text{ kN \cdot m} \]
\[ = 140 \text{ N \cdot m} \]

SOLUTION (1.8)

Free-Body Diagram, Beam AB

\[ \sum F_x = 0: \quad -\frac{2}{\sqrt{3}} F_{CD} + 60 = 0, \quad F_{CD} = 69.11 \text{ kN} \]
\[ \sum F_y = 0: \quad R_A = \frac{4}{\sqrt{3}} F_{CD} - 30 = 0, \quad R_A = 64.3 \text{ kN} \]
\[ \sum M_A = 0: \quad -60(1.8) + \frac{1}{\sqrt{3}} F_{CD} (3) - M_A = 0, \]
\[ M_A = 72 \text{ kN \cdot m} \]

SOLUTION (1.9)

Free body entire frame

\[ \sum M_A = 0: \quad -129.6(0.9) - \frac{1}{2} R_{Dy} (1.2) + R_{Dy} (3) = 0 \]
\[ R_{Dy} = 48.6 \text{ kN}, \quad R_{Dy} = 24.3 \text{ kN} \]

Free body BCD

\[ \sum F_x = 0: \quad R_{Bx} = 24.3 \text{ kN} \]
\[ \sum F_y = 0: \quad R_{By} = 48.6 \text{ kN} \]
\[ R_B = \sqrt{24.3^2 + 46.6^2} = 52.6 \text{ kN} \]
SOLUTION (1.10)

(a) Free-body Diagrams, Arm BC and shaft AB

(b) At C:
\[ V = -2 \, \text{kN} \quad T = -50 \, \text{N} \cdot \text{m} \]

At end B of arm BC:
\[ V = 2 \, \text{kN} \quad T = 50 \, \text{N} \cdot \text{m} \quad M = 200 \, \text{N} \cdot \text{m} \]

At end B of shaft AB:
\[ V = -2 \, \text{kN} \quad T = -200 \, \text{N} \cdot \text{m} \quad M = -50 \, \text{N} \cdot \text{m} \]

At A:
\[ V = 2 \, \text{kN} \quad T = 200 \, \text{N} \cdot \text{m} \quad M = 300 \, \text{N} \cdot \text{m} \]
SOLUTION (1.12)

Free Body: Entire Pipe

Reational forces at point A:
\[ \sum F_x = 0 : \quad R_x = 0 \]
\[ \sum F_y = 0 : \quad R_y - 200 = 0, \quad R_y = 200 \text{ N} \]
\[ \sum F_z = 0 : \quad R_z = 0 \]

Moments about point A:
\[ \sum M_x = 0 : \quad T - 200(0.15) = 0, \quad T = 30 \text{ N} \cdot \text{m} \]
\[ \sum M_y = 0 : \quad M_y = 0 \]
\[ \sum M_z = 0 : \quad M_z - 200(0.3) - 36 = 0, \quad M_z = 96 \text{ N} \cdot \text{m} \]

The reactions act in the directions shown on the free-body diagram.

SOLUTION (1.13)

Free Body: Entire Pipe

(cont.)
1.13 (CONT.)

We have 1 lb/ft = 14.5939 N/m (Table A.2).
Thus, for 3 in. or 75-mm pipe (Table A.4): 14.5939(7.58) = 110.62 N/m
Total weights of each part acting at midlength are:

\[ W_{AB} = 110.62(0.3) = 33.2 \text{ N} \]
\[ W_{BC} = 110.62(0.2) = 22.1 \text{ N} \]
\[ W_{CD} = 110.62(0.15) = 16.6 \text{ N} \]

Reational forces at point A:

\[ \sum F_x = 0 : \quad R_x = 0 \]
\[ \sum F_y = 0 : \quad R_y - W_{AB} - W_{BC} - W_{CD} - 200 = 0, \quad R_y = 271.9 \text{ N} \]
\[ \sum F_z = 0 : \quad R_z = 0 \]

Moments about point A:

\[ \sum M_x = 0 : \quad T - W_{CD} (0.075) - 10(0.15) = 0, \quad T = 2.745 \text{ N} \cdot \text{m} \]
\[ \sum M_y = 0 : \quad M_y = 0 \]
\[ \sum M_z = 0 : \quad M_z = (200 + W_{CD} + W_{BC})(0.3) - W_{AB}(0.15) - 36 = 0 \]
\[ M_z = 112.6 \text{ N} \cdot \text{m} \]

SOLUTION (1.14)

(a) Free body pulley B

\[ \sum F_x = 0 : \quad B_x = 1.6 \text{ kN} \]
\[ \sum F_y = 0 : \quad B_y = 1.6 \text{ kN} \]

Free body CED

\[ \sum M_D = 0 : \quad R_{C} (0.4) - 1.6(0.15) = 0, \quad R_{C} = 0.6 \text{ kN} \]
\[ \sum F_x = 0 : \quad -D_x - 0.6 + 1.6 = 0, \quad D_x = 1 \text{ kN} \]
\[ \sum F_y = 0 : \quad R_{C} = D_y \]

Free body ADB

\[ \sum M_A = 0 : \quad D_y (0.5) - B_y (1.5) = 0, \quad D_y = 4.8 \text{ kN} \]
\[ \sum F_x = 0 : \quad -R_{A} + D_y - B_y = 0, \quad R_{A} = 4.8 \text{ kN} \]
\[ \sum F_y = 0 : \quad -R_{A} + D_y - B_y = 0, \quad R_{A} = 4.8 \text{ kN} \]

(Cont.)
1.14 (CONT.)

\[ \sum F_x = 0 : \quad R_{As} + D_x - B_x = 0, \quad R_{As} = 0.6 \text{ kN} \quad \rightarrow \]

(b) \[ M_g \quad F_g \]

\[ \begin{align*}
V_g & = 0.6 \text{ m} \\
M_g & = 1.6(0.6) = 960 \text{ N} \cdot \text{m}, \quad V_g = 1.6 \text{ kN} \\
F_g & = 1.6 \text{ kN}
\end{align*} \]

**SOLUTION (1.15)**

_Free body entire rod_
\[ \sum M_x = 0 : \quad R_{D_y}(0.25) - 300(0.1), \quad R_{D_y} = 120 \text{ N} \uparrow \]
\[ (\sum M_z)_C = 0 : \quad -200(0.35) + R_{B_y}(0.25) + (300 - 120)(0.2) = 0 \]
\[ R_{B_y} = 136 \text{ N} \uparrow \]

_Free body ABE_
\[
\begin{align*}
\sum M_z &= 0 : \quad -M_z + 200(0.275) - 136(0.175) = 0, \quad M_z = 31.2 \text{ N} \cdot \text{m} \\
\sum F_y &= 0 : \quad V_y = 200 - 136 = 64 \text{ N}
\end{align*}
\]

**SOLUTION (1.16)**

_Free body entire rod:_
\[ \sum M_x = 0 : \quad R_{D_y}(0.25) - 400(0.1) = 0, \quad R_{D_y} = 160 \text{ N} \uparrow \]
\[ (\sum M_z)_C = 0 : \quad R_{B_y}(0.25) + (400 - 160)(0.2) = 0, \quad R_{B_y} = 192 \text{ N} \downarrow \]

_Segment ABE_
\[
\begin{align*}
\text{At point E:} & \\
M_z &= -192(0.175) = -33.6 \text{ N} \cdot \text{m} \\
V_y &= 192 \text{ N}
\end{align*}
\]
SOLUTION (1.17)

**Side view**

- $50 \text{ mm}$
- $100 \text{ mm}$
- $150 \text{ N} \cdot \text{m}$

**Top view**

- $50 \text{ mm}$

Fig. (a): $\sum M_A = 0 : \ F_1 (0.05) - 150 = 0, \ F_1 = 3 \text{ kN}$

Fig. (b): $\sum M_A = 0 : \ F_1 (0.1) - F_2 (0.05) = 0, \ F_2 = 6 \text{ kN}$

Fig. (c): $\sum M_D = 0 : \ F_2 (0.05) - T_d = 0, \ T_d = 0.3 \text{ kN} \cdot \text{m}$

SOLUTION (1.18)

Free body-entire frame

$\sum M_A = 0 : \ R_y (10) - 13.5 (6) - 18 (4) = 0, \ R_y = 15.3 \text{ kN}$

Free body-member BC

$\sum M_C = 0 : \ R_x (3) - R_y (4) = 0$

and

$R_x = \frac{4}{3} (15.3) = 20.4 \text{ kN}$

Thus

$F_{BC} = R = \sqrt{(20.4)^2 + (15.3)^2} = 25.5 \text{ kN}$
SOLUTION (1.19)

Free body-member AB

\[ \sum M_A = 0: \]

\[ R_E (4a) - p \cos 40^\circ (a) - p \sin 40^\circ (6a) = 0 \]

\[ \therefore R_E = 1.156p \]

\[ \sum F_x = 0: \]

\[ R_A = p \cos 40^\circ = 0.766p \] ✗

\[ \sum F_y = 0: \]

\[ R_A + 1.156p - p \sin 40^\circ = 0, \quad R_A = 0.513p \] ✗

Free body-member CD

\[ \sum M_D = 0: \]

\[ R_E (4a) - R_{Cy} (6a) = 0 \]

\[ \therefore R_{Cy} = 0.771p \] ✗

\[ \sum M_c = 0: \]

\[ R_D \sin 30^\circ (6a) - R_E (2a) = 0, \quad R_D = 0.771p \]

\[ \sum F_x = 0: \]

\[ R_C = p \cos 30^\circ = 0.668p \] ✗

SOLUTION (1.20)

(a) Power = \( P = (p A)(L)(n/60) \)

\[ = (1.2)(2100)(0.06)(1500/60) = 3.78 \text{ kW} \]

Power required = \( P_e = \frac{3.78}{0.9} = 4.2 \text{ kW} \) ✗

(b) Use Eq. (1.15),

\[ T = \frac{55492W}{n} = \frac{9549(1.2)}{1500} = 26.74 \text{ N \cdot m} \] ✗

SOLUTION (1.21)

a=1.5 m, b=0.55 m, c=0.625 m, L=2.7 m, V=29 m/s, W=14.4 kN, kW=14

(a) From Eq. (1.15), the drag force equals,

\[ F_d = \frac{10004W}{v} = \frac{1000(14)}{29} = 482.8 \text{ N} \]

See: Fig. P1.21:

\[ \sum F_x = 0: \]

\[ F_d = 482.8 \text{ N} \] ✗

It follows that

\[ \sum M_A = 0: \]

\[ -Wa + F_d c + R_f L = 0 \]

or

\[ -14400(1.5) + (482.8)(0.625) + R_f (2.7) = 0 \]

(CONT.)
1.21 (CONT.)

Solving,
\[ R_f = 7.888 \text{ kN} \]
and
\[ \sum F_y = 0 : \quad R_r - 14.4 + 7.888 = 0 \]
or
\[ R_r = 6.512 \text{ kN} \]

(b)
We have \( V = 0, \ F_d = 0, \ F = 0 \).
See Fig. P1.21:
\[ \sum M_A = 0 : \quad - Wa + R_f L = 0 \]
Thus
\[ R_f = \frac{\ell}{L} W = \frac{\frac{14}{2.7}}{W} (14.4) = 8 \text{ kN} \]
So, \( \sum F_y = 0 \) gives
\[ R_r = W - R_f = 14.4 - 8 = 6.4 \text{ kN} \]

SOLUTION (1.22)

Refer to Solution of Prob. 1.21.
\( a=1.5 \text{ m}, \ b=0.55 \text{ m}, \ c=0.625 \text{ m}, \ L=2.7 \text{ m}, \ V=29 \text{ m/s}, \ W=14.4 \text{ kN}, \ kW=14 \)
Now we have
\[ W_j = 14.4 + 5.4 = 19.8 \text{ kN} \]

(a) From Eq. (1.15), the drag force equals,
\[ F_d = \frac{1000 \kW}{V} = \frac{1000 \times 14}{29} = 482.8 \text{ N} \]
See: Fig. 1.21 (with \( W = W_j \)):
\[ \sum M_A = 0 : \quad - Wa + F_d c + R_f L = 0 \]
\[ = -19800(1.5) + (482.8)(0.625) + R_f (2.7) = 0 \]
from which
\[ R_f = 10.888 \text{ kN} \]
and
\[ \sum F_y = 0 : \quad R_r - 19.8 + 10.888 = 0 \]
\[ R_r = 8.912 \text{ kN} \]

(b) \( V = 0, \ F_d = 0, \ F = 0 \), as before,
\[ \sum M_A = 0 : \quad - Wa + R_f L = 0 \]
Then
\[ R_f = \frac{\ell}{L} W = \frac{\frac{14}{2.7}}{W} (19.8) = 11 \text{ kN} \]
So, \( \sum F_y = 0 \) gives
\[ R_r = W_j - R_f = 19.8 - 11 = 8.8 \text{ kN} \]
SOLUTION (1.23)

(a) Free-Body Diagram: Gears (Fig. S1.23).
Applying Eq. (1.15):

\[ T_{AC} = \frac{9550P}{n} = \frac{9550(35)}{500} = 668.5 \text{ N} \cdot \text{m} \]

Therefore,

\[ F = \frac{T_A}{r_A} = \frac{668.5}{0.125} = 5.348 \text{ kN} \]

(b) \[ T_{DE} = FR_D = 5.348(0.075) = 401.1 \text{ N} \cdot \text{m} \]

\[ T_{DE} \]
\[ T_{AC} \]
\[ F \]
\[ r_D \]
\[ A \]
\[ T_{AC} \]

Figure S1.23

SOLUTION (1.24)

\[ n_1 = 1800 \text{ rpm}, \quad n_2 = 425 \text{ rpm}, \quad kW = 20 \]

From Eq. (1.15), we obtain \( T = 9549 \text{ kW} \cdot \text{m}. \) Thus

For input shaft

\[ T = \frac{9549(23)}{1800} = 122 \text{ N} \cdot \text{m} \]

For output shaft

\[ T = \frac{9549(20)}{425} = 449.4 \text{ N} \cdot \text{m} \]

Equation (1.14) gives

\[ e = \frac{22}{23} \times 100 = 87 \% \]

SOLUTION (1.25)

\[ N=150, \quad F=2.25 \text{ kN}, \quad s=62.5 \text{ mm}, \quad e=88\% \]

(a) Referring to Eq. (1.12):

\[ \text{power output} = Fs\left(\frac{N}{60}\right) = 2250 \times 0.0625(\frac{150}{60}) = 351.6 \text{ W} \]

(b) Using Eq. (1.14), power transmitted by the shaft:

\[ \text{power input} = \frac{351.6}{0.88} = 399.5 \text{ W} \]

SOLUTION (1.26)

Equation (1.10) becomes

\[ \Delta E_k = \frac{1}{2}I(\omega_{max}^2 - \omega_{min}^2) \]

Here, mass moment inertia with 5 percent added:

\[ I = (1.05)\frac{\pi}{32}(d_o^4 - d_i^4) \cdot l \rho \]

(Table A.5)

(CONT.)
1.26 (CONT.)

\[
1.05 \frac{0.4^4 - 0.3^4}{32} (0.1)(7.200) = 1.299 \text{ kg} \cdot \text{m}^2
\]

\[
\omega_{\text{max}} = 1200 \left(\frac{1}{60}\right) = 20 \text{ rps} = 125.7 \text{ rad/s}
\]

\[
\omega_{\text{min}} = 1100 \left(\frac{1}{60}\right) = 18.3 \text{ rps} = 115 \text{ rad/s}
\]

Equation (1) is therefore

\[
\Delta E_k \triangleq \frac{1}{2} (1.299) (125.7^2 - 115^2)
\]

= 1.673 J

SOLUTION (1.27)

Final length of the wire:

\[
L_{AC} = \sqrt{(2)^2 + (1.26)^2} = 2.3638 \text{ m}
\]

Initial length of the wire is

\[
L_{AC} = \sqrt{(2)^2 + (1.25)^2} = 2.3585 \text{ m}
\]

Hence, Eq. (1.20):

\[
\varepsilon_{AC} = \frac{L_{AC} - L_{AC}}{L_{AC}} = \frac{2.3638 - 2.3585}{2.3585} = 0.00225 = 2250 \mu
\]

SOLUTION (1.28)

(a) \( \varepsilon_c = \frac{2\pi (r + \Delta r) - 2\pi r}{2\pi r} = \Delta r \)

\[
(\varepsilon_c)_l = 0.5 \frac{150}{150} = 2000 \mu
\]

(b) \( \varepsilon_c = \frac{\Delta r_c - \Delta r_c}{r_c - r_c} = \frac{0.3 - 0.2}{250 - 150} = 1000 \mu
\]

SOLUTION (1.29)

\[
L_{OB} = d, \quad L_{AB} = L_{BC} = d\sqrt{2} = 1.41421d
\]

(a) \( \varepsilon_{OB} = \frac{0.0012d}{d} = 1200 \mu
\]

(b) \( L_{AB} = L_{CB} = \left[d^2 + (1.0012d)^2\right]^{1/2} = 1.41506d
\]

\[
\varepsilon_{AB} = \varepsilon_{BC} = 1.41506 - 1.41421 = 601 \mu
\]

(c) \( \tan^{-1} \left(\frac{1.0012d}{d}\right) = 45.0344^\circ
\]

Increase in angle \( CAB \) is \( 45.0344^\circ - 45 = 0.0344^\circ
\).

Thus

\[
\gamma = 0.0344 \left(\frac{1}{180}\right) = 600 \mu
\]
SOLUTION (1.30)

(a) \[ \varepsilon_x = \frac{0.8 - 0.5}{250} = 1200 \mu \quad \varepsilon_y = \frac{0.4 - 0}{200} = -2000 \mu \]

(b) \[ L'_{AD} = L_{AD} + \varepsilon_x L_{AD} = L_{AD} (1 + \varepsilon_x) \]
\[ = 250 \times (1.0012) = 250.3 \text{ mm} \]

SOLUTION (1.31)

\[ \Delta L_{AB} = 800 \times 10^{-6} \times 150 = 120 \times 10^{-3} \text{ mm} \]
\[ \Delta L_{AD} = 1000 \times 10^{-6} \times 200 = 200 \times 10^{-3} \text{ mm} \]

We have
\[ L_{BD}^2 = L_{AB}^2 + L_{AD}^2 \]
\[ 2 L_{BD} \Delta L_{BD} = 2 L_{AB} \Delta L_{AB} + 2 L_{AD} \Delta L_{AD} \]

or
\[ \Delta L_{BD} = \frac{L_{AB}}{L_{AD}} \Delta L_{AB} + \frac{L_{AD}}{L_{AD}} \Delta L_{AD} \]
\[ = \left[ \frac{150}{250} \times 120 \right] + \left[ \frac{200}{250} \times 200 \right] \times 10^{-3} = 0.232 \text{ mm} \]

SOLUTION (1.32)

\[ AC = BD = \sqrt{300^2 + 300^2} = 424.26 \text{ mm} \]
\[ B'D' = 424.26 - 0.5 = 423.76 \text{ mm} \], \[ A'C' = 424.26 + 0.2 = 424.46 \text{ mm} \]

Geometry: \( A'B' = A'D' \)

\[ \varepsilon_x = \varepsilon_y = \frac{AD - AD}{AD} \]
\[ = \left[ \frac{423.76}{2} \right] + \left[ \frac{424.46}{2} \right] = -363 \mu \]
\[ \gamma_{xy} = \frac{x}{2} - \beta = \frac{x}{2} - 2 \tan^{-1} \frac{423.76}{242.46} = 1651 \mu \]

SOLUTION (1.33)

We have
\[ \delta_{AD} = \varepsilon_{AD} L_{AD} \]
\[ = 800 \times 10^{-6} \times 0.8 \]
\[ = 0.00064 \text{ m} \]

(CONT.)
1.33 (CONT.)

From triangles \( A^*AF \) and \( C^*CF \):

\[
\frac{0.00644}{x} = \frac{0.005}{1.5-x}, \quad x = 0.17 \text{ m}
\]

From triangles \( B^*BF \) and \( C^*CF \):

\[
\frac{0.33}{\delta_y} = \frac{0.33}{0.005}, \quad \delta_y = 0.00124 \text{ m} = -\delta_{BE} \text{ (contraction)}
\]

Therefore

\[
\varepsilon_{BE} = \frac{-\delta_{BE}}{\varepsilon_{ss}} = \frac{0.00124}{1} = -1240 \times 10^{-6}
\]

\[= -1,240 \mu\]

---

**SOLUTION (1.34)**

\[(a) \quad \varepsilon_x = \frac{0.006}{0.5} = 120 \mu, \quad \varepsilon_y = \frac{-0.004}{25} = -160 \mu, \quad \gamma_{xy} = -1000 + 200 = -800 \mu\]

\[(b) \quad L'_{AB} = L_{AB}(1 + \varepsilon_y) = 25(1 - 0.00016) = 24.996 \text{ mm}\]

\[L'_{AD} = L_{AB}(1 + \varepsilon_x) = 50(1 + 0.00012) = 50.006 \text{ mm}\]

---

End of Chapter 1
CHAPTER 2 MATERIALS

SOLUTION (2.1)

\[ A_0 = \frac{\pi}{4}(12.5)^2 = 122.7 \text{ mm}^2, \quad A_f = \frac{\pi}{4}(12.5 - 0.006)^2 = 122.6 \text{ mm}^2 \]

We have \( \varepsilon_a = \frac{0.1}{200} = 1500 \mu, \quad \varepsilon_r = \frac{0.006}{12.5} = 480 \mu \)

Thus

\[ S_p = \frac{\sigma_f}{A_f} = \frac{18(10^3)}{122.7} = 146.8 \text{ MPa} \]
\[ E = \frac{S_p}{\varepsilon_r} = \frac{146.7(10^3)}{1500(10^{-6})} = 97.8 \text{ GPa}, \quad \nu = \frac{\varepsilon_l}{\varepsilon_a} = 0.32 \]

Also

\( \% \text{ elongation} = \frac{0.3}{200}(100) = 0.15 \)
\( \% \text{ reduction in area} = \frac{122.7 - 122.6}{122.7} (100) = 0.082 \)

SOLUTION (2.2)

Normal stress is

\[ \sigma = \frac{F}{A} = \frac{3200}{\frac{\pi}{4}(3.125)^2} = 286.8 \text{ MPa} \]

This is below the yield strength of 350 MPa (Table B.1).

We have

\[ \varepsilon = \frac{\Delta}{L} = \frac{7.5}{5600} = 0.001339 = 1339 \mu \]

Hence

\[ E = \frac{\sigma}{\varepsilon} = \frac{286.8(10^3)}{1339(10^{-3})} = 214.2 \text{ GPa} \]

SOLUTION (2.3)

The cross-sectional area: \( A = w^t a = 12.7(6.1) = 77.47 \text{ mm}^2 \)

( a ) Axial strain and axial stress are

\[ \varepsilon_a = \frac{0.0841}{63.5} = 0.001324 = 1324 \mu \]
\[ \sigma_a = \frac{F}{A} = \frac{21.500}{77.47(10^{-3})} = 277.5 \text{ MPa} \]

Because \( \sigma_a < S_y \) (See Table B.1), Hooke's Law is valid.

( b ) Modulus of elasticity,

\[ E = \frac{\sigma}{\varepsilon} = \frac{277.5(10^6)}{1324(10^{-3})} = 209.6 \text{ GPa} \]

( c ) Decrease in the width and thickness

\( \Delta w = \nu w_a = 0.3(12.7) = 3.81 \text{ mm} \)
\( \Delta t = \nu t_a = 0.3(6.1) = 1.83 \text{ mm} \)
SOLUTION (2.4)

Assume Hooke’s Law applies. We have

\[ \varepsilon_1 = -\frac{1.5}{5} = -0.3 \mu \]
\[ \varepsilon_a = -\frac{\varepsilon}{\nu} = -\frac{100}{0.34} = 822 \mu \]

Thus,

\[ \sigma = E \varepsilon_a = (105 \times 10^6)(822 \times 10^{-6}) = 92.61 \text{ MPa} \]

Since \( \sigma < S_y \), our assumption is valid.

So

\[ P = \sigma A = (92.61)(\pi/4)(5)^2 = 1.818 \text{ kN} \]

SOLUTION (2.5)

We obtain

\[ L_{AC} = L_{BD} = \sqrt{15^2 + 15^2} = 21.21 \text{ mm} \]
\[ \varepsilon_1 = \frac{L_{AC}}{L_{AC}} = \frac{21.21}{21.21} = -1886 \mu \]
\[ \varepsilon_2 = \frac{L_{BD}}{L_{BD}} = \frac{21.21}{21.21} = 471 \mu \]

(a) \[ E = \frac{\sigma_1}{\varepsilon_1} = \frac{53(10^6)}{-1886(10^{-6})} = 53 \text{ GPa} \]

(b) \[ \nu = \frac{\varepsilon_2}{\varepsilon_1} = \frac{471}{1886} = 0.25 \]

(c) \[ G = \frac{53}{2(1+0.25)} = 21.2 \text{ GPa} \]

SOLUTION (2.6)

Use generalized Hooke’s law:

\[ \varepsilon_x + \varepsilon_y + \varepsilon_z = \frac{1-\nu}{E} (\sigma_x + \sigma_y + \sigma_z) \quad (1) \]

For a constant triaxial state of stress:

\[ \varepsilon_x = \varepsilon_y = \varepsilon_z = \varepsilon, \quad \sigma_x = \sigma_y = \sigma_z = \sigma \]

Then, Eq. (1) becomes \( \varepsilon = \frac{1-\nu}{E} \sigma \). Since \( \sigma \) and \( \varepsilon \) must have identical signs:

\[ 1 - 2\nu \geq 0 \quad \text{or} \quad \nu \leq \frac{1}{2} \]

SOLUTION (2.7)

We have \( \sigma_y = \frac{450(10^6)}{50(75)} = 120 \text{ MPa} \)

(CONT.)
2.7 (CONT.)

(a) \( \varepsilon_x = \frac{0.5}{250} = 2000 \mu \), \( \varepsilon_y = -\frac{0.025}{30} = -500 \mu \)
\[ \nu = \frac{2000}{20000} = 0.25 \]

(b) \( E = \frac{\sigma}{\varepsilon} = \frac{420(10^5)}{2000(10^3)} = 60 \text{ GPa} \)

(c) \( \varepsilon_z = -\frac{\nu \sigma}{\varepsilon} = -0.25 \frac{120(10^5)}{60(10^3)} = -500 \mu \)
\[ \Delta a = -500(10^{-6}) \times 75 = -37.5(10^{-3}) \text{ mm}; \quad a' = 75 - 0.0375 = 74.9625 \text{ mm} \]

(d) \( G = \frac{60(10^3)}{2(1+0.25)} = 24 \text{ GPa} \)

SOLUTION (2.8)

We have
\[ \varepsilon_y = \varepsilon_z = 0 \quad \sigma_x = \frac{25(10^3)}{20 \times 10(10^3)} = 125 \text{ MPa} \]

Thus
\[ \varepsilon_y = 0 = \frac{1}{2} [\sigma_y - \nu (\sigma_z + \sigma_z)] \quad (1) \]
\[ \varepsilon_z = 0 = \frac{1}{2} [\sigma_z - \nu (\sigma_y + \sigma_y)] \quad (2) \]
\[ \varepsilon_x = \frac{1}{2} [\sigma_x - \nu (\sigma_y + \sigma_z)] \quad (3) \]

Equations (1) and (2) become
\[ \sigma_y - \nu \sigma_z = \nu \sigma_x \quad (1') \]
\[ \sigma_z - \nu \sigma_y = \nu \sigma_x \quad (2') \]

Adding: \( \nu (\sigma_y + \sigma_z) = 2 \nu^2 \sigma_x / (1 - \nu) \). Then, Eq. (3):
\[ \varepsilon_x = \frac{1 - 2 \nu}{1 - \nu} \frac{\sigma_x}{E} \]

Substituting the data:
\[ \varepsilon_x = \frac{1 - 0.3 - 0.18}{0.7} \frac{125(10^3)}{70(10^3)} = 1327 \mu \]

SOLUTION (2.9)

Hooke's Law. We have \( \sigma_y = 0 \) and
\[ \varepsilon_x = \frac{\sigma_x}{E} - \frac{\nu \sigma_y}{E} - \frac{\nu \sigma_z}{E} \]
\[ = \frac{10^8}{72 \times 10^3} [(80) - 0 - 0.3(140)] = 0.000528 = 528 \mu \]
\[ \varepsilon_y = -\frac{\nu \sigma_x}{E} + \frac{\sigma_y}{E} - \frac{\nu \sigma_z}{E} \]
\[ = \frac{10^8}{72 \times 10^3} [-0.3(80) + 0 - 0.3(140)] = -917 \mu \]
\[ \varepsilon_z = -\frac{\nu \sigma_x}{E} - \frac{\nu \sigma_y}{E} + \frac{\sigma_z}{E} \]
\[ = \frac{10^8}{72 \times 10^3} [-0.3(80) - 0 + 140] = 1611 \mu \]

(CONT.)